Thèse de doctorat Juillet/ 2019

Université Panthéon - Assas

École doctorale de Sciences Economiques et Gestion

Thèse de doctorat en Sciences Economiques

soutenue le 1 Juillet 2019

Competences, Product Innovation, Growth and Employment. An Agent-Based Approach.

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Avertissement

L'université n'entend donner aucune approbation ni improbation aux opinions émises dans cette thèse ; ces opinions doivent être considérées comme propres à leur auteur.

Remerciements

First of all, I would like to thank my director, Mr. Gérard Ballot, for having introduced me to research, for having been attentive to me throughout this adventure, for having been able to advise me and support me in the difficult moments of the profession.

I would like to thank Mr Bruno Deffains who is my co-director and also director of the laboratory in which I have been working for 5 years. I was able to have pleasant working conditions and had the opportunity to participate in conferences that are very useful for the advancement of my thesis.

I would like to express my gratitude to Herbert Dawid, François Legendre, and Murat Yildizoglu for agreeing to serve on my thesis jury.

Je tiens d'abord à remercier mon directeur de thèse, Monsieur Gérard Ballot, qui a accepté de me diriger d'abord pour le mémoire quand j'étais étudiant en M2 et ensuite pour la thèse. Le travail était intense pendant cinq ans, avec des hauts et des bas lors de la construction de deux modèles. Mais cela a permis d'avancer par rapport au projet initial il y a cinq ans. On s'échangeait des mails ou se voyait presque toutes les semaines, même s'il partait de temps en temps au chalet, pendant les vacances universitaires, le 24 décembre ou le 31 janvier. C'était un engagement sans faille et je tiens à le remercier beaucoup. Cette aide est précieuse surtout pour un jeune étranger qui a toujours, en dehors du travail, d'autres difficultés dans la vie.

Je remercie aussi Monsieur Bruno Deffains, le co-directeur mais aussi le directeur du Centre de Recherches en Economie et Droit. J'ai pu profiter des conditions de travail agréables et avoir des opportunités pour présenter mes papiers dans les colloques et les conférences. Ces présentations sont très utiles pour l'avancement de la thèse. J'aimerais également exprimer toute ma gratitude à Herbert Dawid, François Legendre, et Murat Yildizoglu pour avoir accepté de participer à mon jury de thèse. Mes travaux seront grandement bénéficiés de leurs commentaires qui permettront d'améliorer les modèles dans la future.

Ces travaux n'ont été rendus possibles que par l'atmosphère stimulante et bienveillantes des membres du laboratoire CRED. Je tiens à remercier mes collègues, des enseignant-chercheurs et des doctorants pour leur soutien et leur amitié. Les discussions avec eux ont apporté de nouvelles idées pour ma thèse ainsi que le partage des expériences dans la recherche et l'enseignement.

Je tiens à remercier les deux secrétaires du CRED - Josette et Naima - de m'avoir aidé et partagé des moments agréables durant ces dernières années. Je n'oublie non plus les personnels de l'Université Panthéon-Assas avec qui je m'amuse pendant les pauses de déjeuner, surtout Marie-Christine et Valérie.

D'un point de vue personnel, je souhaiterais remercier mes parents qui me soutiennent depuis tant d'années. Malgré les difficultés financières, ils ont toujours consacré l'effort à l'éducation de leurs enfants. Obtenir le doctorat est aussi en quelque sorte la concrétisation de leur rêve de jeunesse. Eux aussi ils savent très bien que l'éducation est le seul moyen de

sortir de la pauvreté mais à cause de la guerre, les difficultés dans la vie quotidienne, ils ne pouvaient pas aller très loin.

Enfin je souhaiterais remercier mes amis, notamment Phat et Tien, de m'avoir soutenu pendant ces années. Même s'ils ont aussi leurs propres difficultés dans la vie quotidienne, les moments avec eux m'ont permis de détendre et d'oublier le stress dans le travail.

Je remercie l'Université Panthéon-Assas de m'avoir accordé le contrat doctoral et le contrat ATER afin de pouvoir réaliser cette thèse dans les meilleures conditions possibles.

Résumé :

Le concept de compétences et leur hétérogénéité doivent être considérés comme importants en théorie économique et en empirique car les compétences sont une chance pour la croissance mais aussi un problème pour la croissance. Nous étudions le processus de construction des compétences dans deux modèles basés d'agents, mais chacun se concentre sur des caractéristiques différentes de ce processus. Dans le premier modèle, les compétences augmentent avec l'apprentissage et le transfert de compétences dans le cadre d'une alliance. Nous construisons un modèle de co-coopétition où les entreprises sont partenaires en R&D pour l'innovation de qualité mais restent concurrentes sur un marché à secteur unique. Les partenaires ne partagent pas toutes leurs compétences et se spécialisent en partie. Cela permet la persistance d'alliances et d'un réseau à long terme. Le deuxième modèle est un modèle stock-flux cohérent, avec les principaux types d'agents. Elle introduit l'innovation de secteur qui joue un rôle crucial pour la possibilité d'une croissance à long terme en surmontant la saturation de la demande. La demande des entreprises pour des compétences complexes augmente avec la qualité des produits existants et les caractéristiques des nouveaux produits. L'offre de compétences est modélisée au niveau individuel. Nous montrons l'effet de blocage de la contrainte de compétence, en particulier dans les compétences complexes, sur la croissance et l'emploi, avec de possibles dépressions keynésiennes de longue durée.

Descripteurs :

Compétences, tâches, innovation de procédé, innovation de produit, innovation de qualité, innovation de secteur, apprentissage, croissance endogène, modèle AB, AB-SFC, contrainte de ressources humaines, emploi, chômage, saturation de la demande, contrainte financière, alliances, co-opétition, réseau, concurrence schumpétérienne.

Title and Abstract :

The concept of competences and their heterogeneity should be considered as important in economic theory and empirics because the competences are a chance for growth but also a problem for growth. We study the competence building process in two agent-based models but each focuses on different features of this process. In the first model, competences increase with firms learning by doing and competence transfer in an alliance. We build a co-opetition model where firms are partners in RD for quality innovation but remain competitors in a one-sector market. Partners do not share all their competences and partly specialise. This allows for the persistence of alliances and a network in the long run. The second model is stock-flow consistent, with the main types of agents. It introduces sector innovation which plays a crucial role for the possibility of long run growth in overcoming the saturation of demand. Firms demand for complex competences rises with quality of existing products and the characteristics of new products. Competences supply is modelled

at the individual level. We show the binding effect of the competence constraint, especially in complex competences, on growth and employment, with possible long lasting Keynesian depressions.

Keywords :

Competences, tasks, process innovation, product innovation, quality innovation, sector innovation, learning by doing, endogenous growth, AB model, AB-SFC, human resource constraint, employment, unemployment, demand saturation, financial constraint, alliances, co-opetition, network, Schumpeterian competition.

Sommaire

Introduction

The question of the sources of economic growth is central to many debates in our society today. During the last 60 years, the growth rate has kept decreasing in many Western countries. In France, it amounted to 4.6% per year during the period 1960-1980. Then it dropped to 2.3% per year during the next 20 years from 1981 to 2000 and to 1.23% per year since the 2000s. In the U.S., we observe the same trend. The annual growth rate dropped from 3.85% in the 1960s to 3.4% in the 1980s and to 1.86% per year since the 2000s until today (data on the website of Eurostat). At the same time, we observe that the unemployment rate is high in France. Since 30 years, it has rarely fallen below 7%. Before the financial crisis in 2008, it was situated at 7.2% before increasing constantly to 10.5% in May 2015. Since this date, growth seems to be returning to France with approximately 2% per year but the unemployment rate still remains high at 8.8% in the first semester of 2019.

The relationship between growth and unemployment rate cannot be summarized by a causal one where economic slowdown leads to high unemployment rate. The labor factor can play a great role in explaining the growth of the economy. Several theoretical models in economics literature show the effect of human capital on growth ([Romer, 1990], [Lucas, 1988], [Aghion and Howitt, 1992]). Higher education is important for countries close to the world innovation technological frontier because it favors innovation. In addition to this, some empirical studies ([Barro, 2001]) show also the positive effect of education and human capital on growth.

Competences may be a chance for growth but also a problem for growth. Two questions are raised : (1) How do competences may be a chance for growth ? It leads us to study the competence building process and the effect of competences on innovation and growth. (2) How do competences can slow down growth ?

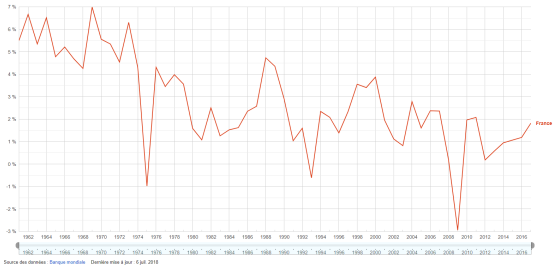


FIGURE 0.1 – Growth rate in France from 1960 to 2019. Source : World Bank

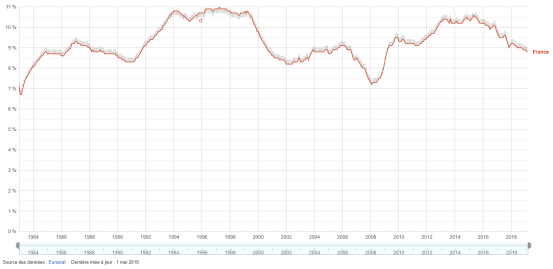


FIGURE 0.2 – Unemployment rate in France from 1960 to 2019. Source : Eurostat

In many countries, we find the following paradox. Even if the unemployment rate is high, in many sectors, firms cannot recruit because they cannot find individuals who can do the job. Data on the website of Pole Emploi[1] in September 2018 shows that 44,4% of

1. Pole emploi is an administrative public establishment (EPA), responsible for employment in France.

recruitment projects of firms are considered as "difficult". There are two main causes : lack of attractiveness (due to lack of applications) and lack of competences (lack of qualified candidates for the position). This proportion has increased constantly since 5 years from 34.7% in 2014 to 44.4% in 2018. Even when the unemployment rate is high, unemployed persons do not have the required competences to do job. This phenomenon is observed not only in France but in many countries in the world. Manpower Group has conducted a survey on the shortage of talent since 12 years with 40.000 employers in 43 countries. It concerns many sectors, from manufacturing to transportation, trade and mining. They found that many firms cannot find profiles that bring together the technical and behavioural skills required to fill the positions they seek. In France, recruitment difficulties concern 29% of firms surveyed. Among the reasons, 20% of employers believe that candidates do not have the required experience. There exists a mismatch between competence supply and demand in the labor market.

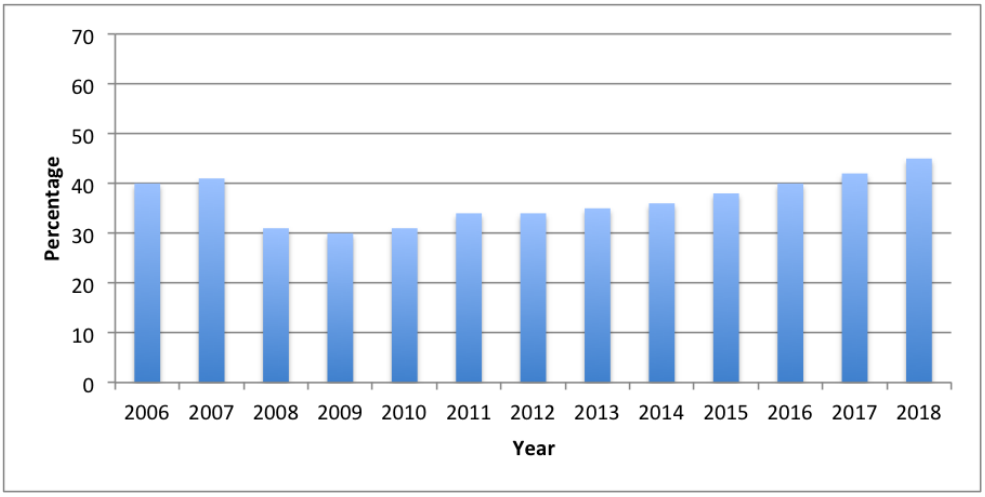


FIGURE 0.3 – Percentage of firms which have difficulties to recruit

This mismatch is explained by many factors which may come from the supply side or the demand side. On the supply side, we have the problem of the education and training system. In a study of France Strategie ([Ru, 2017]), they show that one of the main causes of productivity slowdown in France comes that the skills of the workforce are lower than the OECD average and with little improvement. The French education system is characterized by a larger skills gap according to social background than in other countries. Additionally adult skills are below the average of OECD countries, with a de-skilling over the working life because of the lack of continuous training, especially among the most precarious employees. On the demand side, the literature focuses on the effect of technical progress which changes demand for different categories of workers. The skill-biased technical change literature shows a shift in the production technology that favors skilled over unskilled labor by raising its relative productivity and therefore its relative demand. It has major impact on

the wage inequality and employment structure. In a study of the OECD ([OECD, 2018]) in 2018 on technology, productivity and job creation, there are some key findings : (1) many OECD countries show weak employment growth and/or increasing income inequality, with an employment structure shifting towards high-skilled workers, (2) OECD economies are increasingly knowledge-based, with a shift of economic activity to services and to high-tech and innovative activities, (3) Aggregate productivity growth remains modest, but the combination of technological change and upskilling helps many firms achieve strong productivity growth and job gains. However, if the upskilling is slow-moving, it can damage the economy. In a note (January 2018), the European Commission warned that a return to a certain growth would not automatically lead to a fall in unemployment. The difficulties of firms to recruit have negative effect on growth by limiting their expansion of production. 20% of European firms see their production limited by recruitment difficulties while they were only 12% in this case a year ago (2017). The problem concerns many countries in Europe : Germany (26%), the Netherlands (16.4%), France (11/4%), Slovakia (34%), Poland (46.7%)... The factor of competence cannot be ignored to understand the cause of economic slowdown. This dissertation tries to provide some answers on the building process of competences and the consequences of the competence constraint on growth and employment by two models. Each model focuses on different features of this process.

Several theories aim to explain the relation between competences, innovation - especially product innovation, growth and employment.

Concept of competence

The concept of competence is widely used in the economic and management literature. A first version of the concept is based on the individual and not the firm (an organisation). This is the economics route, with the predominant use of the term "skill". The skill-biased technical change literature tries to show the relationship between technical progress and demand for different categories of competence, and its consequences on the employment and wage structures. A series of studies over the past 30 years has documented the rise in wage inequality in the U.S. and European labor market and pointed to technological change - especially by the development of microcomputers- as an explanation for the rise ([Bound and Johnson, 1992], [Juhn et al., 1993], [Levy and Murnane, 1992], [Katz and Murphy, 1992]). The computer being complementary with human capital, demand for highly skilled workers who are more likely to use computers on the job increases. More recently, a task-based approach appeared which study the relationship between skills, tasks and new technologies ([Katz and Murphy, 1992], [Card and Lemieux, 2001], [Acemoglu et al., 2004], [Goldin and Katz, 2008], [Carneiro and Lee, 2009]...). Skill groups are distinguished and they are imperfectly substitutable. New technologies are considered as task replacing and it has a large negative effect in middle skill or routine tasks. Their demand decreases and the middle wages fall relative to top and bottom.

Competences can also be defined at the firm level. In the management literature, the concept of competence is widely developed in order to understand how competences al-

low firms to grow, especially the literature on core competencies ([Hamel et al., 1989], [Hamel and Prahalad, 1990], [Hamel, 1991]). By identifying, developing and protecting competences which are important to firms, they can sustain their competitive advantage and continue to expand. The concept then is key to understand the primal question of building competences.

Human capital, process innovation and growth

There exists several models of endogenous growth based on human capital and innovation ([Aghion and Howitt, 1992], [Aghion and Howitt, 1996], [Funke and Strulik, 2000], [Pelinescu, 2015]). For [Aghion and Howitt, 1992], the skilled labor force determines the size of innovations which in turn has a positive effect on the growth rate. The blueprints for new technologies are generated by allocating labor to research activities and the productivity of research is increasing because of the accumulation of the stock of knowledge. New technologies are embodied in new intermediate goods (or capital goods) which increases the productivity of producing consumption goods over time. The Schumpeterian mechanism of creative destruction is modelled. The discovery of new intermediate products render previous ones obsolete. Innovative firms obtain higher profit and it boosts the incentives to innovate in the future. There exists a dynamic of entry and exit of firms which depends on innovation results. However this literature lets aside (consumption) product innovation, a fundamental omission.

New (consumption) products, demand and growth

In the literature mentioned, demand never gets saturated, because consumers are always ready to consume more of the unique product. This is an unsatisfactory account of growth, since households do not have homothetic preferences. As their incomes rise, they do not want to consume more of the goods they consume, since they saturate. They want essentially to consume new goods, and this gives a place for product innovation. For this purpose, an another stream of literature on endogenous growth model based on sector innovation has emerged. The subject has been raised by [Pasinetti, 1981] but not pursued. At the best of our knowledge, its models are not many ([Foellmi and Zweimüller, 2006], [Aoki and Yoshikawa, 2002], [Matsuyama, 2002]...). For these models, the factor restraining growth is saturation of demand for individual consumption good. In order to get a sustainable growth in long term, firms should introduce new sectors which create high growth of demand. The history of development of existing sectors has usually the S-shape with initial acceleration and eventual slowing growth. New sectors which command high growth of demand emerge. [Matsuyama, 2002] describes the development process by the term "the Flying Geese pattern" (a series of sectors take off one after another). The necessary condition for the takeoff of new sectors is productivity progress in existing sectors. The prices of existing products decrease, and since household limit the increase in their consumption (or are saturated), their increased purchasing power is available for new goods. The products of these sectors become affordable to an increasingly large number of households which constantly expand the range of goods they consume. Then larger markets for new goods in turn leads to further improvement in productivity. The relationship between

sector innovation and growth is a two-way one because the rhythm of creation of new sectors depends on profit motivated R&D. However the labor market is not introduced in these models.

Process and product innovation, growth and employment

At the best of our knowledge, the relation between innovation, growth and employment is not modelled. However there exists some empirical papers which measure the effect of process and product innovations on employment ([Harrison et al., 2014], [Calvino and Virgillito, 201 [Harrison et al., 2014] find that increases in productivity thank to process innovation are an important source of reduction of employment requirements for a given output. However the growth of demand for the old products through the increase in purchasing power tends to overcompensate these displacement effects. At the same time, the introduction of new sectors creates new jobs. The growth of employment due to the new goods market expansion explains one third of the net employment. These papers are mainly empirical. We need to formalize and model both the competences demand and the competences supply in order to study the role of the human constraint on growth. However, the constraint may not come from all competence classes demand excess. The lack of some competencies may constraint the production process. Competences need to be distinguished according to their degree of complexity.

Our theoretical contributions

In this dissertation, we will present two models. They have some common and separate features.

Common features of two models

In both models, we model competences as source of occupational tasks. The realization of tasks requires different competences. The innovation and production processes are distinguished, as showed by the existence of two departments in firms : research department and production department. The first has the objective of innovating in product (a new higher quality or a new sector) and the second of producing. This distinction leads to the distinction of two types of competences : production competences and innovation competences. Each department requires its corresponding competences to realize its own tasks.

In both models, firms have to change their structure of tasks (and capital) when their R&D department has found a higher quality. In each competence type, we distinguish different competence groups based on their unit efficiency. Innovations change the requirement for each competence.

In both models, We model market competition with entry and exit, with price setting firms and consumers arbitrage between the supplies of the different firms rather than the replicator dynamic which is sometimes used in the literature. The models appear as a new kind of Keynesian-Schumpeterian models with consumption product innovation.

Separate features and contributions of the two models

The first model, SIMECO 1, is a co-opetion model, and also a diffusion model with only one consumption product, but has a macroeoconomic closure, and also an income distri-

bution (with endogneous mean) as it essential as a determinant of consumers'choices. The second, SIMECO 2, has arisen from the desire to jump from a one sector diffusion model with saturation, to a growth model. It incorporates several sectors, and sector creation, and forms a macro and endogenous growth model. Competences are at firm level in SIMECO 1 but are hold by individual workers in SIMECO 2. This distinction has consequences on the competence building process. In the first model, the competence stock increases due to firm learning by doing with dynamic increasing return and the use of alliances. In the second, there is individual learning by doing with accumulation of competence on the career, and training. Additionally there are new generations of capital which increase labor productivity.

As each model focuses on different features, it has its own novel contributions to the literature. In the first model, we found that alliances favor the building of competence and the diffusion of the one-sector product up to saturation. An another result is that the mix of competence integration and specialization is the key to the persistence of alliances in the long run, and the permanence of a network. Competence sharing should lead to uniform competences and the disappearance of alliances, a paradox to which we offer a parsimonious new solution with partial specialisation, and within a market competition framework. The second model is an endogenous growth model based on quality and sector innovations. The introduction of new sectors allows to overtake the demand saturation. However, the financial constraint may hinder new sector creation. An another important result is that competences play a great role in determining growth. They appear as a major supply constraint on growth, particularly the constraint on complex competences when quality increases or when new sectors are high tech. Then our experiments will show that growth is a fragile process under these constraints and that this economy can be trapped in Keynesian recession and even situations of extended depression.

Our methodological contribution

In this dissertation, we will use the agent-based methodology. This method is helpful because it allows a multiple, dynamic and decentralized decision-making of many heterogenous agents. There exists several competences, several types of agent, many agents, many markets in our model, and the interactions are not linear. In the second model, we add the stock flow consistency (SFC) ([Godley and Lavoie, 2006]) to create an AB-SFC model ([Caiani et al., 2016], [Dosi et al., 2019], [Dawid et al., 2011]). To build such a SFC model, we have to introduce new types of agents : the government, the unemployment fund, the central bank, the bank, the investment fund, a capital good firm and individuals as workers/consumers. In order to respect the SFC principles, we build transactions-flow matrix and aggregate balance-sheet at the aggregate level and make sure that every operation has a counterpart elsewhere. The sum of all lines and all columns should be equal to 0 in the transactions-flow matrix. Two examples of the importance of consistency are introduced by this method. The first is the money creation process. Most of the DSGE models assume that banks are totally absent and lending is direct. The role of financial institutions is reduced to intermediaries, accepting deposits from savers and lending them

to borrowers. However in reality banks can create additional means of payment by granting loans to non-bank customers. The loan creation process corresponds to an expansion of the bank's balance sheet. The second is the treatment of firms creation and failure. Agents have to provide wealth to create firms and wealth is destructed when firms fail. Wealth is brought by agents, and losses are undergone by the agents who own these firms. Therefore we can explain the origins of creation and destruction of wealth. This is essential to model carefully the growth process in an economy with entry and exit of firms. Moreover in the initialization process of the AB-SFC model, we make sure that we create a consistent stationary state. To the best of our knowledge, it has only been done by [Caiani et al., 2016] and [Caiani et al., 2018].

Thesis outline

First chapter

In the first chapter, we distinguish different concepts of competence in our model : individual competences versus firm's competence. As the concept of competence is central to this dissertation and that each model uses this concept at different level, we need to define them precisely and distinguish them. We also survey the literature on innovation and growth, and finally expose the theoretical framework that we will employ in the two models. Then we present the characteristics of the agent-based modelling methodology.

Second chapter

In the second chapter, we will present the first model, named SIMECO 1. The aim of this model consists of presenting a new theoretical framework to explain the persistence of the formation of R&D alliances in the long run when they are based on exchanging and building competences for innovating. The exchange of competences normally leads to a convergence between firms, the fast termination of alliances and the absence of new alliance formations in the long run, a result contrary to observation. Analysts have then added independent motives of relational and structural embeddedness to explain the high duration of many alliances and also the persistence of the existence of alliances in the long run. The present paper proposes a model built only on the competence motive, but incorporating the desire of partners to keep for themselves some strategic competences within the alliance, yet making use of them for the joint project. We show that this hybrid behavior is sufficient to obtain the persistence of an alliance network in the long run. The model is new in co-opetion modelling since it is dynamic with productivity increases and the growth in incomes. It generates an endogenous and hierarchical market structure. The good knows an S shape diffusion since not all households want to consume it at the available quality/price ratios, and no one desires more than one unit of this good. The model then shows that a balance between integration and specialisation of competences is necessary for the persistence of alliances formation in the long run and that this mix is an efficient tool for the growth of a market.

Third chapter

In the third chapter, we will present the second model, named SIMECO 2. This model is built upon some of the features of the first model and incorporates several of their blocks,

namely the R&D department organization, the innovation and production functions, the market competition over quality. New elements are introduced in this model. First we introduce sector innovation to desaturate demand and allow a sustainable growth in long term. Second, in this model, individuals are not represented by an income distribution but they are real agent who has different characteristics and is able to make decision. We introduce the labor market composed of several segments corresponding to the competences. The adjustment between competences supply and demand takes place through the labor market but also internal adjustment within the firms based on overtime, training, promotion and reclassification. Financing firm is done by two types of agents. Firms ask for bank's loans for physical investment since they have collateral in capital equipment. Households devote a fraction of their saving to funding the R&D of firms through the investment fund. They receive the flows of dividends.

Fourth chapter

The fourth chapter presents the results of the baseline simulation of the second model and several experiments. 4 experiments are realized : (1) different forms of utility function : lexicographic, hierarchic, and unweighted, (2) the rate of innovation in the capital good, (3) the degree of complexity of new sectors (low tech or high tech) which correspond to the low or high need in complex competences versus simple competences, (4) the aggressive versus defensive strategies of sector innovation of firms. We obtain a number of new results. Some of the essential results are the following :

- As a baseline scenario, we can obtain a sustained real growth with continuous sector and quality innovation and a low level of excess demand in high competences.

- There is a risk of strangulation of an economy through a high demand excess in some competences if the prices through quality improvement rises too fast, and if new sectors are high tech, since complementarities in the different competences lead to unemployment and a depression.

- A Keynesian crisis can take place but the economy can exit by creation and destruction of firms and products in some cases. Exit does not always take place.

- Inequality in wages rises over time.

- Preference for initial products versus new products plays an important role in the model.

1 The competence-based approach and the Agent-Based Methodology

In the first section, we will define different concepts of competences, and show why competences are crucial to understand, in economies in which innovation is fundamental, market competition and structure, and also aggregate growth. In the second section we present the modeling tools, still little used, to formalise the effects of such (heterogeneous) competences on market competition and on innovation, demand and growth. This is the Agent Based methodology.

1.1 The competence-based approach

Competences and their heterogeneity appear to us as essential to understand innovation and production processes which are best described in terms of tasks. They also are an important factor to understand the important change in these processes, which is the emergence of alliances since the 1980's in order for firms to build knowledge faster. They impact market competition. Moreover they appear as an essential factor of aggregate long run growth. Finally competences also appear as constraints on this growth process if in insufficient supply. Worse, since they are complementary rather substitutable, an excess demand in a few competences, normally the most complex can block the development of an economy. The human resources constraint may be, as we will show, the most binding constraint, the climate change excepted. In the first subsection, we will define different concepts of competence, especially the distinction between firms' competences and individual competences. Then, in the second subsection, we will explain the general framework to treat relation between firm competences endowments and their diffusion by alliances, and quality innovation, and the relation between competences and product innovations, demand and employment. Some of these relations have been studied in the literature.

1.1.1 Individuals' competences versus firms competences

In this dissertation, we distinguish two levels of competence : firms' competence and individuals competence. This corresponds to two essentially disconnected scientific literature

on competences. The literature on firms' competences has been developed in management science, and is named the *competence theory of the firm* . It is focused on the advantages that a competence gives to a firm over the others, either because it is idiosyncratic, or because the endowment is substantially higher. Hence the interest, from an economist's point of view is to understand a key factor of market competition. The literature in individual competences has been developed in economics, and is an essential part of labour economics, with the terms of *human capital* to emphasise the embodiment in workers rather than in the firm which employs them. However the use of the term of skills is predominant when one desire to recognize the multidimensional nature of human capital, although most of the models treat skills level as an unidimensional measure on a vertical scale. Competences could be taken as an another name for skills. However often the use of skills refers to an initial education degree, and then narrows considerably the concept. Secondly recent empirical has progressed on the analysis of the heterogeneity of the labor factor, and, therefore, as will be developed below, the use of term of individual's competences is then preferable, and we will use it in this dissertation. The primal interest of the economists has been the understanding of individual wages and careers, but a more recent interest has been on aggregate growth. At first glance, we can see, that considering the three levels of individual, firm, and macroeconomy, the management scientists privilege the second, but the economists often skip or do not treat this second level as important level.

1.1.1.1 Firm competences

Firm's competences are defined at the organizational level. This concept has been widely used in management science, especially in the theory of the firm ([Penrose, 1959], [Wernerfelt, 1984], [Grant, 1996], [Nonaka, 1994], [Quélin, 2000], [Teece et al., 1997]). Firm competences depend not only on their workers' competences but also on other factors like task allocation, organizational ability... For instance, [Grant, 1996] defines organizational capability by the ability of competence integration. As competence resides in specialized form among workers, the essence of organizational capability is the integration of individuals' specialized competences. The integration process is not the sum of different individual competences but takes place at different levels.

The figure 1.1 from [Grant and Baden-Fuller, 1995] shows different level of competence integration inside the firm. At the base of the hierarchy is competence held by individual. At the first level of integration are capabilities which deal with specialized tasks. These tasks are then integrated into broader functional capabilities (R&D, marketing, manufacturing and financial departments). At the highest level, new product development is the result of integration of a wide-ranging cross function. In his other paper, [Grant, 1996] points to four mechanisms for integrating competence : (i) rules and directives (workers follow plans, schedules, forecasts, policies and procedures), (ii) sequencing (imposed by the characteristics of the product, its physical inputs and its production technology), (iii) routines and (iv) group problem solving and decision making.

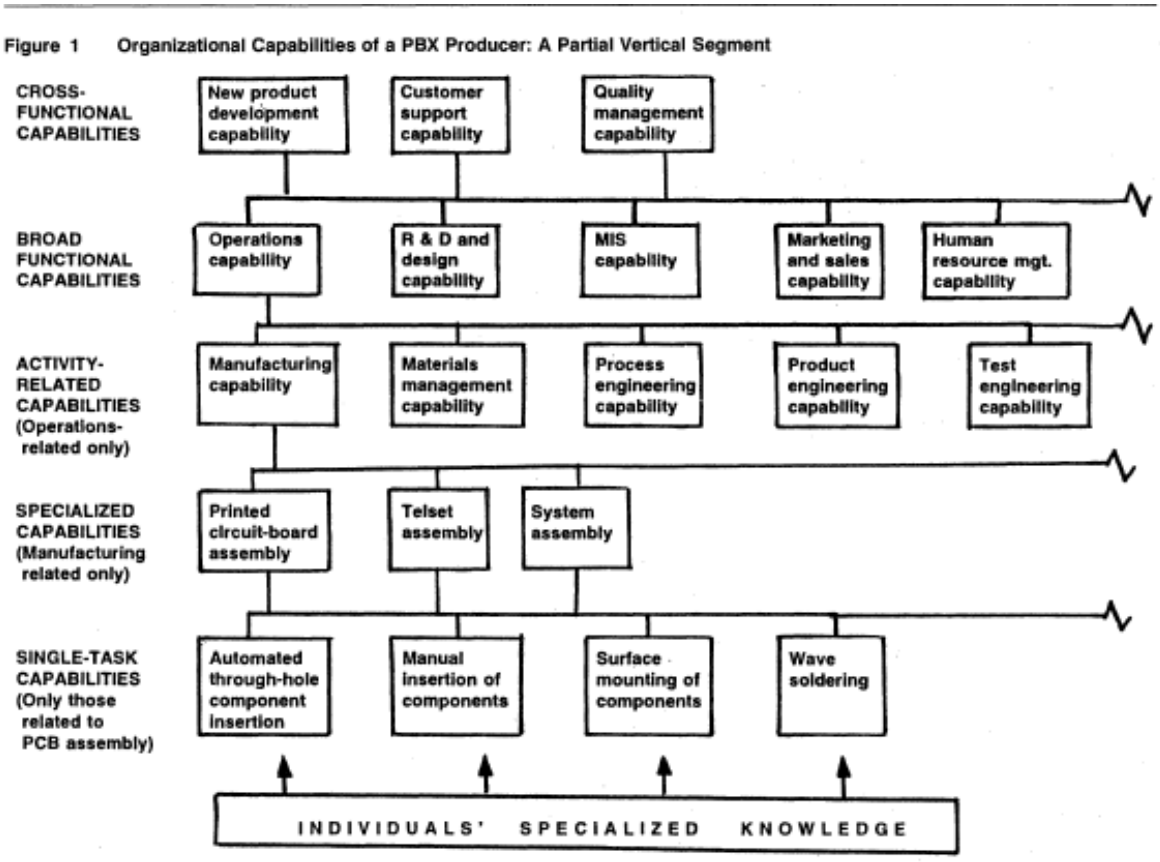


FIGURE 1.1 – Organizational capabilities of a firm : a partial vertical segment ([Grant and Baden-Fuller, 1995])

[Nonaka, 1994] suggests an another way of integration in order to create an organizational ability. It resides in a continuous dialogue between tacit and explicit knowledge. There exists four patterns of interaction between them.

The figure 1.2 from [Nonaka, 1994] explains how to create a new tacit or explicit knowledge from actual tacit or explicit knowledge. For instance, in the first case, firms want to convert tacit knowledge though interaction between individuals (socialization). As tacit knowledge usually takes the form of individual experience, firms may assign apprentices with a mentor. Knowledge is transferred then not by language but by observation, imitation and practice. If knowledge is explicit, in order to create new explicit knowledge, firms may use the social processes like meetings and telephone conversations. Since workers may exchange explicitly their ideas, it helps to create new ones.

The competence-based approach here belongs to a wider approach called the resource-based view of the firm. Since firms' competitive advantage depends on their resources,

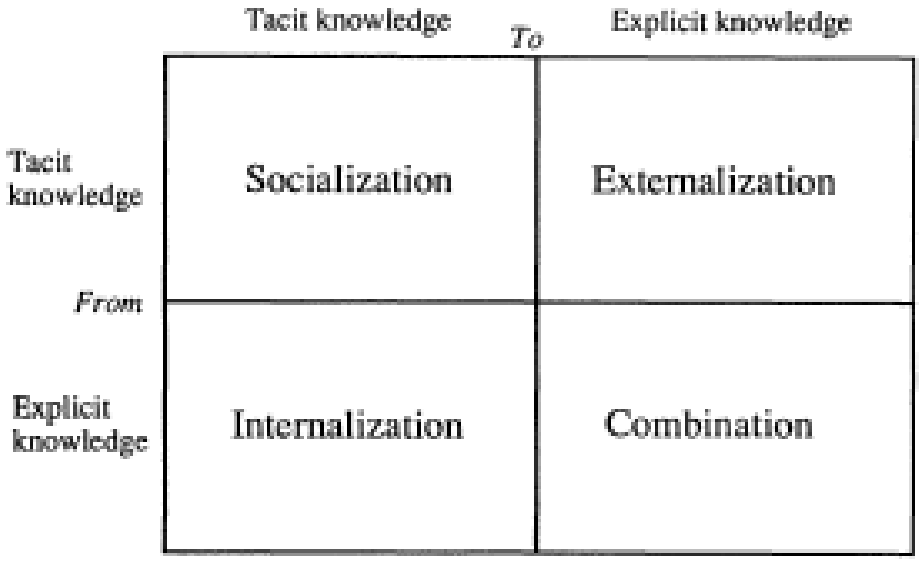


FIGURE 1.2 – Modes of the knowledge creation (Nonaka, 1994)

competences are part of their intangible resources. In Barney, 1991's paper, as strategic resources are heterogeneously distributed across firms and these differences may evolve over time, firms need to identify resources which can generate sustained competitive advantage. The author defines 4 empirical indicators of a strategic resource : value, rareness, imitability and substitutability. If a resource has a weak value or can easily imitable or substituted by its competitors, the comparative advantage based on this resource is not sustainable. Dierickx and Cool, 1989 follow the same path by focusing especially on the imitability. The latter depends on asset accumulation process, time compression, diseconomies, asset mass efficiencies, inter-connectedness, asset erosion and causal ambiguity. For instance, the more complicated the production process is, the more difficult the causal ambiguity can be determined. We can cite an example of the aircraft engine which includes many technologies. This sector is mainly held by three firms : Pratt Whitney, Rolls-Royce and the alliance General Electric-Safran. Other firms in different countries like Russia or China try to enter this market since many decades but the technologies used are too sophisticated with a thousand of components. It is difficult to determine the causal ambiguity of the engine. A competence may be considered as one important resource of firm if it satisfies all these criteria. In the previous example, some technologies or competence can play an important role in the functioning of an aircraft engine. Firms will not show them for fear of losing their competitive advantage. In some sectors, innovation results are protected by patents but firms decide to hide their technology because when patenting, they have an obligation to describe all the production process or technologies. Other firms may try to

steal and wait until the end of the patents' protection duration. An another particularity of competence is its combination process which can be difficult for other firms to imitate. [Galunic and Rodan, 1998] emphasize the process of recombine competences which may synthesize novel competences or experience a reconfiguration or relinking with other competences. Recombination depends on several characteristics of competence (tacitness, context specificity, dispersion) and its social organization.

However, not all competences are strategic resources of firms. We distinguish *strategic and not strategic competences*. If we follow the four criteria of [Barney, 1991], a strategic competence should own 4 characteristics : (i) it brings a highly added value to firm, (ii) it is rare, not widely diffused in the economy, (iii) it cannot be easily acquired by other firms or imitable ; (iv) finally it cannot be substitutable by other competences. This distinction has been developed in a stream of management literature called *core competencies* ([Hamel et al., 1989], [Hamel and Prahalad, 1990], [Hamel, 1991]) in which they emphasize the firm's ability to identify, cultivate and exploit the core competencies that make growth possible. Firms should be considered as a portfolio of competencies and not as a portfolio of businesses or products. More than different individual competences, firm's core competencies are the collective learning in the organization, especially the process of coordination of different production skills and integrate multiple streams of technologies. They include many hierarchical layers of workers and all functions (R&D, production, marketing, after-sale service...). It is "communication, involvement, and a deep commitment to working across organizational boundaries" ([Hamel and Prahalad, 1990]). A firm's core competences do not reside consequently in their workers' competences but also in its organizational competences. Core competencies are particularly important when firms create alliances. Since firms are competitive in building their competence portfolio, they may acquire some competences from their partners but should also transfer the others. If they do not identify and protect their core competences, they may lose their competitive advantage. [Hamel et al., 1989], on the basis of a large set of case studies, show that firms develop a strategy of acquiring core competences of the partner, but never forget that they will be their competitors, and try to transfer as little as possible of their core competences to the same partner. This view puts competence accumulation as a crucial factor of firm innovation and efficiency, a too little used factor of competition in industrial organisation literature. Alliances are an essential tool to build competences. Alliances and networks have been modelled by economists, but emphasis has been more on R&D than on competences.

Then, in a first model, we will the try to make a contribution on this little studied topic of competence building and alliances, using the management scientists concept of firm competences a such, and not as a sum of individual competences, but introducing market competition to obtain endogenous market structures.

1.1.1.2 Individual competences

In economics, several terms are employed, such as qualification, capabilities and skills, and more recently, competences, notably used by OECD (for instance [OECD, 2018]). The term *skills* is the most used in theoretical work ([Katz and Murphy, 1992], [Card and Lemieux, 2001], [Acemoglu et al., 2004], [Goldin and Katz, 2008], [Carneiro and Lee, 2009]...). It defines the efficiency of an individual when producing or doing a task, but remains related to the education level when it comes to measurement. For instance, in a seminal paper, [Acemoglu and Autor, 2011] summarize the neoclassical model as a canonical model where there exists two categories of skills. A high skill worker is considered as having college diploma while a low skill worker a high school diploma. The skills produce output directly. Then they develop a ricardian model in which the concept of skills is broaden to an *endowment of capabilities for performing various tasks*. "The endowment is a stock, which can either be exogenously given or acquired through schooling and other investments". Then the skills produce tasks, and not output directly. However the models developed along the route of the task approach have treated skills as exogenous, although this need not be the case.

The concept of competence can be considered as equivalent to this broad definition. Yet it is broader in recent empirical work, since skills as measured are only one component of the individual factors which determine the capacity to produce a task, and it is this capacity which is defined as a competence. [OECD, 2018] defines competence as "the acquisition of knowledge and skills and the mobilization of knowledge, skills, attitudes and values to meet complex demands". The French National Commission for Professional Certification defines competences as the ability to combine a set of knowledge, know-how and skills to perform a task or activity. It always has a professional purpose. The result of its implementation can be assessed in a given context (taking into account the autonomy, the available resources...). Oxford dictionary defines competence as "the ability to do something successfully or efficiently". This definition implies two ideas : "ability to do something" and "successfully or sufficiently". One example can be used from Dictionary of education : "Competence is the ability to perform to a specified standard. [...] Where previously gaining a qualification might have been based on time served, or courses attended and examinations passed, it was now based firmly on what the candidate could do. And so the emphasis moved from teaching skills to assessing them". In this example, the competence of one teacher is determined not only by his theoretical knowledge but also the way he can apply and explain clearly to students.

Competence includes knowledge, skills and ability. First comes general and technical knowledge. When one individual tries to do some tasks, he has to own some general and technical knowledge which can be acquired by education, training and self experience. For example, an electrician has to possess knowledge about electrics and the repairing procedure otherwise he can endanger his life. In second come the skills. Owning technical knowledge does not imply that he can well realize this task. All electricians can do basic

tasks but some take many days to find the cause of the problem and its solution while the others take only half of day. There exists also good and bad solutions. In the second case, new problems can appear a few hours or few days later. According to Oxford dictionary, skill is defined as "the ability to do something well ; expertise". If knowledge concerns more theoretical requirements, skill is a practical part. Owning all required knowledge does not imply that individuals can do well tasks. There always exists difference between theory and practice. When we practice, we start to use theoretical knowledge learned in school, university or training center to do job. Two individuals were trained in the same school, they got all required knowledge but they do not have the same efficiency. This difference can be explained by factors such as like learning capacity, and past experience... One student who did five internships during three years of bachelor degree can adapt faster with new job than other one who did not do any internship. Additionally, each individual does not have the same social skills which depend largely, but not only, on his character. If he is open and social, he can work in a team more easily than others and outgoing results are better.

Third comes the ability, defined as "the possession of the means or skill to do something" (Oxford dictionary). Even if one individual owns all required knowledge and skills to do a job, maybe he does not have all the means to do that. "Means" includes not only skills but also physical capacity, mental capacity, motivation, necessary equipment and so on. For example, the most important mean is our health. If one individual has some health problem, he may not perform well his job.

To summarize, a full definition of competences may come as a combination of knowledge, skill and ability. It corresponds to three ideas : you know **how** to a job, you **can** do the job and you can do it **well**. It is important to have a comprehensive concept of the individual capacity to do a given task, since we will summarize it in one dimension. On the other hand, trying to decompose it into the different elements would be too complex for the second model that we will build. Our aim is the understanding of aggregate growth under supply and demand of heterogeneous competences, and we have no need to detail technical skills, social skills, abilities to analyse key issues, at least in a theoretical model.

Some empirical studies on individual competences

The concepts of tasks and competences have attracted more and more attention of not only academic researchers but also other public institutions. In France, the number of reports on this fields has soared.

A number of recent empirical studies on competences have emerged (for France, see [Branche-Seigeot, 2015]). They propose a less synthetic view than the one we have exposed and will use in the SIMECO 2. Competences are distinguished according to different criteria, and then several competences must be gathered to produce a task. This growing literature is nevertheless important to provide empirical foundations for future developments of the formalisation of competences in the second model we present, notably to

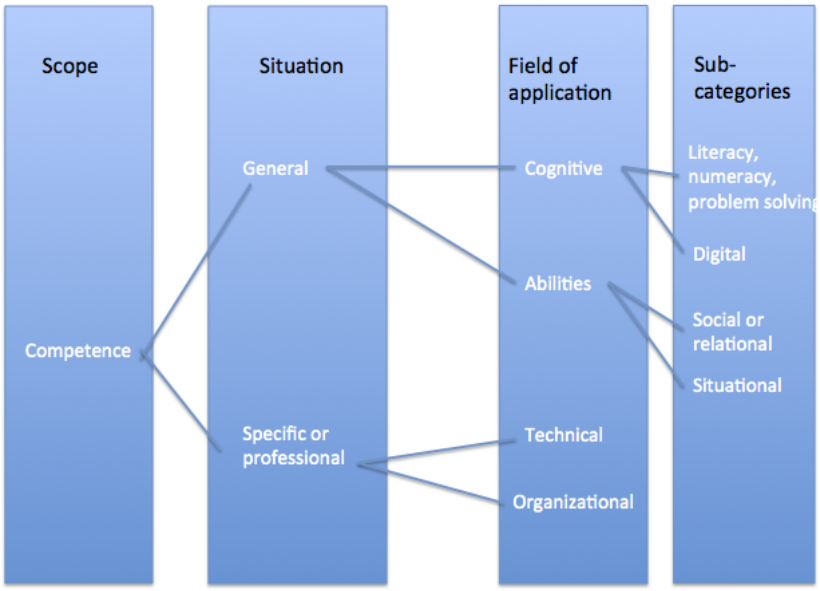


FIGURE 1.3 – Competence Typology (COE)

measure the change in competences demand that technical change requires[1]. In the figure 1.3 from [COE, 2017], according to the situation where the competence is used, they distinguish general and specific competences. The first are used in almost every jobs while the second are specific for a sector, a firm or a profession. Then according to the field of application, general competences may be cognitive (numeracy, literacy, problem solving, numeric..) or behavioral (social relation, learning ability). In a report of France Strategie in 2017 ([Ru, 2017]), they define general competences as those "common to different professions or sectors which can promote professional mobility and secure professional careers". They have two characteristics : (i) first they require basic knowledge which does not depend on some particular professional context but is necessary for many professions, (ii) they include behavioral, organizational or cognitive skills common to different professional situations : ability to manage customer relationship, team working, coordinate a team or a project, adaptability to the working environment, the use of main office software. For instance, the literacy competence is the ability of reading a document like an email, a new law, an information...and is required in almost all professions. The problem solving competence is the ability to resolve different problems in different situations. Specialized competences may be technical and organizational. An IT scientist has to own not only ge-

1. A project NUMJOBS has started to study the effects of numerisation and artificial intelligence on employment, using the Agent base approach. It is a joint project between Pôle Emploi, Sorbonne university and Panthéon-Assas Paris 2 University, and aims to integrate WORKSIM, a large AB model of the French labor market ([Goudet et al., 2017]), and SIMECO 2, and additional research on numerisation.

neral competences which helps him to do calculus or read but also specialized competences like ability to writing code.

The typology of competences is a guide for future work to extend the analysis of different effects of external events (change in quality, new products...) on competences demand and supply. According to the workers' existing competence type and competence level, firms can increase the efficiency of their training policies in order to give them new competences if they do not own or to increase the level of some competences if it stays low.

1.1.1.3 Competences in the dissertation

. In this dissertation, we build two models, named SIMECO 1 and SIMECO 2[2]. The first model uses only firms' competences while the second uses individual competences, yet incorporates some organisational role for the firm.

In each model, the firm has two departments : the R&D department and the production department. This distinction defines separate budgets and processes. Then, the first typology in firm's competences is the distinction between innovation competences and production competences[3].

Each department has a production function which uses a vector of tasks (the production department also uses capital equipment) to produce the output which is innovation, stochastically obtained, for the R&D department, and production of goods for the production department. Then each task requires a competence. It could be more than one, as the empirical research mentioned above suggest, but for our purpose, this does not appear as useful. Firms have a level of endowment in each competence. Each competence is distinguished by its unitary efficiency in the production process, and competences are strictly hierarchised on the efficiency scale, with the idea that the firm uses tasks of increasing complexity on a scale. Then the price of the tasks is accordingly increasing.

For the sake of simplicity all outputs, in all firms, require the complete number of competences, and no new competences are needed. Then a task and the corresponding competence are occupation specific in the sense that they are the same across firms, and also across workers[4]. Then a firm may transfer a competence endowment to another firm and receive a competence endowment from another firm, and also work together on the same task, as is the case in SIMECO 1. Workers with a competence in SIMECO 2 can fully use their competence in all the firms to do the corresponding task.

2. Acronym for Simulation, Innovation, Macroeconomics, Employment, Competences, Organization.

3. There exists some empirical studies on firms' production and innovation competences. For instance, in a report of the French state secretariat for industry (Francois, 1997), the authors define 9 innovation competences : insert innovation in the firm's strategy ; develop innovations ; organize and manage the production of knowledge ; manage human resources from an innovation perspective ; follow, anticipate the evolution of markets ; finance innovation ; sell innovation ; manage and protect intellectual property and finally appropriate external technologies.

4. The literature on human capital now recognizes that occupational human capital is important , besides general human capital and firm specific human capital. For instance Kambourov and Manovskii, 2009.

From the two literatures in management and economics on competences, we take the fundamental idea that competences can be accumulated by their use, hence by the procedure of learning by doing. At the end of the period, innovation competences increase in proportion determined by the quantity of the task done, and so do production competences. In SIMECO 1, this increases then the endowments of the firm in the different competence, and output capacity or efficiency if it reduces the number of units used to produce the same level of output. In SIMECO 2, learning by doing impinges at the workers' level since competences are individual. Then workers accumulate a competence as long as they use it, but at a decreasing rate. It also follows that, since they have a vector of competences, those not used are not increased, but we also assume that they are non decreased. The embodiment of the competences in the workers has a crucial consequence. It is lost to the economy when he retires. We do not want to go into the complications of a partial transmission of part of the competences acquired. Endogenous growth models based on human capital make this transmission, but they do not treat the problem of the embodiment in individual workers. If we had such a transfer to incumbent workers, the wage of the workers of that firm would increase with the endowment, and new cohorts would have immediately much higher competences than other workers of the same age, and be hired on wages much higher than in many other firms, an inconsistent situation. Anyhow, this transfer would be lost with retirement. It then does not appear as a solution for the increase of competences of the economy in the long run. Another solution is possible. Competences can be transferred to the firm as a firm knowledge capital, a new type of capital must be created and dealt with. It is a major modeling issue. It would integrate the firm competences conception of SIMECO 1 and the individual competences conception of SIMECO 2. While it is an interesting option for the future, we have decided not to include it in the present model SIMECO 2. Then growth of competences in the long run rely on the improvement of initial education both in competence structure and in endowments levels. Moreover improved generations of capital goods raise the productivity of all the cohorts of workers. In the short run, However firms can train and promote some workers when they need tasks to be done in some competences classes in which they cannot recruit for insufficient supply.

The ranking of competences based on their unitary efficiency has major consequences in our models. It means that some competences are complex, some simple, and some intermediate. Then a first example, in both models, of the important consequences of a ranking is that the change in the final product quality has not the same impact on the different tasks, hence on competences demand. We assume that a higher quality requires more complex tasks, and less simple tasks. In SIMECO 2, new sectors can also be more demanding in complex competences (or not). We will study the impact of these *high tech* sectors, which will be revealed to be very important. Quality change to a rise in production cost[5]. The figure 1.4 gives an illustration.

5. Shaked and Sutton, 1982 assume that the product cost is zero for all qualities, Grossman and Helpman, 1991 the same marginal cost for all product. Since firms with different

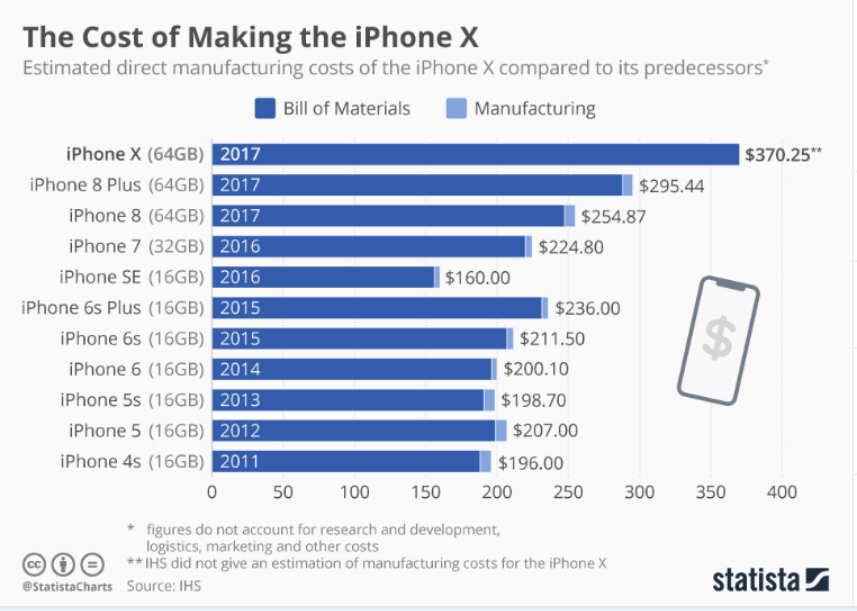


FIGURE 1.4 – iPhone Unit Cost Evolution

In this figure, the unit cost of an iPhone has constantly increased with its quality[6]. When the quality increases, Apple needs to use more rare materials, but also a higher quantity of researchers, IT scientists... which cost more in terms of wage. Higher quality of consumption product requires more high level workers because they can bring higher added value to the product. Difference in costs leads to a difference in price and consequently the competition configuration.

A second example takes place in the first model. the efficiency ranking is used to distinguish two types of behavior : Competences can be considered as *strategic or non strategic competences*, a distinction we have mentioned above in the management literature, and to which we give a fundamental role in our modeling of alliances. In a natural way, the firms consider as strategic the competences that are complex, so that in the alliance, they use it to contribute to task on the innovation project, but do not reveal the corresponding competence to the partner. To be realistic on this secrecy behavior, we assume that only the most competent of the two firms contributes, while the other will have to compensate in the project budget, or be the best in another strategic competence. The consequence is that only the firm which has contributed with a strategic competence increases this

quality level have the same unit cost, the lower quality firms cannot survive because innovators will set the lowest possible mark-up in order to kill other competitors. However this does not allow for a realistic description of market structure.

6. iPhone SE is considered as having lower quality level than its predecessor in order to capture medium income individuals.

competence by learning ; The rates of accumulation of the two firms then diverge competence by competence, with a specialisation and a possible divergence in the global levels of competence. These consequences have major micro and macro effects that we will study.

Let us give some first elements on the supply side and the substitution and complementarity issue in the production of tasks by competences. In SIMECO 1, the firm can obtain quantities of tasks by paying for them. Supply is unlimited. The manpower hired is simply a quantity of a certain task. However the efficiency of each unit is determined by the firm endowment in the corresponding competence. The concept of the competence is then really the concept of the management science where it is an asset of the firm, as shown above, and not of the implicit labor supply. In SIMECO 2, workers have a portfolio of competences at entry. Then they use of them at a time, choosing the one which gives the highest salary. This yields a specialisation by learning. However, if unemployed, they can switch, and when employed, the firm which employs them can promote them if needing another competence than the one they use, but must pay them as least as much (an employer under French law can ask a employee to do another task than the one he does, as long as it is close, but cannot lower the wage, otherwise it is a major modification of the terms of the contract which the employee will refuse). A firm can also train an employee in a competence he does not have if it needs workers. There are two conditions. The first is that the competence class must not be much higher than the one he is in, a realistic assumption. The second is the same legal constraint we listed above. Workers can then enlarge their competence portfolio along their career. Since they have such a portfolio, workers can then be substituted in a given task within organisational and personal limits we listed.

This is an alternative to the assignment of workers to tasks according to comparative advantage as done in the ricardian model of [Acemoglu and Autor, 2011]. In this model, and further work, workers have different hierarchised skills, and they can do all tasks, but with a rising comparative advantage for high skills as tasks are more complex. The comparative advantage assumption assumes that skills are measured on a one dimension scale and are general. Even though workers having a skill level can work on different tasks, market clearing and the law of one price gives them the same wage. This assumption is a source of unrealistic outcomes for the wage structure : in an economy with firms, workers having different skills but doing the same tasks should not earn different wages in the same firm (when they have the same experience). This is either illegal or a source of low efficiency by discontent, as efficiency theory has showed. Moreover, the framework does not look very appropriate to assess a human resource constraint which we consider to be heterogeneous in the competences. [Autor, 2013] in a note 18 of his paper mentions alternatives such as the one of workers having several skills we use, as a very realistic feature : " It captures , in my view an important additional element of realism. When a skilled worker looses his job due to plant shutdown and takes employment instead as a food service worker, it is plausible to think that he has not only changes job tasks, but also changed the skill set used to perform these tasks...". [Acemoglu and Autor, 2011] present

(pp 1142-1145) the case in which workers choose to supply one of the skills. They assume that workers are strictly ranked according to the degree of their comparative advantage in complex skills over medium tasks and medium over simple skills to make the assignment. We have a milder assumption on the workers preferences. As stated above, hey have a different and evolving stock in each competence in their portfolio, and, on the market, choose to supply the competence which offers them the highest wage. Moreover we prefer to consider that the firms (the demand side) has the assignment power in firms, while on the market, both have some decision power. Finally besides comparative advantage, a main divergence point is that we consider that the labor market does not clear. Unemployment and excess demands then coexist in many of the competence segments of the market. The consequences are at the heart of SIMECO 2, among them the role of demand for final goods. This discussion suggests that the precise organisational framework at the firm level that we propose, with could later benefit from finer assumptions on competences. it could include some general competences.

A complementary but different issue is the production functions in tasks. In our models are essentially Leontief. Since such a production function appears as a description of the technology owned by the firm, with the corresponding machines, at a given time, for a given product, this appears as the natural assumption[7]. It is very difficult to understand how a tasks production function could be substitutable in tasks, as is done by a CES in tasks in the models following Acemoglu and Autor, 2011[8]. The absence of substitution allows to obtain excess demands over tasks, when competences are themselves specialised in a task (with the flexibilities we have mentioned). Then we have Leontief functions to obtain a clear view of the effect of the direct change in tasks demands when the quality of the product nature changes, while if tasks are substitutable, the firm optimises the new demands under the wage structure, and this makes the results less clear, all the more because the wage structure evolves (in our models also) in response to excess demands.

To summarise, if tasks (and the corresponding competences) are substitutable, it cannot explain why in many European countries, firms have difficulties to hire in some sectors while the unemployment rate remains high. They cannot ask an accountant to do the job of an IT scientist. The competence "accounting" is not substitutable to the competence "coding", especially when it is a question of specific or technical competence. Producing an unit of product also requires a fixed proportion of each task (and corresponding competence). When the change in competences demands is related to the change in product quality or creation of new sectors, the impact on production and employment depends on the different adjustments that we listed, including the acquisition by workers of competences new to

7. Gregory et al., 2016 find an elasticity of .29 in tradables within regions, a low estimate at a level of aggregation which remains high. Complex processes of competition between firms with Leontief production functions can yield substitution at the aggregate level.

8. Acemoglu and Autor, 2011 never give a justification, but reasons seem to relate to the level of aggregation, which makes it very difficult to deal with Leontief aggregate production functions and to the need of solving for market clearing with wages equal to the marginal products.

them in order to do tasks new to them.

1.1.2 Competences, innovations, demand and employment

The relation between competences, innovations, demand and employment is not a simple one because it includes multiple interactions between many agents and though many markets. In this subsection, we intend to deal with the questions of the relations between these variables as studied in the literature, in a concise way, to e present the routes we will follow, as extensions or new routes. We will study each couple of variables before building a final diagram of interactions between them : between innovation competences and innovation ; between innovations, especially product innovations, and demand ; finally between demand and employment (and competences).

1.1.2.1 Competences building and innovation

The first relation is between competences and innovation. The literature shows some phenomena about innovation like the drop in research productivity ([Griliches, 1988], [Bloom et al., 2017]), the emergence of R&D alliances ([Hagedoorn, 2002], [Tomasello et al., 2013]), persistence of R&D network ([Rosenkopf and Schilling, 2007], [Tomasello et al., 2013]). In this dissertation, we will study these phenomena by using the competence concept. For instance, [Bloom et al., 2017], from a wide range of evidence from various industries, products, and firms, show that it becomes more difficult and requires a higher quantity of resources in order to produce one unit of research output. The most famous example is the Moore's law. In the semiconductor sector, we observe that the number of transistors in a dense integrated circuit doubles about every two years. This can be considered of an anticipation of innovation's appearance timing. However this law is actually questioned. For example, in 2015, Intel stated that the pace of advancement has slowed. It cadence increases from two to two and half years. If we consider a smaller and more powerful microprocessor as an quality innovation, when the absolute quality level keeps increasing, we need more and more research to produce the "same" result (doubling the number of transistors from 2 to 4 does not require the same effort as double from 64 to 128, at least in terms of units). Since the realization of research activities requires competences as inputs, firms should have a higher stock level and a larger portfolio of competences.

The literature on transaction costs theory distinguish three modes of acquiring competence : internal learning, competence market and R&D partnerships or hybrid form. [Grant and Baden-Fuller, 1995] identify circumstances in which alliances give higher results in efficiently utilizing and integrating specialized competence than market or hierarchical governance : (i) when competences cannot be completely embodied within the product being exchanged, (ii) when the incongruity between the product domain of the firm and its knowledge domain is high, (iii) when the uncertainty which firms perceive as to the future knowledge requirements of their present product range is high, (iv) and finally when the benefits of early-mover advantage in technologically-dynamic environments

are great. Firms need to gain access to more types of knowledge than those they have. Alliances combine the different types of knowledge of the partners in order to innovate in a joint project. However, [Hamel et al., 1989] note that firms may loose in partnerships in favor of their partners if they do not manage their competence portfolio. "A strategic alliance can strengthen both companies against outsiders even as it weakens one partner vis-à-vis the other". In his later paper, [Hamel, 1991], from data on international strategic alliances, finds that not all partners are equally adept at learning and this will lead to asymmetries in the competences endowments of firms.

Many papers study the factors which have impact on the efficiency of learning in alliance, such as the literature on the absorptive capacity (the ability to treat and make efficient knowledge transfers) ([Cohen and Levinthal, 1990], [Kale and Singh, 2007], [Lane and Lubatki and competence transfer ([Cummings and Teng, 2003], [Gupta and Polonsky, 2014], [Mowery et al., [Simonin, 2004]) . When firms create research alliances with other firms, the efficiency of innovation depends on multiple factors. A first literature emphasizes absorptive capacity. If firms have a great absorptive capacity, they can recognize more easily the value of new information, assimilate it and apply it to commercial ends. Absorptive capacity is path-dependent, meaning that the actual level depends on prior related competence acquired and on diversity of background. [Lane and Lubatkin, 1998] point that one firm's ability to learn is determined by the similarity of both partners' competence bases, lower management formalization, research centralization, compensation practices and research communities. This literature helps to understand the nature of absorptive capacity and proposes strategies in order to increase the firm's absorptive capacity level and its innovation ability. Firms need to manage their competence portfolio and have a competence acquisition strategy to target some competences considered as the most important to build a strong absorptive capacity. The second literature on competence transfer inside the alliance shows how competence flows between partners. It has a great impact on partners' competence portfolio and also their competitive advantage. When some alliances are characterized by an increased similarity of partners' competence bases ([Gupta and Polonsky, 2014], [Cummings and Teng, 2003], the other by an increased specialization. [Mowery et al., 1996] find that the capabilities of partners become more divergent in a substantial subset of alliances.

In the long term, the creation of multiple R&D alliances leads to the emergence of a network of firms. The literature on R&D network ([Cowan et al., 2007], [Gulati et al., 2012]) finds for instance the emergence of a network named *small world* . It is characterized by short distances and high clustering coefficient between firms. It favors the creation and diffusion of competences because firms belonging to the same cluster (or community) know each other and work better together. Since there exists links between clusters, competences are diffused not only inside the cluster but also to another. The form of the network determines innovation results.

By modelling an R&D alliances network in a co-opetition framework in the Simeco 1, we can understand how competences are built and diffused in the economy and their

impact on innovation results, which in turn impact firms' economic performance. We need to distinguish two concepts : competence access and competence acquisition. In the first case, if a firm lacks some competences, when entering an alliance, the partner can bring its competences to the innovation effort function, but he may refuse to transfer its knowlege (case of a strategic competence in our model SIMECO 1, in the line of Hamel's idea). In the second case, the firm will not only benefit of the partner competences through its contribution to the innovation project, but it acquires this competence (case on non strategic competences) . The question of how competences are diffused over the economy can determine its performance.

1.1.2.2 Innovations types and growth

The innovation literature distinguishes different types of innovation. They have different effects on growth that different growth paradigms, to use Aghion et al., 2009's term. We have built the figure 1.5 to recapitulate different types of innovation. We consider two main types : process innovation and (final or consumption) product innovations. The first concerns the production process while the second deals with the characteristics of consumption products or the creation of new products/sectors.

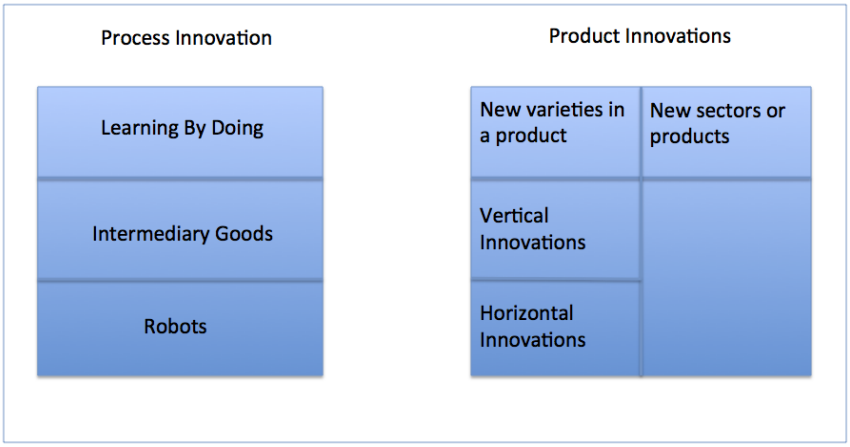


FIGURE 1.5 – Different types of innovation

A process innovation is considered as leading to the reduction of production cost. A process innovation, according to us, may come from the following factors : learning by doing, better intermediary goods, better capital equipment and robots.

A (final) product innovation may be considered as a new variety of existing product or a creation of new sectors/ new products. A new variety of an existing product may come from vertical or horizontal innovations. In the first case, the product varieties have different qualities. All consumers prefer a higher quality to a lower one. However the prices

are different, and they may choose the lower quality if the price is lower. It will depend of their intensity of taste for quality, and this intensity will depend on the income level, but other idiosyncratic factors could play a role. In the second case, the differentiation is based on consumers' heterogeneous preferences. At the same price, each consumer has a different preference for each variety, based on its characteristics. Again the final choice will be influenced by relative prices.

Then we define a new sector when the new product responds to new wants, that arise with the increase in purchasing power, as necessities are fulfilled (Saviotti and Pyka, 2013). Consumers are not interested in buying higher quantities of many goods, such as bread or meat, or more than one unit in durable goods such a washing machine or a smartphone. They are interested by new products or services. A new sector is then defined as one in which the product has a low or zero price elasticity of substitution with existing products. Of course the new varieties within this sector will have significant elasticities of substitution.

The paradigms in endogenous growth explain the effect of one of these types of innovation on growth.

(1) Process innovation literature

(1.1) Learning by doing

Arrow, 1962 builds a growth model based on learning by doing. It is particularly important when the production function is an expression of technological knowledge. Learning is the product of experience and only takes place through the attempt to solve a problem and takes place during activity.

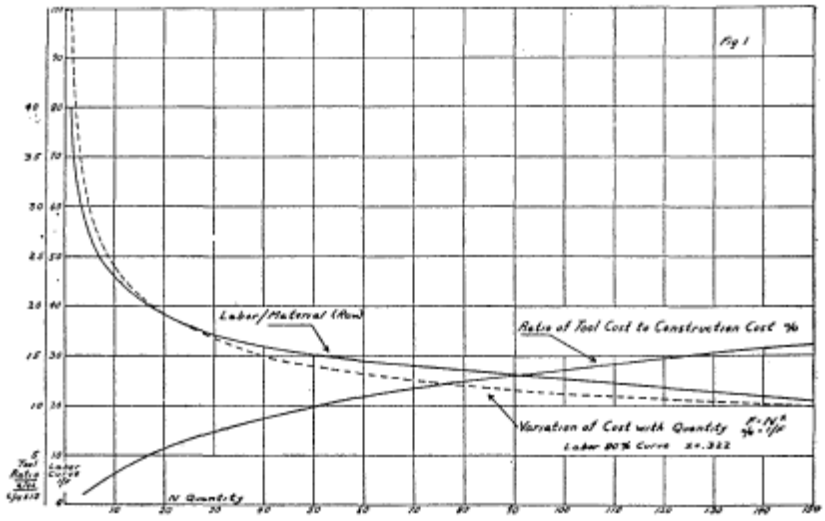


FIGURE 1.6 – Variation of cost with quantity

The author uses an example of [Wright, 1936]'s production cost variation with quantity in the aeronautical industry. The number of labor-hours expended in the production of an airframe is a decreasing function of the total number of airframes of the same type previously produced. This curve is called a "learning curve" or progress ratio". The reduction of production cost is explained by the improvement in proficiency of a workman with practice (when the same task is repeated in a series of trials) or when a body of knowledge is learned over time. When price decreases, a larger proportion of individuals can buy this product. The growth is based on the increase of quantity. The Arrow's model has been the base of the AK model of endogenous model. As [Aghion et al., 2009] summarise it, "learning by doing generates technological progress that tends to raise the marginal product of capital, thus offsetting the tendency for the marginal product to diminish when technology is unchanged". The marginal product is then the constant A. The savings rate is an important determinant of the growth rate.

(1.2) Intermediate goods

Different branches of endogenous growth models have been developed. [Romer, 1990] considers that innovation introduces new but not necessarily more efficient varieties of intermediate goods. As [Aghion et al., 2009] summarise," The degree of variety raises the economy's production potential because it allows a given capital stock production potential to be spread over a large number of uses, each of which exhibiting diminishing returns."

A more elaborate version comes which the self named *Schumpeterian model* by [Aghion and Howitt and later work. It assumes that new qualities of intermediate products render the old obsolete, involving a creative destruction process. This Schumpeterian process however takes place only in *in the intermediate goods market*, since the models never introduce several and new final product sectors. There are several intermediate industries. Each intermediate product is produced and and sold exclusively by the most recent innovator. It is displaced by a new innovator. Faster growth is then generally positively correlated with higher firm turnover. The expenditures in research, and past endowment are important determinants of growth, and co-vary with it ([Aghion and Howitt, 1996]). The macro agent based models include more efficient generations of capital in a more or less sophisticated modeling ([Dosi et al., 2010]). Some include several capital firms which then may compete. Some allow a firm to choose among the vintages it uses.

(1.3) Robots

Recent literature studies the effect of robots and artificial intelligence (AI) on economic growth. [Aghion et al., 2017] model AI as a process where capital replaces labor at an increasing rate and tries to reconcile evolving automation with the observed stability in the capital share and per capita GDP growth over the last century. They find a set of sufficient conditions in order to obtain a balanced growth with constant capital share, especially the condition of a structural transformation of the economy with the introduction of robots, AI and automation. The share of automated sectors in GDP should decreases

over time even as an increasing fraction of sectors are automated. On the labor market, even if AI is skill-biased for the economy as a whole, in long term, firms should outsource a higher fraction of low-occupation tasks to other firms and pay a higher premium to the low-occupation workers they keep inside the firm. [Acemoglu and Restrepo, 2017] and [Acemoglu and Restrepo, 2018]) also build a growth model in which the displacement of workers by automation can be compensated if new non automated tasks are developed and use labor. However there is no explanation for the use of new tasks. Only one final product is consumed, and the innovation in new products could be a needed justification.

(2) (Consumption) product innovation literature

Firms may try to innovate by changing the characteristics of existing products or by creating new product/new sector. In the first case, when all products are identical, price competition leads to low mark-up level and zero profit. firms have an incentive to differentiate their variety from competitors' varieties. The concept was proposed by [Chamberlin, 1933] in The Theory of Monopolistic Competition. A monopolistic market is defined by five characteristics : there exists many firms and consumers in the market ; nobody has total control over the market price ; consumers can perceive the existence of non-price differences among products ; there are few barriers to entry and exit ; each firm has some degree of control over price. We have distinguished vertical and horizontal differentiation. In the second case, firms may create new sectors which satisfies to new needs.

(2.1) Consumer product differentiation

(2.1.1) Vertical innovation

One of the first papers studying vertical differentiation is [Shaked and Sutton, 1983]. They build a non-cooperative game with three steps : (1) enter or not enter to the market, (2) choose the quality level, (3) set price. They find a perfect equilibrium characterized by a duopoly. The reason why firms choose different quality level because consumers do not have the same income level. When their qualities become closer, price competition will reduce the profit of both firm. Distinct qualities give them a positive profit at equilibrium. If other firms try to enter in this market, the equilibrium will not be stable. Later [Grossman and Helpman, 1991] develop a model of repeated quality improvements in a continuum of sectors and each product follows a stochastic progression up a quality ladder. Even if progress is not uniform across sectors, the rate of aggregate growth is constant and it responds to profit incentives in the R&D sector[9].

(2.1.2) Horizontal innovation

Horizontal differentiation has been studied by [Hotelling, 1929], [d'Aspremont et al., 1979]). However, increased differentiation does not appear to play an important role in growth ana-

9. New sectors are not created, and consumers are a representative agent who spends an equal share of his income on each good. this explains why this model does not belong to the product innovation paragraph below.

lysis, probably, as will be shown below, developing varieties of a same product constitute a business stealing which does increase production at the aggregate level, at least in part (see below).

(2.2) Creation of new sectors

Firms may try to create new sectors to obtain a higher potential of demand and profit. [Stokey, 1988] builds a model with the introduction of new and better product. There exists a continuum of potentially producible goods but in each period, only a limited subset is really produced. Goods of higher quality enter each period while those of lower quality drop out. In the long run, growth continues without bound. [Aoki and Yoshikawa, 2002] build a model of demand saturation for each consumption good and the need of introduce new products/sectors in order to have a sustainable growth. There is ample evidence that no individual product or sector can grow exponentially. If in the beginning of the product cycle, demand increases almost exponentially, its growth decelerates and it reaches a ceiling. It is assumed that the consumers buy a limited number of units or zero, because their demand is saturated by more, a very realistic assumption. The diffusion rate then approaches a ceiling at 100% or lower (exogeneous parameters control this ceiling). The diffusion curve has a logistic shape. When consumption products innovation is considered, in long term, the factor that limits capital accumulation and growth is not diminishing returns on capital but the declining growth of demand for the existing products. Firms must do R&D activities to create new sectors for which demand will grow fast again.

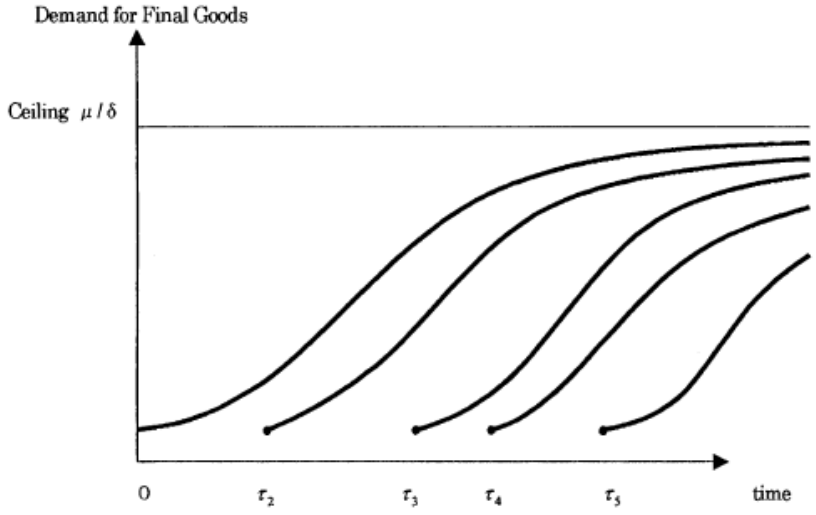


FIGURE 1.7 – Demand saturation and emergence of new sectors ([Aoki and Yoshikawa, 2002])

In the figure 1.7 from [Aoki and Yoshikawa, 2002], each sector grows logistically once it emerged. New sectors emerge stochastically . The aggregate value added is the sum of

the outputs of all the existing sectors (including new sectors). The growth of older sectors keeps declining while new sectors enjoy high growth. On the demand side, the logistic equation of product diffusion is consistent with the intertemporal utility maximization of Ramsey consumer with a particular utility function. [Aoki and Yoshikawa, 2002] make the assumption that the utility coming from the consumption of a particular final good depends on how long a time has passed since the final good first emerged. This however makes the diffusion curve an assumption, not a result.

[Matsuyama, 2002] builds an another model of creation of new sectors in order to explain both how a series of sectors can take off one after another, and why each has the logistic shape. The global pattern is the Flying Geese pattern of figure 1.7. When a new product appears, its production cost stays high. As productivity improves, it becomes more affordable to an increasingly large number of households, which constantly expand the range of goods they consume. It can explain how a mass consumption societies rises. The curve of demand evolution for each good is identical to that of [Aoki and Yoshikawa, 2002] but its ceiling correspond to 100% (each household consumes 0 or 1 unit of the product, such as vacuum cleaners, washing machines, television sets, car...). Then the ranking of the products must be explained. The author introduces the idea that necessities and luxuries are not fixed, as was often assumed in consumer theory, but which evolves over time. Many consumer goods that have penetrated into the majority of households are considered now as necessities. On the consumers' side, the first product is food and the others are manufacturing goods. Food is a necessity. Each manufacturing good has a number starting from 0, 1, 2... to k. The author assumes that households consume good k only if they also consume all the manufacturing goods whose indices are less than k. This lexicographic ordering means that they have to consume the first manufacturing goods from 0 to k-1 before consuming the good k. Each household has a budget constraint. A poor household can only consume j-1 products. Good j is considered as a luxury one because it is beyond its budget. If his income level increases, additional income will be spend on manufacturing goods or services with higher indices.

Some foundations for this lexicographic ordering have been given by the recent literature on consumption. [Witt, 2001] studies how the structure of consumption expenditure is transformed with rising income. The motivational force for this transformation is constituted by innate needs and drives. As part of the genetic endowment, needs represent human universals. And to satisfy needs, individuals will take actions and in our case by consuming one or several goods. It justifies the existence of the utility function which depends on the consumption of a bundle of goods and services. In [Witt, 2016], if a consumer has a set N of innate needs with elements 1, 2..., n, and to satisfy a need, he should consume a vector of M goods and services $x_i = (x_{i1}, x_{i2}, ..., x_{im})$, the total utility U_N is obtained by :

$$U_N = U_N[u^1(x_i), ..., u^n(x_i)] \tag{1.1}$$

Two mechanisms can explain the transformation of the structure of consumption with rising income. First when the resources available for the consumers' satisfaction are gro-

wing, some of the motivations which drive consumption activities start to change. It arises from acquired wants and new preferences are formed. The utility function is extended by new arguments and it increases without bounds. Second, when the ability to spend increases, some needs seem to be rapidly satiable when the consumption of goods serving them goes up. They are referred to as basic needs. However, other needs are difficult to satiate, such as needs for status and social recognition, needs for cognitive and sensory stimulation... Consequently the growing consumption is motivated by the second type of need and promise little welfare gains when expenditures are raised.

1.1.2.3 Innovation types and employment

Process innovation has a negative displacement effect on employment. However it has also a positive effect on employment since the price of the intermediate or capital goods fall, and the price of the consumption good should fall, under market competition. The net effect is not obvious, and can depend on number of factors, although in balanced growth, as we have seen with [Acemoglu and Restrepo, 2017]), assumptions must be made to obtain a stable rate of utilisation of the population. As for product innovation, the models of [Aoki and Yoshikawa, 2002] and [Matsuyama, 2002] do not include labor as a factor, and it will be precisely one of our contributions in SIMECO 2 to include it (for an interesting survey of empirical research on the effects of both types of innovation on employment, see[Calvino and Virgillito, 2018]). Their theoretical models suggest that the creation of new products can help to create new jobs and aggregate dynamics when existing sectors are already saturated. In these sectors, not only the quantity increases slowly, the continuous learning effect and process innovation lead to jobs' destruction. All along the product cycle, we have two effects : (i) the decline of tasks demand by unit of product leads to a drop of unit cost and price, it boosts the consumption, quantity increases and it creates new jobs. (ii) process innovation which reduces jobs demand for the same number of units. At the beginning of the product cycle, the first effect overrides the second, the net effect on employment is positive. However, the increase of quantity slows down while the economies of scale become stronger. In the long term, the second effect overrides the first. At this moment, the creation of new products helps to maintain the unemployment rate at a reasonable level because they create new jobs. We have a jobs transfer between old and new sectors. This mechanism explains the increase of the growth rate in the first industrial revolution. Productivity has increased in the agricultural sector and freed labor force for new industrial sectors (and so on). This is a well acknowledged story, which was however yet in need for modeling.

The figure 1.8 from [Dachs and Peters, 2014] recapitulates the effects of process and sector innovation on employment. Some empirical studies estimate the effect of process and product innovation on employment ([Harrison et al., 2014], [Chennells and Van Reenen, 2002], [Spiezia and Vivarelli, 2002]). On the whole, product innovation leads usually to employment growth, although the intensity of the effect differs across studies ([Franz et al., 1990],

	Employment-reducing effects (displacement effects)	Employment-creating effects (compensation effects)
Product innovation	*Productivity effect of product innovation:* New products require less (or more) labour input (–) *Indirect demand effect:* Decrease in demand of existing substitutes (–)	*Direct demand effect:* New products increase overall demand (+) *Indirect demand effect:* Increase in demand of existing complementary products (+)
Process innovation	*Productivity effect of process innovation:* Less labour input for a given output (–)	*Price effect:* Cost reduction passed on to price expands demand (+)

FIGURE 1.8 – Effects of sector and process innovation on employment ([Dachs and Peters, 2014])

[König et al., 1995], [Garcia et al., 2004]). By contrast, the effects of process innovation are found to range from negative ([Ross and Zimmermann, 1993]) to positive ([Doms et al., 1995], [Blanchflower and Burgess, 1998]), according to the potential of demand increase.

From a random sample of 20,000 firms from France, Germany, Spain and the UK during 1998-2000, using data from the Community Innovation Survey (CIS), [Harrison et al., 2014] have made a decomposition of product and process innovation effects on employment, distinguishing industry and services. When looking at industry with a rise of 8.3 points in employment in 1998-2000, process innovation is an important source of reduction of employment requirements for a given output (-2 points). Yet the growth of demand for the old products over compensates these displacement effects, with own price productivity effect (+0.7), and a rise in a purchasing power effect (+4.1 points). If new products appear, the net effect of the demand of these new products is an increase in 5.5 points, after deducting the business stealing of old products which amounts to one third of this figure. Then the demand for the new products is the strongest force behind net employment creation[10].

[Dachs and Peters, 2014] estimate the effect of both types of innovation on employment on the same survey, but for the period 2002-2004, with 64 600 firms from 16 European countries. They find that sector innovation is positively correlated to employment growth because it leads to an increase in sales. An increase in sales growth due to new products of 1% leads to an increase in gross employment by 1% in manufacturing. The net effect on employment over this period is +4.42% : the effect of productivity and process innovation -1.87%, employment growth due to old products is +5.14%, and net contribution of sector innovation +3.54%.

1.1.2.4 The nexus competences- innovation -employment in the dissertation

There theoretical literature we have surveyed focuses very little on (consumption) product innovation. In similar way, the empirical literature is rare on product innovation is also rare. In this dissertation, the first model sets a first building block for the study of competence building and quality innovation. The second enlarges the study of innovation

10. The definition of new products is taken from the CIS survey, and covers new and significantly improved products.. The results in services are similar.

to new sector innovation. It sets the nexus, with 6 markets : labor market, consumption product market, capital good market, deposit market, credit market and finally capital share markets. In the first model, we consider two types of innovation -learning by doing and quality innovation and their effects on product demand and competence demand. Since the characteristics of existing varieties changes (here the quality), it has an impact on the tasks and competences structure, as well as on incomes and diffusion of the unique product. The second model builds on the first with the introduction of sector innovation, as well as competences supply. In the long term, when existing product markets become saturated, new sectors help to increase demand and create new jobs. There exists also a capital firm and a capital-good sector. Individuals in the first model are not the agents but represented only by an income distribution, whose mean is endogenous but shape exogenous. In the second model, they are agents and make the decisions related to consumption and work. A multi layered labour market is build where there are interactions between individuals and firms. Change of existing products' characteristics and the creation of new products change competences' demand and consequently the wage structure. The figure 1.9 has been conceived to recapitulate all the effects of innovations on employment through the change of demand[11]. It is intended to encompass the effects listed by the recent task approach theoretical literature (Acemoglu and Restrepo, 2017) and the Harrison et al., 2014 empirical decomposition. It is more detailed than the effects listed in the two papers. It has not been tailored made to SIMECO 2, and the price effect of learning is likely to be zero since workers are compensated fully. Process innovation effects on the decrease in prices are obtained by new generations of capital and replace learning by doing with a similar effect.

There are 4 effects in the consumption sector :

1. Process innovation by learning by doing : the stock level of competence of workers increases if they do the task. It is also called **replacement effect** in the literature. For the same unit number of output, firms need less workers.

2. Process innovation by the use of less costly capital goods leads to price decrease and then product diffusion because products are affordable to a higher portion of population. Demand increase creates new jobs, within the limit of saturation (**price-productivity effect**).

3. Increase in purchasing power increases demand and for existing products and therefore employment (**productivity-purchasing power effect**).

4. Sector innovation : introduction of a new sector. It increases demand and employment (**new sector innovation effect**).

And 3 effects in the capital sector :

5. Quality innovation of the consumption product induces a more capital demand, for a constant quantity (more capital or replacement), since quality is assumed capital intensive. This increases employment (**demand effect of new capital**).

11. prepared by G.Ballot and T.T.Huynh for an internal Pole Emploi seminar, June 2018.

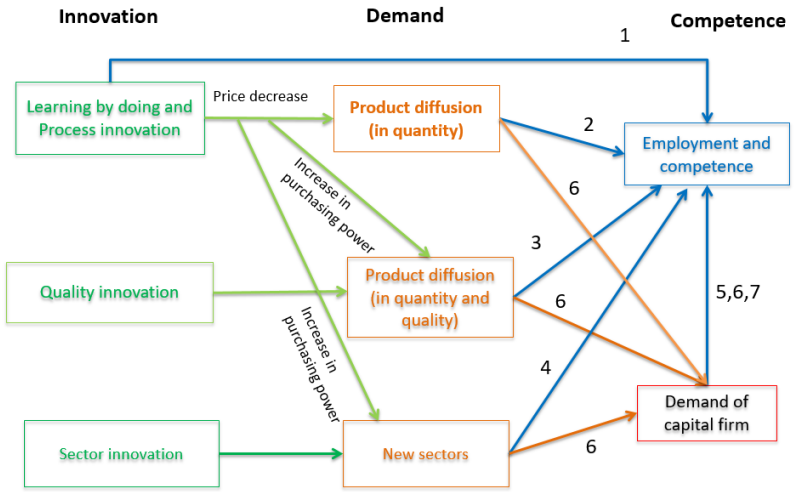


FIGURE 1.9 – Relations between innovations, demand and employment

6. The increase in demand leads to a demand for additional capital to increase production capacity. This increases employment (**effect of increasing production capacity**).

7. Effects of productivity in the capital sector, with constant production. The effect on employment is negative (**replacement effect of the capital good**).

This dissertation will study some questions which, at the best of our knowledge, remains unanswered, or some others, when we remove some assumptions in the existing models.

a) The effect of innovation, not only on net employment, but also on employment structure and income distribution.

As we saw in the previous subsection, the net effect of innovations on employment is positive. However, we do not know what kind of jobs are created or destroyed by each type of innovation. The competence demand may change when the characteristics of existing varieties change or when new sectors do not require the same competences as existing products. For instance, we consider the case of quality change. Producing low quality cars may not require the same number of each categories of workers as for the high quality cars. The term "production" includes not only workers in the plant but also in other departments like R&D. The production of high quality cars ask for a higher number of researchers and IT scientists if they want to give more digitized functionality in their cars. Consequently if there exists only high quality products in an economy, the demand for high level workers is higher since they can bring higher added value for the products.

The characteristics of new sectors can play an important role in this case. These products can be high tech, low tech or medium tech. Consequently they will not require the same categories of workers. In high tech sectors, they need more researchers, IT experts,

electrical engineers, computer scientists...than in low tech sectors.

b) Excess demand of some classes of competences and their effects on some on the economy

As developed above, we consider a Leontief function where all competences are needed to produce a product. Competences are not substitutable. If the change in the structure of competences supply cannot follow the change in the structure of competences demand (as a result of innovations), the production may be blocked and it has a negative effect on employment and the economy. The intensity of the blocking effect depends on the evolution of both side : competence demand side and competence supply side. In the first case, it depends on how change of the new characteristics of existing varieties in quality, the intensity of the learning by doing effect, the creation of new products and their characteristics. In the second case, it depends on the possible strategies of firms : continuous training, promotions, as well as the workers reservation wages. it also depends in the long run on hte rate of adjustment of the initial education.

When the economy is blocked by the supply in some categories of competences, the continuous upgrading of quality or the creation of new sectors which demand also these competences may damage the economy more. A positive effect of innovations on employment is consequently conditioned by the adjustment of the competence supply.

1.2 Methodology : Agent-based modelling

1.2.1 Criticism of neoclassical assumptions

First we summarise some of the main assumptions of neoclassical modes, whose criticism has lead to build ABM.

Before presenting some main assumptions of the ABM method, we start by remind some main assumptions of the neoclassical models since it helps to better compare two methods. There exist three main assumptions in neoclassical methods.

(i) They can get all relevant information before making decision (perfect information)

(ii) They try to optimize their objective function.

(iii) a fictitious auctioneer makes market clear

First assumption : The first assumption can be considered as unrealistic. Agents cannot always know exactly all relevant information before making decision. For instance, the agency theory shows that households cannot sometimes distinguish the quality of a product like a car. Consequently firms need to pay an additional cost in order to signal their quality. If we look at our daily decision making process, we can recognize that we cannot know or compare the price and/or the quality of one product we want to buy from over the world. That explains how different homogeneous products can have different prices in real life since there exists other costs like transaction costs and transportation costs.

Second assumption : When modeling decisions, neoclassical economists assume that agents always try to optimize their objective function. For instance, individuals try to

maximize their utility under the budget constraint. Firms try to minimize production costs under the production of pre-fixed quantity or maximize their profit. However behaviour studies ([Sinitskaya and Tesfatsion, 2015], [Hommes et al., 2017]) show that individuals' decision seem to follow some simple rules rather than be the results of optimization calculation, that are beyond the possibility of a human brain to make. It does not mean individuals or managers are irrational. [Simon, 1959] has introduced the concept of bounded or procedural rationality and highlights the important role of learning in the decision making process. People follow some behavioural rules that have been learned, and whose satisfactory results they have observed. These rules continue to be updated with new information, new observations and learning. They cannot be considered as irrational since they will not make a decision which reduces their utility.

Many papers in the literature show that we can get the same results of optimization by simple learning principle ([Assenza and Gatti, 2013], [Arifovic, 1994], [Hommes et al., 2017]...). [Arifovic, 1994] uses a genetic algorithm which competitive firms to update their decision rules about next-period production and sales. Their simulation results converge to the rational expectations equilibrium for a wide range of parameter values. Later [Hommes et al., 2017] use as well the genetic algorithms in a model where individuals optimize an adaptive, a trend following and an anchor coefficient in a population of general prediction heuristics. In their results, they find that the evolutionary learning model can replicate three different types of behavior : convergence to steady state, stable oscillations and dampened oscillations in the treatments. [Arifovic et al., 2012] model the effect of social learning in a monetary policy and challenge Taylor principle. According to this principle, the central bank should change the nominal interest rate more than increase in inflation. If the flexible price or potential level of output deviate output or inflation deviates from target, the policy maker must react sufficiently aggressively. Consequently that leads to a rational expectations equilibrium. However, even small expectational errors may deviate the economy from intended equilibrium, especially in presence of social learning. They show that evolutionary learning may converge to a small neighbourhood of the minimum state variable solution whether or not the policy maker follows the Taylor principle.

Third assumption

A fictitious auctioneer makes the market clear. This is not an innocuous assumption, since, if agents set the prices, they have their own criteria to set them, and the outcome of the different decisions leads to disequilibria such as unemployment and excess demand on the labor markets, and excess demand or supply on goods. The dispersion of prices or wages on one market are also a fact, which has important consequences for the firms, which may obtain different profits, as well as workers who have unequal wages and incomes. A large part of the economic facts and problems are related to disequilibria.

1.2.2 Agent-Based Methodology

We will use the agent-based model (ABM) method in this dissertation. It is also called agent based computational economics (ACE).The characteristics and assumptions are opposite to many of the neoclassical models. [Ballot et al., 2015] list five characteristics of Agent based models :

- (i) Agents interact in market and non-market relations.
- (ii) They are heterogeneous by design and/or because of their interactions. (Agents do not stay identical after interactions like in orthodox economics).
- (iii) Agents are autonomous, no fictitious auctioneer controlling the system.
- (iv) Bounded rationality
-(v) Definition of the law and norms constraining the agents' autonomy.

It can be added that they are open-ended dynamic systems which are driven by the successive interactions of agents.

According to [Colander et al., 2008], the advantage of the ACE modelling is that it gives a large choice of micro economic forms for the issues at hand : breadth of agent types, number of agents of each type, hierarchical arrangements of agents. One agent is defined as an entity who is autonomous and capable of making decision according to some pre-defined behavioural law and his environment. These agents can be firm, household, government, bank and so on. They interact with each other and all multiple decentralized decisions lead to the emergence of some macro results. Researchers may study the interactions among agents simultaneously with the agents decisions and the dynamic macro interplay among them. In the models, no equilibrium conditions have to be imposed. Quasi equilibrium can emerge for some time at the aggregate level. The term "quasi" applies since agents are always individual in a dynamic process of change. Multiple equilibra may exist and (quasi) equilibrium is considered more as an outcome than a requirement.

The heterogeneity of agents has important macroeconomic consequences. The results brought by ABM method show that the macro properties are not the sum of different micro properties ([Stiglitz and Gallegati, 2011]). [Nelson and Winter, 1974] notes the inconsistency of neoclassical growth theory with the micro studies on technical change. Since it is based on aggregation, maximization and equilibrium, diversity and change are hidden. For instance, neoclassical economists assume that firms always maximize their profit. However, their choice sets are not static and well defined to make profit maximization descriptively plausible. If one firm innovates, it may not get a higher profit if other firms can also success their innovation projects or if consumers may not prefer the new product or quality. This shows how another factors like consumers' preference and budget constraint, chance, competitors... co-determine the rent of one firm's innovation. "The extent of the rewards and penalties depends on a complex of environmental and institutional considerations that differs sharply from sector to sector, country to county, and period to period" ([Nelson and Winter, 1974]). The firms are not all alike and the situation is not one of moving equilibrium.

ABM method becomes more and more useful when we study technological change or in-

novation where markets are dynamic. Since five decades, evolutionary and Schumpeterian approaches are widely acknowledged by economists, even neoclassical ones. They have been continuously extended by [Nelson and Winter, 1974], [Nelson and Winter, 1982], [Greenwald and St In these approaches, innovations or technical change are not pre-defined and identical. Products' quality or cost do not evolve at the prefixed path. It then becomes difficult to anticipate which kind of innovation or technical change which appear each period and in what extent it impacts the global economy. The ABM method helps answer these questions by building a complex adaptive system. It can also reproduce some stylized facts like the skewed distribution of firms' size, the persistent technological and behavioural heterogeneity among firms, the clustering in time of the major innovations...([Dawid, 2006], [Ballot and Taymaz, 1998], [Ballot and Taymaz, 1999], [Silverberg and Verspagen, 1994], [Chiaromonte and Dosi, 1993]..., and then heterogeneous households ([Fagiolo and Dosi, 2003], [Dosi et al., 2010]).

1.2.3 Examples of macroeconomic Agent-Based Models

Macroeocnomic ABM have a long tradition starting with the simultaneous MOSES model by [Eliasson, 1977] and the TRANSACTIONS model by [Bennet and Bergmann, 1982]. Eliasson built an endogenous growth model with all the types of agents needed for stock flow consistency, and introduced an input-output structure with firms which compete within sectors with entry and exit. In this creative destruction framework he added a aggregate consumption and a Keynesian loop as well as a Wicksellian treatment of anticipations. Later R&D and investment in human capital and innovation were added ([Ballot and Taymaz, 1997]). Bergmann has built a complete model of the US economy with appears as Stock Flow Consistent, and calibrated well enough to do as well as or even better then macroeconometric models of this time. The usefullness of these models starts to be recognized since the great Recession which DSGE models have not been able to predict nor analyse. [Stiglitz and Gallegati, 2011] build a bottom-up model with heterogeneous agents following simple, observation-based behavioral rules and local interactions. They find that macroeconomic results may possess new and different properties than the microeconomic level on which they are based. The decisions of the agent depend upon multiple factors such as his characteristics, the information he obtained, his local and global environment and his state.

An another example of ABM model is the Eurace model - an agent-based platform for European economic policy, first built by a consortium of economists in Europe ([Deissenberg et al., 20 and more later developed by [Dawid et al., 2011] in a version named Eurace@unibi. The baseline model includes households, acting as workers, consumers and financial investors ; firms, producing a homogeneous consumption good ; a capital goods producer ; commercial banks and two policy makers agents, namely a government and a central bank, in charge of fiscal and monetary policy, respectively. Agentsâ behavior has been modelled as myopic and characterized by limited information and adaptive expectations. The consumption market

is based on the marketing literature while the firm behavior is based on the management literature. The parameters have been set to reproduce important stylized facts in the European economy. The version by [Dawid et al., 2018] obtains results such as the positive effect of firmsâ intensity of reaction to competitors on initial growth and employment, and the positive effect of the improvement in the quality of the firmsâ capital vintage choice on the output and productivity.

[Caiani et al., 2016] build a macroeconomic model (without technical progress) where there are five agents (households, firms, banks, government and the Central bank) who interact with each other on five markets (consumption goods, capital goods, labor market, credit market and deposit market). Each agent has many behavioral equations which allow him to make a decision according to some micro or macro parameters or variables. For instance, consumers, according to their preference and budget constraint, choose the "best" consumption products among products sold by consumption firms. Consumption firms, according to their need, choose one among different capital firms who propose different capital goods. Each decision changes the state of agent. [Caiani et al., 2018] extend the model by introducing process innovation.

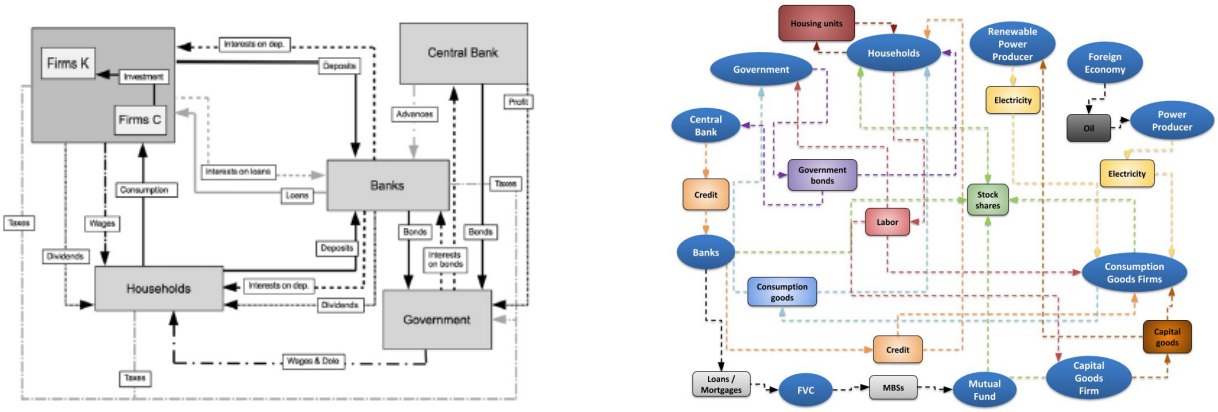


FIGURE 1.10 – Flow diagram of the models, [Caiani et al., 2016] and Eurace

1.2.4 Validation and Calibration

One of the main methods which has been used to validate the model is to reproduce some stylized facts. [Kinsella et al., 2011] build a macroeconomic model with heterogeneous interacting agents on product, labor and money markets. They show that without any restrictions on the type of interactions and with asymmetric information, they can get from multiplicative processes originating in the labor market power-law dynamics with respect to firm size and age, income distribution, skill set choice, returns to innovation and earnings. [Caiani et al., 2016] try to build a benchmark ABM-SFC model and show that their results match many empirical regularities. They distinguish macro-stylized facts

(time series for GDP, unemployment, investment, and consumption) and micro-stylized facts, represented by a distribution of characteristic (high degree of heterogeneity among firms with high persistency ; right skewed and fat-tailed distribution of firm sizes ; Gibrat's law...). Models are also submitted to Sensitivity analysis or robustness checks. In [Caiani et al., 2016] model, some parameters are identified as playing a crucial role in explaining the results. They did some sensitivity experiments on the parameters referring to these results. For instance, parameterization of investment and credit behaviors may affect the cyclical properties and the transition phase of the model. They check then the sensitivity of banks' aversions in assessing firms reliability, the weights given to the profit rate, capacity utilization and firms' precautionary deposits. In conclusion, they find that the cyclical properties hold under different parameterizations. Calibration of large models remains very rare. The WORKSIM model of the French labor market has been calibrated over 60 parameters and a close number of targets ([Goudet et al., 2017]). However the calibration is for a stationary state, and calibrating a dynamic model remains difficult. Progresses are however made. Smaller models can benefit from meta-modeling with the Kriging technique ([Salle and Yıldızoğlu, 2014]). Large models could be estimated using neural networks ([van der Hoog, 2018]).

2 Competences and persistence of alliances in quality innovation co-opetition

The chapter 1 is organized as follow :

1. Introduction
2. The Model
3. Results
4. Conclusion and Discussion

2.1 Introduction

2.1.1 Empirical alliances

Alliances in R&D between firms have emerged in the 1990's and become a very significant phenomenon in the organization of R&D (Hagedoorn, 2002 , Schilling, 2009).

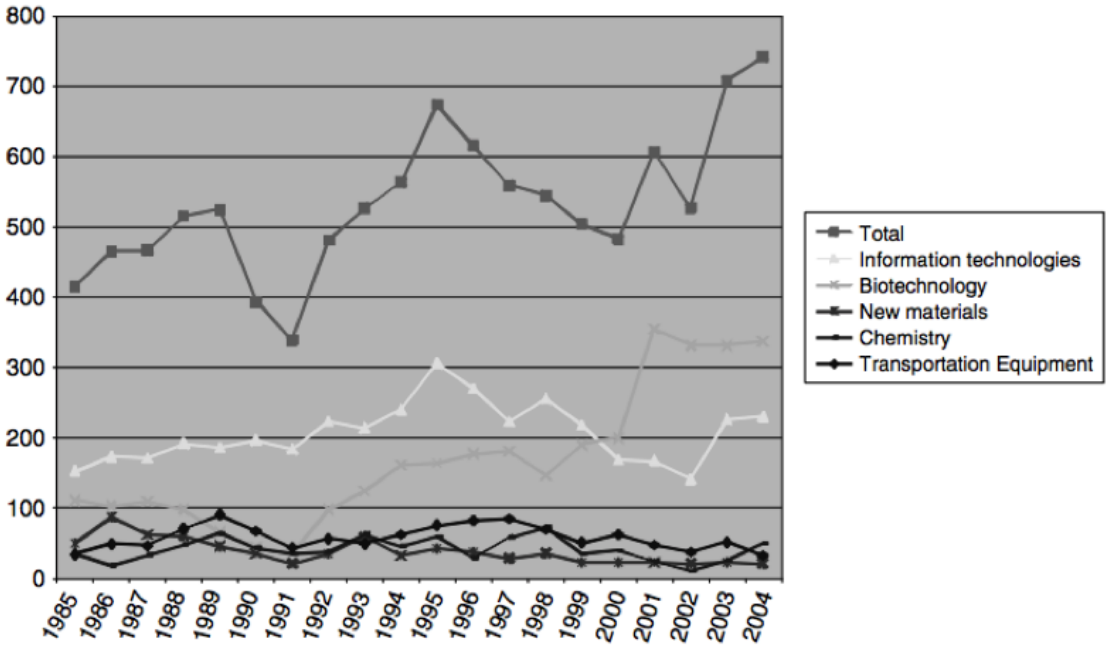


Figure 1. MERIT-CATI data, with sector decomposition, 1990–2004

Figure from Schilling, 2009

The number of inter-firm partnerships has increased strongly from zero in the 1960's to more than 500 newly established alliances per year in 1998 (Hagedoorn, 2002). Schilling, 2009 uses the same database[1] and shows that this number continues to grow to more than 700 per year in 2004. In his paper, Hagedoorn, 2002 defines R&D as "the standard research and development activity devoted to increasing scientific or technical knowledge and the application of that knowledge to the creation of new and improved products and processes". Using the same definition, our firms use R&D alliances in order to increase the quality of their existing product (quality/product innovation) and also their competence though competence transfer between partners (process innovation). The quality competition between firms on the same product market is called "vertical differentiation" in the literature. We use the term "competence" instead of "knowledge" because it has a broader meaning. Competence includes knowledge, skills and ability.[2]. Since we want to model behaviours, we will narrow the subject and consider only alliances between firms which

1. Both authors used the MERIT-CATI database which covers all inter-firm partnerships from over the world for the period 1960-1998. The data is now updated to 2004. They used newspapers and journal articles, books, and especially specialized journals which report on business event.

2. The distinction between competence and skill concepts is very unclear in the literature. Management studies use more the competence concept and economics papers more the skill concept, especially in labor economic field. For us, we consider only the competence of the firm. The term skill is more relevant to the individuals.

compete on the market for the same (differentiated) good, a situation named co-opetition. We will leave aside other types of alliances and market configurations such as the links between producers and suppliers.[3]

One major characteristic of the R&D alliances between firms is that they usually last for a finite and often short time. Our focus in this paper is on the dynamics of the alliances creations and destructions in order to understand better how alliances and the network of alliances can persist in the long run on a market while the partners change. In each period, firms who stayed autarkic from last period try to find only one partner to do research and firms in alliance decide to stop or renew their existing alliance. The accumulation of multiple dyadic partnerships over the time leads to the emergence of R&D network. A preliminary remark is that destructions of alliances are not mainly in the form of acquisitions ([Hagedoorn and Sadowski, 1999]), so that the former partners remain free to engage in new alliances. There is large evidence that alliances break, although little measurement exists on alliances durations. [Kogut, 1994] computes hazard rates and does not provide a mean duration, but his table 1 implies that 44% do not last more than 6 years, while 4% dissolve within the first year. [Deeds and Hill, 1999] find a range between less than a year and 12 years in the biotechnology industry. [Dussauge et al., 2000] find that alliances which end by dissolution last an average of 8 years in Europe, with a high variance. [Phelps, 2003] finds an average duration of 3 years. [Hagedoorn, 2002] notes that the destruction of alliances is mainly due to their project-based organization[4]. Before alliance, each firm defines its motives and prepare a contract. When they reached all pre-defined goals, they will examine if they renew or stop the alliance. In the first case, they continue their partnership but it will base on a new project and new motives. [Reuer and Ariño, 2007] distinguish time-bound alliances and open-ended collaborations and note that alliances last in average 4.9 years if they are time-bound.

The networks are then dynamic, with participants who change of partners, and also new participants. Data collected on a worldwide level have shown that in a number of sectors these networks persist in time ([Rosenkopf and Schilling, 2007] and [Tomasello et al., 2013]), while in some other sectors they tend to become smaller, without disappearing. [Tomasello et al., 201 shows that between 1986 and 2009, the size of the R&D network remains persistent, even if a little smaller, in pharmaceuticals, medical supplies, electronic components... But in some sectors (computer hardware, business service, motion picture production...), the networks are quite disappeared.

3. In fact, firms create alliances with different kinds of partners according to their motives. These partners go from vertical supplier-buyer relations, technology and know-how exchanges, to joint product development, cooperative research, and collaborative arrangements ([Grant and Baden-Fuller, 1995]).

4. Firms in partnerships can choose different governance structure like joint-venture, contract-based projects... [Hagedoorn, 2002] showed that contractual partnerships had become the dominant form of R&D alliances and it counts for 90% of the recently established partnerships thank to the more general demand for flexibility though short-term joint R&D projects with a variety of partners.

	1986-1989	1990-1993	1994-1997	1998-2001	2002-2005	2006-2009
Pooled Network	280	2515	4918	2626	2219	1829
Manufacturing Sectors						
Pharmaceuticals (283)	77	645	935	682	825	949
Computer Hardware (357)	51	385	744	202	92	29
Electronic Components (367)	54	328	581	253	222	165
Communications Equipment (366)	17	207	475	181	113	60
Medical Supplies (384)	10	164	280	122	119	123
Laboratory Apparatus (382)	10	139	243	116	94	87
Motor Vehicles (371)	6	108	190	97	85	78
Aircrafts and parts (372)	8	83	136	60	40	26
Inorganic Chemicals (281)	15	108	152	50	45	31
Household Audio-Video (365)	9	110	164	90	65	30
Plastics (282)	11	97	121	44	36	18
Electrical Machinery NEC (369)	2	54	96	26	24	37
Special Machinery (355)	2	33	82	34	17	11
Crude Oil and Gas (131)	3	42	72	62	35	27
Naut./Aeronaut. Navigation (381)	1	49	82	21	16	12
Organic Chemicals (286)	5	44	60	18	23	18
Service Sectors						
Computer Software (737)	69	560	1488	549	284	122
R&D, Lab and Testing (873)	26	477	848	534	596	500
Universities (822)	3	192	374	166	152	83
Telephone Communications (481)	12	184	350	132	82	22
Investment Companies (679)	14	138	298	232	207	125
Professional Equipment Wholesale (504)	4	64	142	26	8	8
Engineer.,Architec.,Survey (871)	2	74	129	62	26	16
Radio and TV Broadcasting (483)	2	26	88	22	7	4
Electric Services (491)	NaN	50	78	38	26	15
Electrical Goods Wholesale (506)	NaN	26	84	19	10	8
Cable and TV Services (484)	NaN	18	78	8	6	3
Motion Picture Production (781)	NaN	15	91	14	4	1
Business Services (738)	1	15	66	37	30	5
Management,Consulting,PR (874)	1	28	96	61	64	28

Table 1: Network size for the pooled and the sectoral R&D networks (SIC codes are in brackets). The values are averages within each sub-period. *Note*: missing values refer to sectors with not enough observations.

Table 1 from [Tomasello et al., 2013]

In this chapter, we try to discover what explains the dynamic evolution of the R&D network. For that, we want to build a coherent explanation of the observed microeconomic decisions of firms which form and later break alliances, while they will form others, and the aggregate fact that the process goes on indefinitely (at least in many sectors) so that at in the long run a network always exists. This is less trivial that it may seem since the co-opetion which results from the alliances affects the market structure. If a monopoly emerges for instance, it eliminates the possibility of alliances. Alliances impact the market structure which in turn changes the motive of firms for creation or destruction of alliances next period.[5] The market structure must be endogenous to the alliances dynamics in

5. [Tomasello et al., 2013] finds that the rise and fall of R&D networks were mainly driven by the entry and exit of firms rather than by more or less intense activity of the incumbents.

this long run perspective. Then a model of these dynamic processes must be embedded in a minimal macroeconomic model in which consumers' decisions over which producers they choose are endogenous. We will build such a model with R&D (joint or autarkic) determining innovation in the quality of a good and the market structure of such a vertically differentiated good. We then go further than much of the literature on R&D networks which focuses on the characteristics of a static network.

2.1.2 Theoretical explanations

Several theories aim to explain the creation and destruction of alliances and the persistence of R&D network. In the literature, firms have different motives when creating R&D partnerships. [Hagedoorn, 2002] defines three groups of motive for technical partnering : (1) motives related to basic and applied research or some characteristics of technology development, (2) motives related to concrete innovation processes, (3) motives related to market access and search for opportunities. In our paper, first pooling rare resources is an important motive, equivalent to the first group of motive of Hagedoorn. It can be seen as crucial when innovation is a tournament in which the winner (here the firms in the alliance) takes all the market because patents are important or the innovation radical. Even if R&D leads only to lower costs, it may be beneficial although dangerous since the rival partner also benefits from this reduction of costs ([Goyal and Joshi, 2003]). In these papers, firms create R&D partnership in order to share knowledge about a cost-reducing technology. The competition is rather price competition than vertical differentiation. For given level of R&D effort, adding a collaboration link leads to lower costs for all partners. Market configuration plays a great role in determining the stable network form though its impacts on incentives of the firms in forming alliances : if product markets are independent, the stable network is a complete network and if they are homogeneous - product market, collaboration leads to asymmetric stable network with the dominant group architecture since some firms take more advantage of the alliances than the other. We will show that otherwise the network fades away, since we do not take the pooling of resources as a strategic network reason for making an alliance[6].

A second theory emphasizes that the crucial motive is the need of firms to gain access to more types of knowledge than those they have (second group of motive), and the impossibility to buy such knowledge on the market, since it is often tacit or secret[7]. Partners in alliance combine different types of knowledge in order to innovate in a joint project.

6. This is certainly a strong assumption, but having two strategic motives would make the model unclear, and the calculus of the cost-benefit of pooling for firms is very complex because of the externality on the partner's costs and benefits which are co-determined with the market structure. Moreover the reduction of costs motive has been extensively studied by the game theoretical approach ([Goyal and Moraga-Gonzalez, 2001], [Goyal and Joshi, 2003], [Goyal et al., 2008]) to co-opetition unlike the strategic sharing of the competences.

7. A mean to acquire such a knowledge on the market is to acquire the firm with this knowledge. This is sometimes done but very costly.

A very important consequence of a R&D alliances based on such knowledge complementarity is that a firm may learn some of the types of knowledge its partner brings, and can use them for future projects and not only the present joint project. This phenomenon is also often called cognitive embeddedness in the network literature ([Uzzi, 1996]). The two first groups of motive can be better explained when situated in resources-based or knowledge-based view of the firm ([Penrose, 1959], [Wernerfelt, 1984], [Barney, 1991], [Nelson and Winter, 1982]). In fact, there are multiple views of the firm in the literature like transaction cost theory ([Coase, 1937], [Williamson, 1979]). It considers inter-firms partnerships as intermediate organizational forms between firm (organization cost) and market (transaction cost) where under certain circumstances a hybrid mode can be superior to either market transactions or internal governance. Efficiency is the guiding force. The choice of the governance structure results from the comparison of the relative cost of each form ([Williamson, 1979]). However [Grant and Baden-Fuller, 1995] note that a knowledge-view of the firm can provide insight into fundamental issues of organization and competitive advantage which underlie and explain transactions cost. We can get a new way of estimating the efficiency of the firm and it changes the results of the comparison. If the role of firms consists of creating, storing and applying knowledge, so their efficiency depends more on the efficiency of the processes of creating, storing and applying knowledge. [Grant and Baden-Fuller, 1995] identify two conditions for this efficiency : (1) the efficiency of integration mechanisms, (2) the extent of capacity utilization of knowledge. The first condition leads us to determine the process of transformation from different inputs into output. If we use individuals to produce output, then firms competences are more than the sum of individual competences. But each worker does not work alone, how can firms integrate these different specialized knowledges in order to produce efficiently output. The second condition helps to understand how firms can manage their knowledge because the efficiency depends upon matching the firm's product domain to its knowledge domain. In case of R&D partnerships, firms will then search for partners who can help increasing the efficiency of the process (for instance partners with complementary competences).

Broader than the knowledge-view of the firm is the resource-based view of the firm. Competence or knowledge can be considered as one of the key resources which can help sustain their competitive advantage. But acquiring knowledge or competence in market can reveal inefficient because knowledge has a tacit and explicit dimensions. When it is explicit, the cost of transfer is low. We find the problem of appropriation if knowledge is revealed to other firm. When it is tacit, it becomes difficult to transfer since it is not capable of articulation by definition. [Grant and Baden-Fuller, 1995] define five characteristics of the firm : (1) knowledge is the key productive resource ; (2) knowledge comprises information, technology, know-how and skills ; (3) knowledge is acquired by individuals and tacit knowledge is stored by individuals ; (4) because of the cognitive and time limitations of human beings, individuals must specialize in their acquisition of knowledge, it increases the depth of knowledge and sacrifices the breadth of knowledge ; (5) production requires the application of numerous different types of specialized knowledge. If we apply this in

our model, in order to ameliorate the quality of the product, firms need some specialized competences, called innovation competences. And they also need some production competences to produce the consumption products. But as innovation becomes more and more difficult and risky, and because of cognitive limitations, firms use more alliances in order to share the innovation cost, pool their competence in order to increase their efficiency and reduce the risks. [Grant and Baden-Fuller, 1995] identify two advantages of collaborative arrangements : access and integrate knowledge which can be more efficiently provided by other firms ; more fully utilize knowledge which is only partially deployed within the firm.

The third motive of alliance consists of market access and search for opportunities. The motives of R&D partnership can come from the inputs or outputs of the production function. In a quality co-opetition, firms need to continuously innovate in quality or they loose their market share. Alliances can help firm to get the results faster, bigger and less costly than in autarky. If firms failed in quality innovation, they lose market share since consumers always choose the product with the highest quality-price ratio. If R&D alliances can boost their quality innovation, firms do not want to stay out of this competition.

2.1.3 Theoretical puzzle and solutions

However this theory has a consistency problem at the aggregate level. The persistence of a network built upon the exchange of competences is a contradiction. Firms converge to the same competences by exchanging them. One alliance between two firms will lead only to a uniform vector of competences for the partners, but in the long run, the turnover of alliances will lead to a uniform vector of competences for all firms so that the no new alliances will form and the network disappears. The argument that some firms take more time than others to learn does not work, since those which are unable to learn fast enough will fail and the aggregate result will be the same with no alliances. [Gulati et al., 2012], [Tomasello et al., 2013], [Cowan et al., 2007] show that in some sectors, networks become smaller and even disappear. The origin comes from the increased information flows between clusters which reduce the unique value of each cluster. Recombination brings homogeneity into knowledge bases, consequently reduces the incentive for knowledge exchange and thus for alliance formation.

Two solutions have been proposed. The most popular is the concept of relational embeddedness ([Gulati, 1995], [Cowan et al., 2007]). Firms who have been some time in an alliance develop trust, and tend to resume collaboration, at the end of the project, or later. Moreover this trust may become a good reputation for a third party looking for an alliance - the so called structural embeddedness, which naturally leads to the emergence of networks. [Gulati, 1995] called that path dependence of alliance decisions. The underlying social network is affected by a firm's own past alliances and those of other firms in a network. [Cowan et al., 2007] propose a static equilibrium model of such a network. However trust or reputation does not justify the formation of alliances if all knowledge has been exchanged. Introducing trust in the formation of alliances is a completely autonomous ex-

planation of the persistence of alliances when firms have built reciprocal trust, hence have an expected constant higher joint productivity in research based on pooling for instance, than in autarky. Reputation is also an autonomous explanation of new alliances, based on the diffusion of information that a firm can be trusted on the base of former alliances, hence forming an alliance with a firm with good reputation yields higher expected productivity than choosing a partner randomly. It is not inconsistent to put the three motives in one model, but the exchange of competences (cognitive embeddedness) does not lead by itself a long run persistence of alliances. It is neither necessary nor sufficient. It then makes the exchange of competences not a crucial issue, since in its absence trust is a sufficient motive to explain persistence in a given alliance, while reputation favors new alliances. The problem of the fall of the value added in terms of knowledge acquisition is skipped. This is not to deny that trust is an important phenomenon in alliances but it should rather be a necessary condition for any exchange of knowledge, rather than a sufficient condition in the long run. There is some empirical evidence that prior ties first increase and then lower the probability of renewing an alliance, generating an inverted U relationship ([Gulati, 1995], [Chung et al., 2000]). Relational embeddedness based on trust could explain the increase, and the exhaustion of knowledge exchange the decrease, as [Baum et al., 2010] suggest. ([Gulati et al., 2012]) find in his more recent paper in 2012 that the R&D network can disappear in long term even if having relational and structural embeddedness. This results from three factors : (1) homogenisation in the information space and decreased propensity of firms to form new alliances, (2) homogenisation of the social system which makes the small world[8] less attractive to new actors, (3) fragmentation of the network or the system's inability to retain current clusters. [Zaheer and Soda, 2009] show that social network social network, especially relational embeddedness, has little effect in the partners' decision. The average number of prior alliances between partners was 0.52 (partner) and only 19.8% of the firms had a prior alliance with each other.

A second theory is based on the continuous appearance of new competences. [Caminati, 2016] proposes a model along this line. This increase in the number of competences demanded certainly takes place, but empirical work would be needed to examine if it is faster than the transfer of competences in alliances, and can prevent convergence and the fall of alliances in the long run to a narrow set of firms looking for new competences. If the renewal or growth of competences is assumed to be fast, it is an easy explanation of the persistence of R&D networks, but if it is not, the solution we offer avoids the difficult assessment of the speed of emergence of new competences.

We propose a solution to the apparent impossibility to obtain a persistent network based on exchange of competences (cognitive embeddedness) only, without the assumption of an increasing number of competences. Our solution builds upon the occurrence of specializa-

8. A small world network is a network having two characteristics : low average degree between each node ; high clustering coefficient. That means this network contains many clusters (collection of some nodes of the network) which are connected by some bridges. The tie between nodes of a cluster is called strong tie while these between nodes belonging to different clusters is called weak tie.

tion between the partners in the R&D project, at least in some alliances. By specialization we mean that some competences are used in the project, but not transmitted to the partner. This concept has been proposed in the management literature [Mowery et al., 1998] but not introduced in a model of an endogenous R&D network. However some other competences are shared since we consider that learning is the strategic motive for alliances. [Cowan et al., 2007] also use the same terms "cooperation versus specialization" but it does not have the same explanation. Their distinction is based on the nature of the task : when some tasks are decomposable, the other does not. Firms choose specialization when the innovation process is made up of discrete tasks that can be done in isolation. Only the most efficient partner in this task realizes and brings the result at the end to the complete innovation. And if the process is more systemic, each partner will be involved in all aspects. The second explanation of the stability of R&D network comes from the creation of new knowledge. Firms cooperate in R&D in order to create knowledge ; the product market does not exist in their model. When the project is successful, new knowledge is created and added to both partners' knowledge stock. "Firms move further from the origin but closer together in knowledge space". This property can help sustain the network in long term but makes the alliance less attractive. When firms become more and more similar when approaching in knowledge space, they have less interest in renew their alliance. But they move father from other firms and it brings certain heterogeneity in the knowledge space. The difference with our model is that we introduce a consumption product market and model a quality co-opetition[9] . Firms create alliances in order to produce a higher quality to their product. Cowan's model seems to us more related to basic research while our firms try to apply existing knowledge to create more competitive product. Since firms are competitive on the product market, they sometimes do not want to transfer some competences considered as key resources. The justification that we will adopt is that a firm fears that the partner will use the acquired competence and use it in other projects. We name these competences "strategic". Moreover they are likely to be the most complex and those that provide the highest efficiency. The core competences uncovered by [Hamel and Prahalad, 1990] are the candidates for the strategic competences we introduce in the model. [Hamel, 1991] emphasizes that firms develop a strategy of acquiring core competences of the partner, but mentions also the effort of each partner not to allow this internalization by a rival. [Hamel et al., 1989] note that the challenge of the partners in collaboration consists of sharing enough skills to get the results but in the same time they must carefully select what skills and technologies they pass to their partners. So firms usually cooperate in a single or some technology rather than an entire range of technologies. Firms in an alliance therefore use their strategic competences to develop some parts of the joint research project, but do not share these competences. Then they alone benefit from the learning by doing that the use of a competence provides. They become specialists, to a degree which depends on the importance of their learning. This has the major consequence that an alliance may lead to a divergence of the endowments in some competences between the two firms rather than

9. [Zaheer and Soda, 2009] find that the majority of alliances were horizontal (72%) rather than vertical.

a convergence. The complementarity between firms increases for these competences, and the overall complementarity between firms as measured by a synthetic index may increase, although not necessarily. The alliance can then be renewed for another project, and the cumulated duration of some alliances can be higher than in other alliances in which there is convergence, as shown by [Nakamura et al., 1996].

At the aggregate level the rise of competences owned only by some firms prevents the decay of alliances since firms need partnering to access strategic competences for the innovation projects *even if they will not acquire them*, and a long run steady state for the network, under some conditions that the model will uncover. A low mean duration will be the outcome of the non renewal of many alliances in which convergence or failure to innovate have taken place, and the heterogeneity of the effective duration of alliances will be a specific consequence of our theory. Another motive could explain specialization, which would imply a slightly different story, namely the technical impossibility to share a research task, and as a consequence the absence of transfer of a competence. The modelling is the same, but it would be less natural to consider that these competences are the most sophisticated, as [Hamel, 1991] and other authors observe.

An important point in the understanding of a R&D network is why some firms are in alliances while others are autarkic. The analysis of alliances we develop takes a heterodox position on the subject. Theories have evolved from a dichotomic choice between internal and external R&D ([d'Aspremont and Jacquemin, 1988]) to a new position, in order to explain a stylised fact, namely that firms often use internal and external R&D as complements ([Arora and Gambardella, 1994], [Cassiman and Veugelers, 2006]). Motives for autarky can be the cost and risks of alliances, which can override the advantages of pooling resources and sharing competences to innovate faster. Theoretical explanations of a hybrid research (part autarkic and part joint) by [Goyal et al., 2008] find a complementarity between internal and joint projects based on the decrease in marginal costs through market advantages. The calculus of the costs and benefits is much too complex for firms in an evolving environment in which the levels of competences change, and we will adopt a bounded rationality approach. We assume that alliances have a cost but that firms consider that the expected benefits are higher, yet conditional on the partner. We then use a search approach to alliances formation. Firms prefer an alliance to autarky, but not any alliance randomly selected. When autarkic, a firm searches for an alliance it expects to provide complementary competences, and it also wants a partner which has an R&D budget and a global competence endowment of a similar size in order to obtain reciprocal benefits to what it has to offer. Then a firm sets as a stopping rule a set of complementary minimum conditions that the partner must fulfill for these three variables. Since search takes time, it is possible that a firm will remain autarkic during several periods.When a firm has failed to find an adequate partner, it works in autarky on a research project until success or failure over the project time limit. The higher the firm on the competence and R&D budget scale, the more demanding on partners characteristics it will be, a realistic consequence of search theory.

The present has two purposes. First it describes a simplified macroeconomic and industrial organization framework in order to study the co-opetion of firms which collaborate in R&D to innovate in quality but compete on the market for the vertically differentiated good. Demand decisions by consumers are then essential. These consumers are heterogeneous in the taste for quality since they have different incomes. The market structure is endogenous. Second we propose a novel theoretical explanation of the persistence of R&D networks over the long run, with a steady state, while firms individually search for partners to form a R&D alliance, innovate in quality or fail, break or renew an alliance.

Our theoretical framework builds on *four* strands of research. The first deals with the role of competences and tasks for innovation, but also for production, although the tasks approach has been rarely tackled in the context of R&D (except [Cowan et al., 2007]). The tasks approach to production allows to analyse the effects of technical change or organization change in the firm in a much more effective way[10]. A competence allows a firm to do one or more tasks efficiently. Several tasks are needed to produce a good, which means they are complementary or imperfect substitutes. Education, training and learning by doing modify the competences offered, while the technical progress modifies the demand for the different tasks, hence the demand for capital and for competences. While the approach is becoming increasingly popular, the dominant track puts skills services (and/or capital) as the producers of tasks. Competences is a concept different from skills. We see skills (at least in models) as a concept associated with initial education or general training so that workers' kills can be ranked on a cardinal scale, as in (general) human capital theory. Competences can be seen as professional knowledge which is horizontally differentiated as is the case for innovation and production competences in our model. It follows that workers can have several competences, and their endowment may evolve differently with learning by doing and training. Finally, as was suggested above, the competences can be considered at the firm level rather than at the workers' level[11].The *second* strand of research is R&D networks analysis. Networks have been extensively studied by management scientists empirically ([Gulati, 1995]) , and within simulation or analytical models by [Cowan et al., 2007] [Cowan and Jonard, 2004], [Baum et al., 2010]). Yet the added feature of co-opetition i.e. interaction with the market for the good, has been studied only by the game theoretical approach in industrial economics [Goyal and Joshi, 2003], and the analysis is not dynamic. The *third* strand is quality innovation theory which explains how different qualities can coexist if tastes (based on income) differ ([Shaked and Sutton, 1983], [Bresnahan, 1987]). The *fourth* strand is the search approach, but we are not aware of its use in alliances formation.

Section 2 will present the model, section 3 the results, and section 4 will conclude.

10. See [Autor, 2013] for a summary of the skills-tasks approach.

11. In this paper we do not use the full potential of the competences- task approach since workers are not individualized. In a future model, SIMECO 2, workers are individual agents and have several competences, which enable workers to change the tasks they do or acquire new competences.

2.2 The model

2.2.1 Overall structure

The theoretical structure of the model SIMECO 1 builds on the four strands presented[12]. We set a dynamic economic environment in which firms find no barriers to entry and continuously try to innovate in order to avoid the risk that their variety looses consumers. Variety is only based on quality, perfectly observed and ranked in the same order by all households[13]. Therefore only lowering the price is assumed not to be a strategy, since all incumbent varieties see their cost decrease with experience. Clearly the product belongs to the widespread category of products for which innovation beyond the quality at invention is vital (smartphones, social networking applications...). All firms have two departments, R&D and production. The R&D department uses innovation competences to do tasks in order to innovate, and the production department uses production competences to do production tasks. R&D effort generates quality innovation which may brings a higher price and a better quality/price ratio to some (not all) of the consumers[14]. The firm then switches to the most recent quality variety. The task approach allows to represent the evolution that the production function undergoes. We make the novel and fundamental assumption that complex tasks in production become more needed and simple tasks less required as the quality of the good increases. The concrete justifications can be that, when introduced, a new quality requires more problem solving, and consumers will have less tolerance to defect in a higher quality good. A more sophisticated marketing will be needed to attract consumers etc. Learning by doing late will decrease the labor requirements for all competences. The change of labor demand towards more skilled labor is a stylized fact of technical progress known as Skill Biased Technical Change or SBTC (see [Vivarelli, 2014] for a survey of evidence)[15]. We introduce it here in the specific context of quality innovation in goods[16]. To our knowledge the model is new in this approach to the

12. SIMECO 1 is an Acronym for Simulation, Innovation, Macroeconomics, Employment, Competences, Organization. The number 1 has been given because a version 2 extended to innovation of new goods (or sectors) and a labor market to take into account the human resources constraint in terms of competences is under way.

13. We assume perfect information since consumers are not individually represented, and no indirect signal of quality is used, since this could modify considerably the market structure, as theoretical analysis of quality shows ([Schmalensee, 1979]).

14. In a rare study on the topic, ([Cantner et al., 2012]) offer evidence that firms with a higher quality/price ratio obtain larger market shares than the others.

15. We do not study automation in the present version of the model, since our focus is on alliances and quality innovation, and not on process innovation. No simple task is completely replaced by capital as in [Acemoglu and Restrepo, 2018]. We then assume for simplicity that the capital coefficient is constant. There is now a large evidence than as a consequence of automation the intermediate tasks are getting suppressed more than the others so that modeling this bi-polarization of jobs is more complicated than replacing simple jobs by machines.

16. Not many empirical studies focus on the specific topic of SBTC when quality increases. [Abowd et al., 1999] find a (weak) increasing relation between workers' quality and product quality.

organisation of R&D and production with different competences in the two departments, and the change in demand of the competences structure linked to quality innovation.

In order to innovate a firm may form an alliance with another partner to benefit from its contributions to the project in term of competences and research effort and also learn some of these competences (we assume dyads for simplicity). Alliance partners innovate simultaneously and improve their quality of the same amount, so that their qualities remain different and coexistence on the market remains possible[17]. Firms are then heterogenous through their success in innovation, their quality level and price position. Firms go bankrupt if they cannot sell for some periods, since their assets fall to zero. Failed firms are replaced one to one by small, different, entering firms, in order to get a stable number of firms and obtain easily network measures. The households are represented as potential consumers by an income distribution function with an endogenous mean, indexed on average productivity growth. Demand choices are based on utility comparisons for the different quality/price ratios offered by firms according to the quality ladders approach, and consumers choose the qualities according to income cut-off levels. The competition allows for the coexistence of a substantial number of firms, although the market concentration depends on factors such as the distribution of incomes and the differentiated and endogenous speed of competence building and innovation by firms[18]. The demand for the good becomes saturated in the long run as the incomes rise, since demand by a household is discrete and limited to 1. The model deals with diffusion, not unlimited growth. However consumption in nominal terms can grow if new qualities raise the prices more than the decrease by learning and the entry of firms with a low absolute cost, and competition can go on forever. Building a growth model in real terms would require the invention of new goods as pointed forcefully by [Pasinetti, 1981] and [Aoki and Yoshikawa, 2002], and is left for future work.

The model includes a two-way causality in quality innovation and diffusion. The new quality has a higher production cost at the beginning. It is a necessary assumption in quality ladder theory to avoid monopoly. However this differential in the production cost is justified on economic grounds by the substitution of more costly complex tasks to simple tasks[19]. This mechanism then represents a process change and not a process innovation. However the variable unit cost of production of a quality decreases in its quantity with learning by doing, generating a larger diffusion and dynamic increasing returns. The higher the past production, the more the production competences increase, and the lower the cost, a mechanism uncovered by [Arrow, 1962]. The high income consumers are the first to buy the good if the quality/price ratio is good enough. Later lower income consumers start

17. For instance in 2004, PSA and BMW announced the creation of an alliance on 1,6L engines to equip certain Peugeot et Citroen models as well as the next BMW Mini.

18. In static quality ladders theory, it can be formally proved that the market structure is a natural oligopoly under some conditions ([Shaked and Sutton, 1982]).

19. Empirical data are difficult to obtain. [Bils and Klenow, 2001] show that the rise in quality on a sample of durable goods representing 80% of the durable goods in US is responsible for a 3.7% annual rise in prices of these goods.

buying the good since the firm lowers the price under the joint effect of cost decrease and competition of better new qualities that attract high income consumers. New qualities continuously appear and low qualities may (but need not) disappear as incomes grow, as well as some qualities that are no longer competitive or dominated (as defined). The interaction between quality innovation, learning and price decrease is enhanced by the rise in incomes induced by the productivity increase. Then one of the novel achievements of the model is to formalise the dynamics of the qualities not only inside a market but also in a very simplified aggregate framework[20].

The sequence of decisions in the model within a period can be summarized by figure 2.2.1.

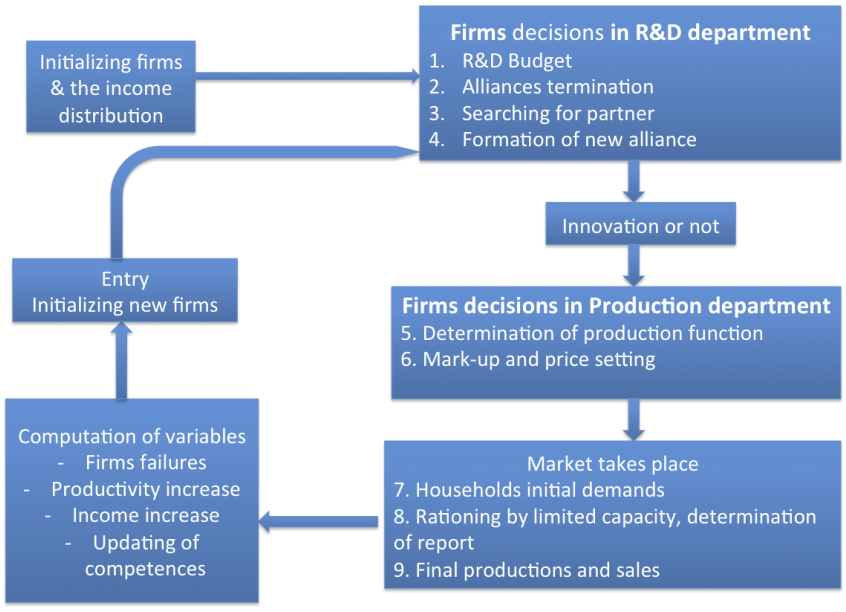


FIGURE 2.1 – Simulation Cycle

Firms take decisions within the R&D department on the budget and the alliances. Then they do the research effort and innovate or not. Firms change their production function if they have innovated in quality, and set the price by adding a mark-up to marginal cost. Then demands are expressed, and the firms produce within a capacity bounded by the physical capital. The demand for some qualities can be rationed, and unsatisfied demand is reported on the closest lower quality. Sales take place. Some firms may then fail and

20. Stokey, 1988 offers a model with new goods bringing better quality. The model is based on economy wide learning by doing. The framework is then completely different from ours. Klette and Griliches, 2000 have proposed a model of firm growth with a quality ladder interpretation. They assume a market with monopolistic competition and fixed demand curves, while we consider heterogeneous consumers and dynamic increasing returns as determinants of market structure.

are replaced by young firms on an equal number basis. Competences levels are updated for each firm as a result of learning by doing and transmission from the partner if any. Productivity increase is measured, and the mean income of the households distribution is indexed on it. Then a new period takes place, and as the model is parametrised with a period corresponding to a year, to fit the real innovation rate in France, we run it for 500 years. This lets the possibility for the diffusion of the good to attain saturation. The presentation will follow this order.

2.2.2 R&D department decisions and alliances

2.2.2.1 Innovation Competences

Each firm has a vector of dimension L_I of competences to innovate. We set $L_I = 50$ to allow for large differences of knowledge between firms[21]. We define the level of the endowment of the firm in this competence as X_{Il}. This stock provides services in terms of research. Each unit of the stock in competence l provides x_{Il} efficiency units when applied to one labor unit in this competence. Such a labor unit is an abstract concept since workers are not represented, and labor supply is non constraining. To be illustrative, it could correspond to the legal number of hours during one year for a full time worker. To avoid ambiguity, we name such labor unit a *task unit* in a given task class. Each unit of innovation task of type l offers a contribution V_{Il} to the research effort made by the l task class[22].

$$V_{Il} = x_{Il} X_{Il} \tag{2.1}$$

Competences are numbered in increasing order of efficiency x_{Il}.

$$\forall l \in [1, L_I], x_{Il}/x_{I,l-1} < x_{I,l+1}/x_{I,l}. \tag{2.2}$$

where the x_{Il} are increasing convex in l, and reflected in the task price scale. This is a useful assumption to make new varieties more costly at start[23]. The assumption is validated by empirical evidence that the wage scale is convex in the task hierarchy in a firm (Lemieux, 2006). It can be justified by theories of the hierarchy in the firm (Rosen, 1982),

21. The innovation competences are not only the scientific competences. They also cover a number of organisational competences, as appears in the 1996 French survey on competences for innovation (François, 1998). This survey lists and measures the degree of endowment of the firms for 9 broad competences such as *the integration of innovation in a global strategy* or *manage and defend intellectual property*, and 73 more narrowly defined competences.

22. For the objectives of the present paper, there is no need to consider that each task requires more than one competence, so that we assume that this is the case, and conversely each competence produces one task, but the stock of a competence and the quantity of the corresponding task evolve differently, so that the two concepts are distinct.

23. It is also a necessary assumption if a change in the total quantity of tasks to produce the new quality would decrease. However we make the reverse assumption below.

but it is more general since the very high competences are rare on the market, without a need to recur to convex marginal effects in the number of supervised employees. In the initialisations we assume that firms are heterogeneous in terms of X_{Il}, randomly chosen between [0,1], but this is not crucial, since heterogeneity becomes endogenous during the simulation, and only aims to speed up the formation of alliances.

2.2.2.2 R&D budget

We make the standard assumption that the R&D department has only labor costs. The desired budget is the sum of two terms. One part is determined as a ratio of last period sales, one by local competition in terms of quality ([Acs and Audretsch, 1991]). However if the sales are too low, firms have to invest a minimal amount since it is a question of survival in a model with quality competition and no spatial monopolistic advantage[24]. Local competition is defined by the distance between a firm and the closest firms in terms of quality/price ratio. These firms are the only ones which are rivals unless an innovator comes in after the budget decision. When the distance is below a limit, the competed firm increases its R&D according to the following procedure.

For that purpose, firms are ranked in ascending quality/price ratio. The number of local rivals N_{LC} is computed, with the following definition of a rival.

A firm m is a local rival of firm j if :

$$\text{for } (k/p)_m < (k/p)_j : (k/p)_m/(k/p)_j > z \text{ with } z \in [0,1]$$

$$\text{for } (k/p)_m > (k/p)_j : (k/p)_j/(k/p)_m > z \text{ with } z \in [0,1] \tag{2.3}$$

where z is an exogenous parameter defining local competition as perceived by the firms.

The R&D budget is then determined by the equation :

$$B_{If} = min(k^1 N_{LC} + k^2 \Omega_{f,t-1}, B_I^{min}) \tag{2.4}$$

in which k^1 is the coefficient of the effect of local competition, k^2 the share of sales $\Omega_{f,t-1}$ devoted to R&D in t-1, B_I^{min} the budget floor corresponding to a share of initial assets.

The quantities demanded are constrained by the R&D budget :

$$w_{I1}\tau_{I1} + w_{I2}\tau_{I2} + \ \ldots \ + w_{IL}\tau_{IL} \leq B_{If} \tag{2.5}$$

24. Most agent based models assume a specific form of imperfect competition based on imperfect information or spatial location to prevent both the possibility of an emerging monopoly, and large fluctuations in demand. In order to endogenise the market structure, we have chosen a less artificial *no friction* assumption which allows for any market structure but makes the model more difficult to parameterise and stabilise.

where w_{Il} is the cost of one unit of task l in the R&D department. The w_{Il} are increasing in l at the same rate as the x_{Il}.

The organization of the R&D department in a firm is assumed fixed, meaning that each task class has the same relative quantity of tasks (or number of jobs) over time, and, for a fixed task price structure, receives a constant share of the budget.

Let τ'_{Il} be the percentage of the R&D devoted to labor in task l. Each τ'_{Il} is randomly chosen when the firm is created so that $\tau'_{Il} > 0$ and $\sum_{l=1}^{L_I} \tau'_{Il} = 1$. The task quantity in each class is then :

$$\tau_{Il} = \tau'_{Il} B_{If} / w_{Il} \tag{2.6}$$

2.2.2.3 Innovation tasks and the research effort function

The contribution to the research effort of the sum of the task units in class l is then :

$$T_{Il} = V_{Il} \tau_{Il} \tag{2.7}$$

The total innovation effort T_I in the R&D department is given by a CES function over the contributions T_{Il} of all the task classes :

$$T_I = (\sum_{l=1}^{L_I} T_{Il}^{-\gamma})^{-1/\gamma} \tag{2.8}$$

where γ is the substitution parameter, $\gamma \in [-1; +\infty[$ and $\delta_I = 1/(1+\gamma)$ is the elasticity of substitution[25].

2.2.2.4 Probability to innovate and quality increase

An innovation project lasts at most 3 years. It may succeed before. In both cases, the firm plans to form an alliance and another project. The innovation probability increases in the research effort T_I and decreases in quality k already obtained by a firm, since the higher the quality is, the higher is the effort to improve it. The effort T_I is cumulated over a maximum of 3 periods.

$$Pr_I = Pr(T_I, k) \tag{2.9}$$

25. While the tasks quantities by class are derived from the budget through a Leontief, the CES in research effort allows for some substitution between the tasks. If there was no possibility of substitution in tasks, two firms which are complementary in 49 of the 50 competences, but have a zero level in the 50th, could not cooperate efficiently in an alliance, and autarkic firms, if they lack a single competence, would not be able to innovate. This seems unrealistic.

where Pr_I is a Bernouilli with parameter $Pr_I = 1 - e^{-aT_I/k}$ and $0 \leq Pr_I \leq 1$, $Pr_I = 0$ for T = 0 and $Pr_I = 1$ for $T = +\infty$. It implies decreasing returns of innovation in the research effort. This is a stylized fact for innovation ([Kortum, 1997]).

Let k_t be the present quality :

$$k_{t+1} = k_t + \Delta k \tag{2.10}$$

with Δk chosen from a Pareto distribution[26]. We have made three assumptions for the determination of the increases in quality, embodied in the equations 3.21 the and 3.22. First quality change is modeled as an improvement over the present quality, and not the attainment of a certain exogenous quality level (as could be obtained by buying a patent). This improvement view of technological progress is a widely accepted contribution of evolutionary economics since [Nelson and Winter, 1982], and based on path dependence. Second increases in quality are drawn in a distribution of absolute increases, meaning a decrease in relative terms. Third, the Pareto specification (with adequate parameters choice) means that the probability of high jumps is low compared to small jumps. The decline in relative improvements in quality is not an issue for a realistic modeling of a market it which demand can become saturated[27]. The decrease of the return of effort in terms of innovation rate and the decline in the relative improvements in quality are both incentives for firms to switch to the innovation of new products, a possible extension of SIMECO 1 to model permanent growth.

2.2.2.5 R&D Alliances

Firms consider forming an alliance, when they have finished a project (joint or autarkic). The matching rule is a set of three reciprocal requirements, one is on a minimal complementarity of competences between the firm and a potential partner, the second is a minimum similarity in the partners global competence level, the third a minimum similarity in the R&D budget level.

First the complementarity index in competence l, which measures the degree of differentiation in the endowments in l is $\underline{\zeta_l} \in [0, 1]$. Two firms f and j are complementary in competence l if :

$$\zeta_l = \frac{min(X_{Ilf}, X_{Ilj})}{max(X_{Ilf}, X_{Ilj})} \leq \underline{\zeta} \tag{2.12}$$

26.

$$f = \begin{cases} \frac{ax_m^a}{x^{a+1}} \text{ if } x \geq x_m \\ 0 \text{ if } x < x_m \end{cases} \tag{2.11}$$

where a is the shape coefficient (a = 2), and m the scale coefficient (m=2).

27. Moreover high jumps could favor the emergence of monopolies too easily compared to the real world since consumers decide only on quality and price. Monopolies can emerge in the model, but other reasons are more realistic.

Where ζ_l is less than a value $\underline{\zeta}$, firms are sufficiently complementary in competence l for a partnership. This test is repeated for each l. The firms count the number of complementary competences, α_a. If $\alpha_a > \underline{\alpha_a}$, the two firms are sufficiently complementary to form an alliance. In this model $\underline{\zeta} = 0.3$ and $\underline{\alpha_a} = 20$.

Second firms have a reciprocity requirement in alliances, as shown by [Von Hippel, 1998] and [Dyer, 2000] , and this is implemented here by a minimum similarity in the global level of competence.

Let GC_j and GC_f be the global competence levels of firms j and f.

$$GC_j = x_1 X_{I1j} + x_2 X_{I2j} + ... + x_{50} X_{I50j} \tag{2.13}$$

$$GC_f = x_1 X_{I1f} + x_2 X_{I2f} + ... + x_{50} X_{I50f} \tag{2.14}$$

Then the similarity coefficient Λ_I is sufficient if :

$$\frac{min(GC_j, GC_f)}{max(GC_j, GC_f)} \geq \underline{\Lambda}. \tag{2.15}$$

where $\underline{\Lambda}$ is the minimum similarity level and $\underline{\Lambda} \in [0; 1]$.

Third each firm devotes its entire R&D budget to the joint project so that a similarity constraint in the budgets levels is necessary for reciprocity.

$$\frac{B_{Ij} - B_{If}}{max(B_{Ij}, B_{If})} \leq y_I \tag{2.16}$$

where y_I is the minimum similarity level in the budgets and $y_I \in [0; 1]$.

Two firms are selected at random. If they satisfy the three requirements, they form an alliance. If they do not satisfy them, each firm has two other chances. This limit is justified by the time spent to examine a possible alliance, and the observation that many firms remain autarkic. Past alliances with a contacted firm do not have an influence, since we want to avoid introducing relational effects. Unmatched firms start an autarkic project for 3 years, and matched firms start a joint project for 3 years.

2.2.2.6 Allocation of tasks between firms

First let us precise that the alliance contract constrains the two partners to spend the same amount on R&D, hence the smallest of the autarkic budget of the two firms, since otherwise one firm may not afford it. Since the a similarity of budgets is a condition for the match, this lowers the largest autarkic budget only at the margin. The two partners are aware of who has the highest level in a strategic competence. The firm which masters the best this competence then uses this it in isolation to do the research task necessary for the project. This firm then does not disclose the knowledge to the other partner. The

lower level partner does not contribute to this research task. When the competence is not strategic, both firms cooperate to do the corresponding task. The partner with the lower level in the competence then learns from the higher level partner during the cooperation, and we therefore make two assumptions. First the level of competence applied to the task is the highest of the two levels. Second the lower level partner by the end of the period has learned a part of the difference between the two initial competence levels.

For the sake of simplicity, we have assumed that the strategic competences are those above the efficiency floor $\overline{x}$. All those such as $x_{Il} \leq \overline{x}$ are non strategic. Then there are L_c non strategic competences and $L - L_c$ strategic competences. The floor is exogenous and while the reference experiment considers an equal number of strategic and non strategic competences, the effects of having different proportions will be studied.

Let us consider first the production and learning when a competence is strategic and entails specialisation.

If f and j are partners, the contribution of a unit of task l is :

$$V_{Il} = x_{Il} Max(X_{Ilf}, X_{Ilj}) \tag{2.17}$$

Only the most competent firm contributes to task l in the innovation effort. In the unlikely case in which are equally competent, we have adopted the rule that the firm which is ready to devote more labor resources does the task :

$$T_{Il} = \begin{cases} V_{Il}\tau_{Ilf} \text{ if } V_{Ilf} > V_{Ilj} \\ V_{Il}\tau_{Ilj} \text{ if } V_{Ilj} > V_{Ilf} \\ V_{Il} max(\tau_{Ilj}, \tau_{Ilf}) \text{ if } V_{Ilj} = V_{Ilf} \end{cases} \tag{2.18}$$

Now we consider the case of the non strategic competences in which there is integration of the efforts. The efficiency of the competence involved is the efficiency of the most competent of the two partners in l, since the both partners work in common and the highest level of competence is used. The innovation effort function is different since both partners work. The number of task units is then the sum of the units contributed by each partners :

$$T_{Il} = \sum_{l=1}^{L_c} [Max(V_{Ilf}, V_{Ilj})](\tau_{Ilf} + \tau_{Ilj}) \tag{2.19}$$

2.2.2.7 Innovation effort in an alliance and quality determination

This is an extension of the autarkic effort function. The effort for a task is either the effort in a strategic task, either f or j or the integrated effort for a non strategic task. The alliance effort function comes as :

$$T_I = [\sum_{l=1}^{L_I} T_l^{-\gamma}]^{-1/\gamma} = [\sum_{l=1}^{L_c} [V_{Il}(\tau_{Ilf} + \tau_{Ilj})]^{-\gamma} + \sum_{l=L_{c+1/C_1}}^{L_I} [V_{Ilf}\tau_{Ilf}]^{-\gamma} + \sum_{l=L_{c+1/C_2}}^{L_I} [V_{Ilj}\tau_{Ilj}]^{-\gamma}]^{-1/\gamma} \tag{2.20}$$

where condition C_1 is : $X_{Ilf} > X_{Ilj}$ or if $X_{Ilf} = X_{Ilj}$, $\tau_{Ilf} > \tau_{Ilj}$, and condition C_2 is : $X_{Ilf} < X_{Ilj}$ or if $X_{Ilf} = X_{Ilj}$, $\tau_{Ilf} < \tau_{Ilj}$.

The innovation probability function over the efforts of all the competences (2.9) remains identical. When an innovation occurs, the cooperation in R&D induces a identical rise Δk of the two qualities, in accordance to our assumption of incremental increases, but the starting and final qualities are different .

$$k_{f,t+1} = k_{f,t} + \Delta k$$

$$k_{j,t+1} = k_{j,t} + \Delta k \tag{2.21}$$

The specialisation of partners in strategic tasks leads to possibly unequal ex post R&D expenditures between the partners, since one partner does not participate in these tasks, while they both have agreed on equal R&D budgets[28]. There is a financial compensation mechanism in the model.

For firm f :

$$B_{If} = \sum_{l=1}^{L_c} w_{Il}\tau_{Ilf} + \sum_{l=L_{c+1/C_1}}^{L_I} w_{Il}\tau_{Ilf} \tag{2.22}$$

with C_1 when $X_{Ilf} > X_{Ilj}$ or when $X_{Ilf} = X_{Ilj}$, $\tau_{Ilf} > \tau_{Ilj}$

Pour firm j :

$$B_{Ij} = \sum_{l=1}^{L_c} w_{Il}\tau_{Ilj} + \sum_{l=L_{c+1/C_2}}^{L_I} w_{Il}\tau_{Ilj} \tag{2.23}$$

with C_2 when $X_{ij} > X_{if}$ or when $X_{if} = X_{ij}$, $\tau_{ij} > \tau_{if}$

If $B_{If} > B_{Ij}$, then the firm which spends less than the other partner compensates it with a money transfer so that the real budget expenditures amount to :

$$B^R_{If} = B^R_{Ij} = (B_{If} + B_{Ij})/2 \tag{2.24}$$

When the partners succeed in innovation, they can decide to renew or not the alliance. Since we consider that the knowledge transfer motive is a necessary condition for an alliance, they examine again the three criteria we have listed. If they have not succeeded at the end of the project (3 periods), they break the alliance.

28. An empirical interpretation of the sudden cancelling of the R&D tasks could be that researchers are only hired on project contracts.

2.2.2.8 Evolution of competences

The evolution of competences is very different for strategic and non strategic competences. When a competence is strategic, at the end of the period, only the firm using its competence l has learnt and improved its competence stock $X_{Il,t}$. The other firm keeps the same competence level in l.

If $V_{Ilj,t} > V_{Ilf,t}$:

$$X_{Ilj,t+1} = X_{Il,t}(1 + \chi(\tau_{Ilj,t})) \tag{2.25}$$

$$X_{Ilf,t+1} = X_{Ilf,t}$$

with χ the rate of learning of the competence, $0 \leq \chi \leq 1$. The specialisation case clearly leads to a growing divergence between the two partners in competence l.

When a competence is non strategic, the increase in competences at the end of the period is different, since the partner with the highest level in competence l has transferred a fraction Υ of its difference in knowledge to the other partner in the course of the cooperation.

If $X_{Ilj,t} > X_{Ilf,t}$:

$$X_{Ilf,t+1} = (1 + \chi)X_{Ilf,t} + \Upsilon(X_{Ilj,t} - X_{Ilf,t})$$

$$X_{Ilj,t+1} = (1 + \chi)X_{Ilj,t} \tag{2.26}$$

where $0 < \Upsilon \leq 1$. The transfer is strictly positive since the two partners have worked together but we assume that it is only gradual since competences are partially tacit. This transfer is clearly a factor of convergence. However if the partners contribute very different task quantities, they will increase their competence level unequally, and this is a factor of divergence.

2.2.3 The production department

2.2.3.1 Production function for a quality

If firms follow the rules imposed by the competition authorities, they are autarkic in production. First production requires capital, and the capacity is fixed at the beginning of the period :

$$Y_t^K = \sigma_K K_t \tag{2.27}$$

with Y_t^K the capacity, σ_K the capital coefficient and K_t the real capital. Only capital may constrain production Y_t^S since labor supply is unlimited.

$$Y_t^S = \min[Y_t^K, Y_t^D] \tag{2.28}$$

where Y_t^D is the demand determined below.

The level of capital in t depends on investment $I_{K,t-1}$ and the rate of depreciation κ.

$$K_t = K_{t-1}(1-\kappa) + I_{K,t-1} \tag{2.29}$$

A firm decides to invest if the demand exceeded the production capacity last period. Investment is a fraction of the gap between demand and capacity.

$$\Delta K_t = \begin{cases} \Delta K_t = \zeta_A(1/\sigma_K)(Y^D_{t,1} - Y^D_{t-1}) \text{ if } Y^D_{t-1} > Y^K_{t-1} \\ \Delta K_t = 0 \text{ otherwise} \end{cases} \tag{2.30}$$

where $\zeta_A \in [0,1]$ is the adjustment coefficient. Capital has a unit cost p_K, set exogenously and fixed[29].

Second a firm also needs L_P types of labor to produce (L_P=50). The same competences tasks structure takes place but the competences and tasks are different. Dropping t, the contribution of a unit of production task l is :

$$V_{Pl} = x_{Pl} X_{Pl} \tag{2.31}$$

where X_{Pl} represents the production competence stock in l, x_{Pl} the efficiency of the service of a competence unit with :

$$\forall l \in [1, L_P], x_{Pl}/x_{P,l-1} < x_{P,l+1}/x_{P,l}. \tag{2.32}$$

We assume a Leontief production function at the firm level. This is a natural way to represent the technology, since we consider that the coefficients change differently and in a skill biased manner when a quality innovation appears. A function that allows substitution would make less clear the effects of technical change on the demand for the different competences[30]. Supply responds to demand expressed by consumers, under the capacity constraint. Then there are no inventories, a variable which would be difficult to deal in a market in which new qualities replace often old qualities offered by a given firm.

$$Y^S = min[A_{P1}V_{P1}\tau_{P1}, ..., A_{PL}V_{PL}\tau_{PL}] \tag{2.33}$$

where A_{Pl} is a production coefficient and τ_{Pl} the quantity of task l (which must be carefully distinguished from the number of efficiency units $\tau_{Pl}V_{Pl}$). Since labor is non constraining but costly, the tasks quantities in the production department are then derived from the level of Y^S as :

$$\tau_{Pl} = Y^S/V_{Pl}A_{Pl}, \forall l \tag{2.34}$$

29. The cost of capital then over time falls relatively to nominal tasks unit costs which are indexed on productivity growth in the model. This relative fall is a well established fact. The cost of investment is then $p_K \Delta K_t$. We assume a zero use cost.

30. In the present model, a CES would not bring relative wage effects since supply is assumed unlimited, and the structure of tasks unit prices is fixed.

Each competence stock X_{Pl} in a given firm is limited, and this affects the efficiency in a class of tasks, but does not constrain production. However the inefficiency yields high costs and a firm may fail in the quality/price competition.

As in the innovation department, at the end of the period, firms increase their production competences by learning according to the quantity of tasks which are done in the period.

$$X_{Plj,t+1} = (1 + \chi)X_{Plj,t} \tag{2.35}$$

where $0 \leq \chi \leq 1$, χ is the fixed rate of learning which makes competences rise linearly in the task quantity realized during the period.

2.2.3.2 Quality innovation and change in the production function

As stated, innovation biases labor demand for production towards highly skilled labor, and at the firm level that this model considers, higher competences categories. This should be true for quality innovation while process innovation can induce a decrease in the intermediate tasks as emphasised by the task literature ([Autor et al., 2003]). This literature points out that the routine tasks can be replaced by computers, and that intermediate tasks are often routine, while simple tasks can be non routine and very difficult to automate. Quality improvements, during the period they are introduced, should not increase the use of routine tasks, but rather the need of cognitive non routine tasks. Tasks are ranked in order of increasing x_{Pl}. A floor $\bar{l}$ is set under which tasks are labelled as simple, and over which they are labelled as complex. For the sake of simplicity, we have assumed that half of the tasks are simple, and half complex. As quality rises, the demand for simple tasks decreases, and the reverse for complex tasks.

For $l^P \leq \bar{l}$,

$$A_{Pl} = A_{01}.e^{u(k,l)} \tag{2.36}$$

with A_{01} the initial coefficient of production for a simple task l. First $u_l(k,l) < 0$, the simpler the task (lower l), the higher the coefficient, and the higher the demand. Second $u_k(k,l) > 0$. When the quality rises, the coefficient increases and demand for this task type decreases.

For $l^P > \bar{l}$

$$A_{Pl} = A_{02}/e^{v(k,l)} \tag{2.37}$$

with A_{02} the initial coefficient for complex tasks. First, $v_l(k,l) > 0$, hence the more complex the task type, the lower is the coefficient and the higher the demand. Second, $v_k(k,l) > 0$. When the quality rises, the more complex the task, the faster the coefficient decreases, and demand increases accordingly.[31].

31. Functions u(k,l) and v(k,l) are adjusted so that $u(k,l) < v(k,l)$. The decrease in simple tasks is weaker than the increase in complex tasks which have a higher unitary cost. Therefore the new quality is

2.2.3.3 Production costs and price setting

For a production level Y^S, and the corresponding task quantities τ_{Pl}, production labor costs come as :

$$C_P = w_{P1}\tau_{P1} + w_{P2}\tau_{P2} + ... + w_{Pl}\tau_{Pl} \tag{2.38}$$

with w_{Pl} the task unit costs in production. The structure of these costs is exogenously determined and, like the efficiency, is convex in task complexity :

$$\forall \mathrm{l}^P \in [1,\mathrm{L}_P],\ \mathrm{w}_{Pl}/w_{P,l-1} < w_{P,l+1}/w_{Pl}$$

Total cost is :

$$C_T = C_P + B_I^R + C_A + I \tag{2.39}$$

where C_A is an exogenous alliance cost.

The marginal cost (also the variable unit cost) of a firm f is labor costs and, from equations 2.31 and 2.33 comes as :

$$uc_{f,t} = \sum_{l=1}^{L} \frac{w_{Pl}}{x_{Pl}X_{Pl}A_{Pl}} \tag{2.40}$$

The higher the endowment of the firm in the competence X_{Pl}, the lower the marginal cost.

Each firm sets its price at the beginning of the year, taking into account its innovation (when it is the case) which modifies its cost, by adding a mark up μ_f on the marginal cost, in line with the bounded rationality approach, and much empirical work.

$$p_f = uc_f(1 + \mu_f) \tag{2.41}$$

The mark up is influenced by the intensity of local competition, i.e. the number of close neighbors on the quality/price scale, as defined in equation (2.3). This accounts for a simple yet coherent behavior since only the neighbors are competitors.

$$\mu_f = \mu(N_{LC}) \tag{2.42}$$

where $N_{LC} > 0$, and $\mu'_{N_{LC}} < 0$.

more costly to produce.

2.2.4 The market for the product

We will first study the level of demand and the initial allocation of this demand between qualities. Second, when all demands have been expressed, we introduce the possibility that some consumers are rationed since the capacity of the firms is limited, and they report their demand on a second best choice. This report is necessary to avoid possibly a huge rationing when a firm has made a large advance in innovation, while at the same time its competences levels are high enough to obtain a low cost, and many consumers. It appears also as empirically sound since the period is the year. Then production and sales take place.

Households consume at most one unit of the good, and the good lasts one period. The good can be seen as a durable good with a quick depreciation. The smartphone is an example. We set the simplest demand model in vertical differentiation in which households agree on the quality ranking but the taste for quality is increasing in income.
We use an utility function in quality and price to derive the demand for the different qualities and firms. The utility function of household i has the simple specification used for instance by ([Tirole, 1988]). If we consider a quality j provided by the corresponding firm :

$$v_i = \theta(R_i)k_j - p_j \tag{2.43}$$

with k_j the quality of j and p_j its price. $\theta'(R_i) > 0$, θ"$(\mathrm{R}_i) > 0$. $\theta(\mathrm{R}_i)$ represents the degree of preference of the household for the quality. It is assumed increasing convex in income R_i. If $v_i \leq 0$, he does not buy the good. Moreover if $R_i < p_j$ he does not buy the good[32]. This specification suffices to capture the following crucial feature : the higher the income, the more he is willing to spend on a higher quality, accepting worse quality price ratios than households with lower incomes, so that some coexistence between firms may occur.

It is possible to aggregate the consumers if we use a distribution function over their income, the only determinant of their choice. There are no identified workers in the model so that we need not individualise consumers. This economizes computer resources in massive way. There are M households who are distributed according to their income R_i. The distribution $F(R_i)$ is a Weibull with parameters estimated on the French distribution in 1994, which generates a value of 0.37 for the Gini)[33]. This allows to represent correctly the moments of the distribution which have an important impact on the allocation of demand among the qualities and the firms.

32. The empirical specifications of the $\theta(R_i)$ function have been chosen so that the budget constraint is always respected. We have also set an algorithm which checks that for each quality variety chosen by the consumer with the lowest income who wants to buy it, as explained below, the budget constraint is respected.

33. The parameters are taken from a comparative study made by [Bandourian et al., 2002] who found that the best fit for France in 1994 is a two parameters Weibull (1,498 ; 30489)

Not every firm obtains consumers, even if the net utility of its quality is positive. Competitors may offer a better choice. Two conditions are necessary to obtain a positive demand for a firm in a given period. First, a firm must be competitive. A contrario a non competitive firm is one in which the quality is weaker and yet the price higher than for any other firm to which it is compared. This is not sufficient however. The second condition is that the firm must not be dominated in the following sense. All possible couples of firms are compared. If a firm has a weaker quality and a weaker quality/price ratio than the other firm, it is dominated by the latter, since no consumer will prefer its quality[34].

Households as a group eliminate these firms from their possible list before making their choice between remaining firms. In the initialisations, we create 100 firms with random quality, which, given their competences levels, and production function for this quality, determines a price. Since many are eliminated, we renew the process until 100 firms are competitive and non dominated. Thereafter, each period, some firms will turn non competitive or dominated, but they will stay until they run their assets to zero, or, because they innovate and become again non dominated. Bankrupt firms, at the end of the period, are replaced by new small competitive and non dominated firms.

The second selection by households is the choice of a particular firm, or possibly none, on the basis of quality and price. The N remaining firms are ranked in increasing quality, and this ranking is also a decreasing quality/price ranking. This happens since the firms which would not fit in the same position in the two rankings have been eliminated above. The firm with the highest quality then has the worst quality/price ratio, otherwise it would have dominated some others.

Each period, after the innovations have taken place, we rank competitive non dominated firms, and label the firm with the lowest quality and the highest quality/price ratio j=1. This firm is such that $p_1/k_1 = Min(p_j/k_j), j = 1, 2...N$. It serves the limit household, i.e. the poorest household who buys a unit of the good. This household has an income $R_1 = \theta^{-1}(p_1/k_1)$. Households with an income below R_1 prefer not to buy the good since all the qualities offered bring a negative net utility to them. They are assumed to have alternatives to spend their income, and obtain some net utility, that a model of one market needs not consider. Next we determine the market market share of firm 1.

Let the firm with the second highest quality price ratio be firm $j = 2$ characterised by p_2/k_2 such that $(p_2 - p_1)/(k_2 - k_1) = Min[\Delta p/\Delta k], j = 2, ..., N$. The ratio $\Delta p/\Delta k$ is also the smallest increase in the price/ quality ratio or the smallest decrease in the quality/ price ratio when quality increases. Consumers whose income is R_2 such as $\theta(R_2) = (p_2 - p_1)/(k_2 - k_1)$ are indifferent between buying quality 1 and quality 2. Consumer i with $R_1 \leq R_i < R_2$ buys quality 1. This requires $k_1\theta(R_i) - p_1 < k_1\theta(R_i) - p_1$. It follows that $\theta(\mathrm{R}_i) < (p_2 - p_1)/(k_2 - k_1)$, which is true since $R_i < R_2$ and θ is increasing in R. The demand for firm 1 has an upper cut-off income :

34. Presenting this elimination as a first sequence of selection is important, since these firms will not benefit from the report of consumers below if these are rationed in their first choice : consumers will always choose competitive and non dominated firms as second choice.

$R_2 = \theta^{-1}((p_2 - p_1)/(k_2 - k_1))$

and its initial demand is given by its prices and qualities and those of the firm next up on the price /quality ratio :

$$Y_1^D = M[F(\theta^{-1}((p_2 - p_1)/(k_2 - k_1))) - F(\theta^{-1}(p_1/k_1))] \tag{2.44}$$

The reasoning can be generalised recursively to the firms which care for higher income households, since their higher taste for quality leads them to accept a lower quality price ratio. This implies that the Δp/Δk >0 increases on the quality and income scale ([Berry, 1994]).

Let $(\Delta p/\Delta k)_{j+1}$ be the smallest increase charged by a firm compared to firm j. j will serve consumers whose income is such as $R_j \leq (R_i) < R_{j+1}$ where :

$R_{j+1} = \theta^{-1}(\Delta p/\Delta k)_{j+1}) = \theta^{-1}((p_{j+1} - p_j)/(k_{j+1} - k_j))$

and the market share of firm j is :

$$Y_j^D = M[F(\theta(R_{j+1})) - F(\theta(R_j))] \tag{2.45}$$

with R_j defined accordingly. Firm N which serves the highest incomes households has the lowest quality price ratio among firms present on the market this period and its share comes as :

$$Y_N^D = M[1 - F(\theta(R_N))] \tag{2.46}$$

The initial demand for a quality may not be satisfied because the firm which produces it has a limited capacity. Since the period corresponds to a year, if consumers could not report their excess demand on another firm, besides an unrealistic situation in which many households would not be able to consume the good, the economy would be producing much below its aggregate capacity, bankruptcies could be very high, and innovation and diffusion low. We then assume that households can report their excess demand to the firm next on the left, i.e. with a higher quality/ price ratio, meaning also a lower price, so that they can afford to pay for this second rank choice.

Let us assume that firm j can produce only $Y_j^S < Y_j^D$, then the quantity produced and sold is $Y_j^Q = Y_j^S$

The transfer of demand to j -1 is :

$$V_j = Y_j^D - Y_j^S \tag{2.47}$$

and the total demand to firm j-1 after transfer is :

$$Y_{j-1}^{Dr} = M[F(\theta^{-1}(\Delta p/\Delta k)_j) - F(\theta^{-1}(\Delta p/\Delta k)_{j-1})] + V_j \tag{2.48}$$

If $Y_{j-1}^{Dr} \leq Y_{j-1}^S$, then $Y_{j-1}^Q = Y_{j-1}^{Dr}$

If $Y_{j-1}^{Dr} > Y_{j-1}^S$, then $Y_{j-1}^Q = Y_{j-1}^S$

In the latter case, some consumers move on to firm j - 2 and so on, as long as consumers are rationed. It can be the case that rationing stops, if firms lower on the quality scale have a sufficient capacity, but starts again lower on the quality and income scale. Transfers down the quality scale cannot go beyond the firm with $(p/k)_{inf}$.[35].

2.2.5 Dynamics of wage costs and incomes

In the model, learning increases productivity. However new qualities are more costly to produce when they are first implemented since they use more costly tasks. Moreover wages are likely to evolve and rise. This is an important feature to endogenise, since otherwise, there could be no or a very small market for the new qualities. In the model, the rise of wages, as a result of the productivity increase, is a major engine of the market competition based on innovation and of the diffusion of the product. We then model the link between marginal costs, productivity index, and incomes in a simple way.

We assume that workers benefit of the productivity increases in the economy through an indexation on average productivity. First we compute an aggregate productivity index, based on the marginal cost of production in equation (2.40). We make the choice to adjust for the quality bias which affects, through new varieties, the aggregate productivity, as advised by specialists([Triplett, 2004]). Otherwise the introduction of new qualities would bias downward the productivity index. We use the matching technique according to the following definition. The year a firm innovates, it is taken out of the sample for this period. This induces another bias since the weights of other firms are increased, but the bias should not be less important since there are 100 firms.

The weighed geometric mean of the variations in the marginal costs of the non innovating firms in t is the change in the productivity index between t-1 and t :

$$\omega_t = \prod_{f=1}^{N} (uc_{f,t}/uc_{f,t-1})^{Y^s_{jt}/(\sum_{j=1}^{N} Y^Q_{jt})} \tag{2.49}$$

for firms non innovating in t. This is a Paasche type index since weights correspond to t and are changed each period. Non competitive and dominated firms as defined above have a zero weight, and entering and exiting firms as well.

Next we assume that tasks unit costs w_{Pl}, which represent only labor costs, are completely indexed on the productivity index and downward rigid.

$$w_{Pl,t} = w_{Pl,t-1} Max[1, (1/\omega_t)] \ \forall l \tag{2.50}$$

All task costs increase at the same rate, and this corresponds to an economy wide negotiation of wages between employers and workers unions, in the absence of a limited

35. Firms with lower quality receive no initial demand and have been assumed to produce zero during the period. Some households with income higher than the limit consumer in the initial demand could get a positive net utility from a lower quality if rationed but it could be cumbersome to model this transfer.

and differentiated labor supply[36]. It can contribute to the failure of less competitive firms. Since we do not model wages and the structure of incomes of individual households, we make the increase rate in the mean nominal income equal to the increase rate in the tasks unit costs and consequently to the adjusted productivity index rise. This is done by multiplying the scale coefficient of the Weibull by the productivity index.

2.2.6 Entry and exit

Firms fail when their assets run down to zero. They are replaced by new firms one to one. This assumption, which is current in ACE modeling, also avoids to introduce determinants of entry, which would make the model more complex. However, we model the new firms as small firms, which may or not grow[37]. Each new firm is given a quality drawn among the 70% lowest qualities on the market with equal probability for each quality. Its characteristics (production coefficients, capital coefficient, stocks of competences) are interpolated between those of the two firms closest on the quality scale to the selected incumbent, in order to avoid head-on competition. It is a well acknowledged fact that new firms are not at the technological frontier on average, and this assumption avoids a takeover of the whole market by a new firm, after a few periods[38].

2.3 Results

First we present the results of the baseline simulation. Then we analyse the results of experiments to understand the roles of some parameters considered as the most important in SIMECO 1 and how they can impact alliances, market structure and the diffusion of the good.

2.3.1 Baseline Scenario Results

In the baseline simulations strategic and non strategic innovation competences are in equal number, namely 25. Low numbered competences are non strategic while high numbered competences are strategic. As a fundamental assumption of the model, the efficiency contribution to the research effort increases with the rank so that in the baseline

36. A full indexation corresponds to the post second war period. [Pasimeni et al., 2018] show that it might be more around 0.66 in the recent period. However the model runs 500 years, and the estimated coefficient could drive the labour share to almost zero, an unlikely forecast.

37. This has however the interest of eliminating the unbalance between entry and exit as a determinant of the market structure to concentrate on the alliances and competition on the incumbents. Entering firms may not manage to obtain a significant share of the market and may quickly fail. Even alliances may not prevent bankruptcies as stated in [Hagedoorn, 2002] and [Hamel et al., 1989]. A monopoly can emerge, but, and this is very important, entry always takes place and this monopoly can be challenged by a specially innovative firm which initiates again competition.

38. The range of qualities has been chosen so as to obtain a failure rate of the order of the real rate.

the strategic competences are the most important. In this base line We set the transfer rate of each non strategic competence between partners is 50% of the gap between the partners each year, so that the gap diminishes quickly.

The baseline simulation lasts 500 periods. Each period is considered as one year, this correspondence being driven by the calibration of the model on the French annual innovation rate in products, as detailed below. The results are averaged over 50 runs, except for network representation, and some other figures, for which it then be mentioned. We first present results on alliances and on the network, then the market structure and its dynamics.

2.3.1.1 Characteristics of the alliances

Alliances are dyadic, meaning that in each period, one firm can only have one partner. In order to get a R&D network, we cumulate all dyadic links of all firms over a large time window (100 periods). One node (one firm) can then have multiple links since it can have different successive partners. For instance when a firm breaks its alliance with one partner, next period it can create a new alliance with another one.

One of the main objectives of this model consists in showing that alliances continue to exist in the long run, giving life to a persistent network. This happens in spite of a transfer of competences which could make alliances useless by convergence, since complementarity is the condition for alliance formation. Yet alliances form and break, and have limited and heterogenous durations.

The figure 2.2 shows the distribution of terminated alliances by duration, averaging over 50 runs during the last window (t=400 to t=500)[39]. The duration of an alliance cumulates successive contiguous renewals between the two partners, when there are renewals. Several results emerge. First, in after 400 periods (and years), many alliances continue to be formed, as implied by the durations, so that the curse of convergence is contained. Second the mean duration is 16 years, much longer than the contractual duration of 3 years. Third, very few projects last less than 3 years, a possibility in case of an innovative success which gives the option not to renew. Fourth only a small number of alliances are not renewed on the third year. Fifth alliances durations do not decline in number between the 4th and 9th years, indicating that renewals are very frequent. Sixth, for longer durations, the frequency declines with the duration, yet the distribution has a long fat tail, with durations at 30 years still a fifth in frequency of the most frequent durations of 4 to 9 years. The mean duration is higher than in the (rare) empirical studies we have mentioned in the introduction. The information, not available for France to our knowledge, is so scarce elsewhere that it is not very important to calibrate on the durations. The motives of non renewals are displaid in table 2.3. The main motives are innovation failure and

39. We take into account only the duration of alliances which are already terminated before the final period. Since we do not know when the other alliances will terminate, we cannot assign them a precise length.

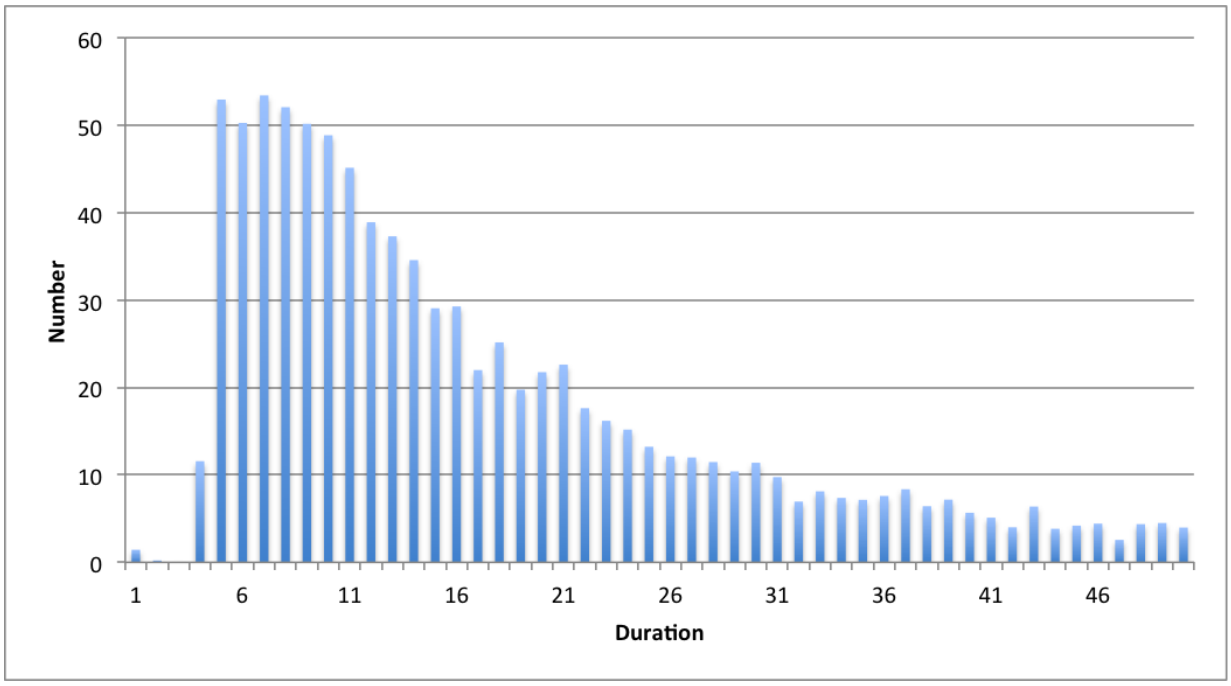


FIGURE 2.2 – Distribution of the alliances durations - baseline scenario

the global complementarity similarity. The former does not require comment. The second corresponds to the fact that one firm has gained much more than the other in global competence and, according to the criterium of a minimal similarity, renewing the alliance is not possible. This divergence should come from the specialization in some competences which can benefit one partner more than the other, and illustrates a common fact in real alliances, besides the mutual benefit of sharing that is at the heart of the competence based approach of alliances. Finally the non renewal for the complementarity motive, i.e. for too high convergence in the competences, is not important, a result which shows that specialisation keeps enough divergence between firms'competences, as was hoped. Our interest was to obtain the persistence of the formation of new alliances in the long run, periods, renewals and heterogenity, and will be in the comparison with the experiment in the model. However the heterogeneity of the durations found in the empirical studies is reproduced, and it is not simply the result of random interactions, as experiments below will show. Specialisation explains that we find high durations. Convergence in non strategic competences through transfer explains that alliances tend to be less and less renewed when time elapses. The skewed distribution is then in accord to our theoretical framework, while it less obvious that it fits the argument of the relational embededdness which predicts that alliances should have an increasing probability to be renewed. In the latter theory of competence networks, convergence and relational embeddedness have opposed effects that render the net effect on the distribution shape uncertain. Anyhow, in the long run, in the

latter theory, without new competences, the convergence should make alliances vanish.

These results can be sumarized as follows :

Result 1 : Alliances are heterogeneous in durations and the distribution of durations is skewed on the right..

Result 2 : Alliances formation persists in the long run.

Explaining the persistence of alliance formation, hence a network, on the unique motive of competences building and transfers then appears as feasible, and this is the main purpose of the paper. However, we need to do some experiments below to uncover the precise determinants of the results above. We now describe the network structure.

2.3.1.2 Network characteristics

The figures 2.3 and 2.4 represent the R&D alliances networks for different runs. A network represented here is obtained by accumulating the links of all the firms present in t=500 over the window t=300 to t= 500. The constant number of firms avoids the bias that a declining or increasing number of firms over the time window would have on the network measures. However we are able to compute measures only on those firms which are present at the end of the window, since firms enter and exit. This biases the measures but there is no easy way to solve the problems of measure in an evolving network[40]. Our interest is mainly in the search for small world characteristics, which uses a limited set of variables, among which the clustering degree. Kossinets, 2006 shows that this clustering degree is not sensitive to randomly missing data caused by the boundaries of a network. Our methodology is similar to reference studies such as Gulati et al., 2012.

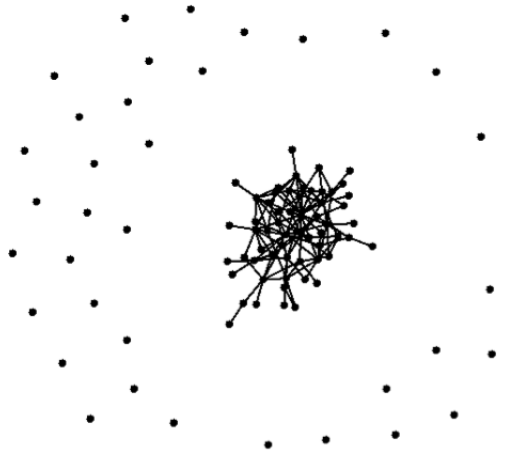


FIGURE 2.3 – First example of network

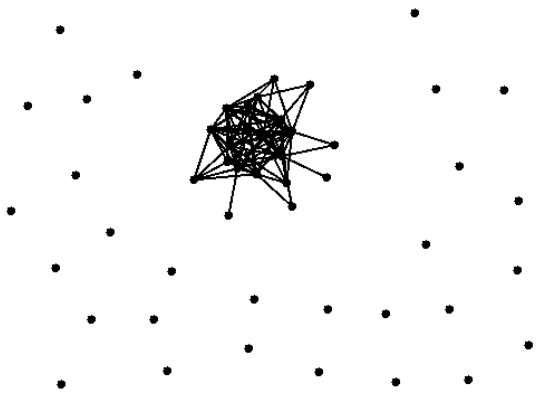


FIGURE 2.4 – Second example of network

40. Even if the window was one year, firms exiting during this period would not be present and their possible alliances would be missing, while the network would be reduced to a set of dyadic relations without any giant component.

Network Measures	$\rho = 0$	$\rho = 0.5$ (baseline)	$\rho = 1$
Giant Component Size	18.3	67	15.22
Average Degree	8.593	6.381	7.75
Clustering Coefficient	0.267	0.404	0.417
Average Path Length	1.807	1.622	1.59
Betweenness	10.236	16.381	7.39
Density	0.032	0.028	0.025

TABLE 2.1 – Network Characteristics Comparison

Table 2.1 shows the main characteristics of the R&D networks, more precisely those of the giant component since the distance between two nodes which are not linked is considered as infinite[41]. Some firms do not have any link for one of two reasons : (i) a firm stays autarkic because it cannot find any partner which satisfies its alliance criteria (the firm is too strong or too weak in global competence or R&D, or not enough complementary with the firms contacted) ; (ii) it can be a new entrant, if the dynamics of bankruptcies and entries is strong. This makes the network density low in table 2.1, a frequent feature of R&D networks (see for instance [Tomasello et al., 2013]).

In this table, the giant component size is 67 (baseline simulation column). There is no other component and 33 firms have stayed autarchic over the window. We then look if the network is a small world, since it is a stylized fact of the literature on R&D networks ([Allen, 1982], [Watts and Strogatz, 1998], [Cowan and Jonard, 2004], [Gulati et al., 2012]). A small world has two main properties : high clustering coefficient and short path length. We compare the clustering coefficient and average path length in the baseline scenario network to those of an equivalent random network. A small-world network is situated between a random and a regular network. If we call δ the degree of a network and n the number of the network/giant component, the clustering coefficient of an equivalent random network is δ/n and its path length is $ln(n)/ln(\delta)$.

In the table, the clustering coefficient is 0.404, and the average path length is 1.622 An equivalent random network has a clustering coefficient $\delta/n = 6.381/67 = 0.095$ and an average path length $ln(n)/ln(\delta) = \ln(67)/\ln(6.381) = 0.06381$. Since the baseline scenario network has a much higher clustering coefficient and lower path length, We obtain a third result :

Result 3 : The network is a small-world, since it has a high clustering coefficient and a low average path length. It emerges from the interaction between alliance formation and breach decisions on the one hand, and endogenous market structure on the other hand.

41. According to [Goyal et al., 2008], two nodes belong to the same component if and only if there exists a path between them. A network has a giant component if the largest component covers a relatively large fraction of the nodes while all other components are small.

This interaction constitutes the novelty of the result.

This small world feature of the network favors the diffusion of the competences in the center of the cluster (strong links), and increases the total competence of firms and attract similar partners (since this is another requirement for alliances). This can last since specialisation delays the convergence. At the same time the small world allows to obtain different competences from non central firms (weak links).

	a=5	a=10	a=20 (baseline)
$\gamma(C/C_R)$	0.019	0.042	0.063
$\beta(L/L_R)$	4.485	5.097	3.006
Q	0.004	0.0083	0.021

TABLE 2.2 – Small world sensitivity to minimum complementarity requirement

The sensitivity of the small world pattern can be tested by varying the criteria for alliance formation. For sake of space, we vary only the most relevant one, the complementarity criterium, and more precisely $\underline{\alpha_a}$, the minimum number of competences in which firms must be complementary to sign an alliance. Table 2.2 compares the ratios of clustering coefficients and the average path lengths (simulated over random) between the baseline simulation and two other simulations in which $\underline{\alpha_a}$ is lower (5 and 10) than the baseline (20)[42]. To do so, we must correct for the bias induced by the difference in the sizes of the giant component. We therefore multiply the ratio of the clustering coefficient by $\gamma = 1/\mathrm{n}$, and the ratio of the average paths β=ln(n). As expected, the ratio of the clustering coefficient increases in the complementarity requirements, and the ratio of the average path lengths tends to decrease in complementarity. A common summary measure in the network literature is the ratio of the adjusted clustering coefficient over the ratio of the adjusted average path coefficients, namely the small world coefficient Q (see [Gulati et al., 2012]). When Q increases, it indicates that the small world property is more present. This is the case in the model when the requirement for complementarity increases from 5 to 20, as less firms can pretend to fit to requirements and form a cluster for alliances.

2.3.1.3 Market structure and dynamics

The model has not been calibrated over real data except for the innovation rate and the income distribution, but we have tried to replicate some figures and stylised facts which are important in a model of innovation. As is usual with Agent-Based models, there is a period of unstable aggregate behavior caused by initialisations based on artificial data. It lasts until around period 250 in the model, a long delay which seems to be caused here not only

42. We do not test for higher $\underline{\alpha_a}$ since over 25 some non strategic competences have to be complementary. As they tend to be transferred and uniformized, this makes strong links in the cluster more difficult and the strong world property cannot be improved.

by the stabilisation of the model but also by an endogenous cycle in the first 250 periods. The main results are afterwards fairly stable, as the innovation rate and the Herfindahl are stable, and the quality steadily increasing, and the diffusion rate is increasing but concave. One has to keep in mind that we have not introduced characteristics which are often used to smooth production an such as inventories and to smooth sales such as frictions on the goods market. However the market we model is a market for one good, and we assume that households do not consume more than a unit per period. Therefore, growth in real terms has a potential limit which is the complete diffusion of the good.

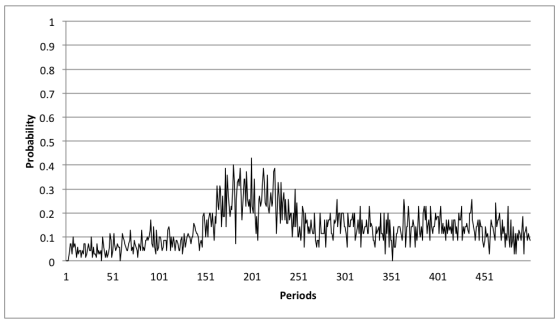


FIGURE 2.5 – Innovation Probability - Baseline scenario

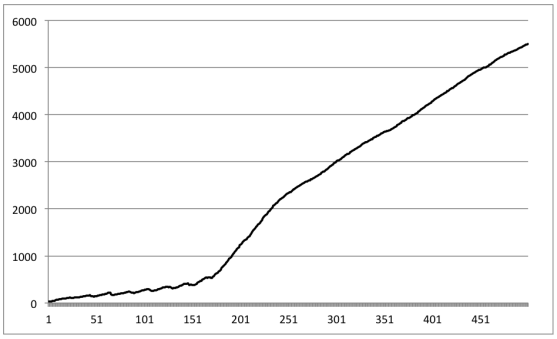


FIGURE 2.6 – Average Quality - Baseline scenario

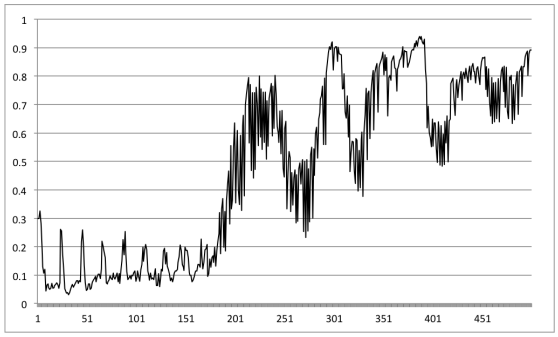


FIGURE 2.7 – Average Markup - Baseline scenario

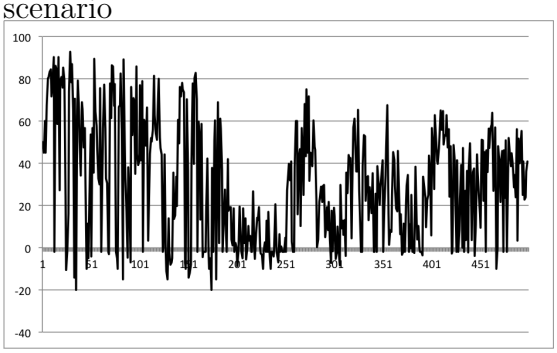


FIGURE 2.8 – Markup difference between innovating and non innovating firms - Baseline scenario

Free parameters have been set so as to obtain an average innovation probability per year close to 0.17, a figure taken from the CIS data for France over the period 2002-2004 for product innovation[43]. The stability of the innovation rate in figure 2.5 after t=250 is not

43. This firms innovation rate has been computed by Ballot et al., 2015 (table 1) on a sample of firms having an innovative activity according to the CIS definition (which is the case for all firms in the model, since they all do R&D). Innovation consists in introducing a *new product for the market* (we do not take *products only new to the firm* into account). The figure computed from CIS is for a three year period, and it has been annualized

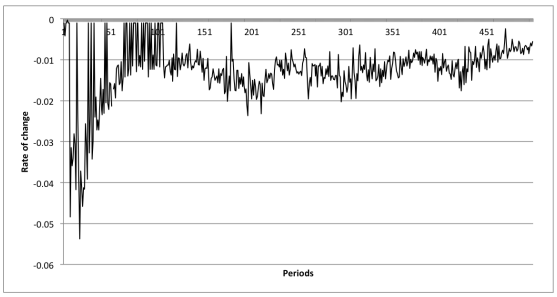


FIGURE 2.9 – Average rate of price variation adjusted for quality- Baseline scenario

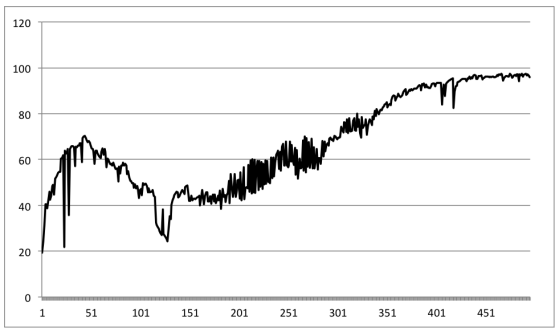


FIGURE 2.10 – Diffusion Rate - Baseline scenario

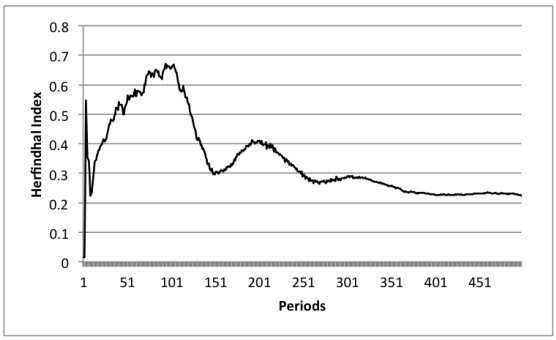


FIGURE 2.11 – Herfindahl Index - Baseline scenario

a trivial result. Two forces go in the opposite direction. When quality rises, the innovation rate decreases for a given effort in R&D. However firms devote a constant share of their sales to R&D (with some deviation because of a floor and an extra effort if competed strongly). They then increase their expenditures since sales increase.

Then the model results display the story of quality competition and diffusion that we presented in the theoretical framework. The continuous innovation activity triggers the competition between firms which introduce new qualities. Figure 2.6 displays the continuous increase of the average quality at a linear rate after t=250, then slowing in relative terms[44]. The competition stabilizes after t=250 with an Herfindahl of 0.2 (figure 2.11), indicating a broad distribution of market shares since firms can serve different income classes of households who value quality differently (figure 2.12). Figure 2.13[45] shows the shares of the firms as areas between the boundaries, the lowest area corresponding to the households who do not buy. Each run is specific in terms of shares. The run selected shows that the density of firms is lowest at the extremes of the distribution. Another mechanism

44. Not all new qualities are higher, however. New firms introduce fairly low qualities at entry, but they are competitive in terms of quality/price ratio.

45. Boundaries can be confused in the areas in which the firms are dense.

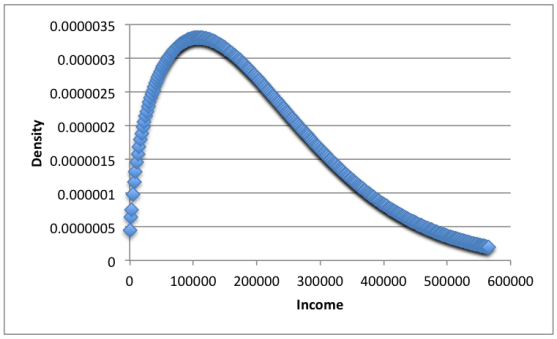


FIGURE 2.12 – Weibull adjusted Income Distribution in t=30 - Baseline scenario

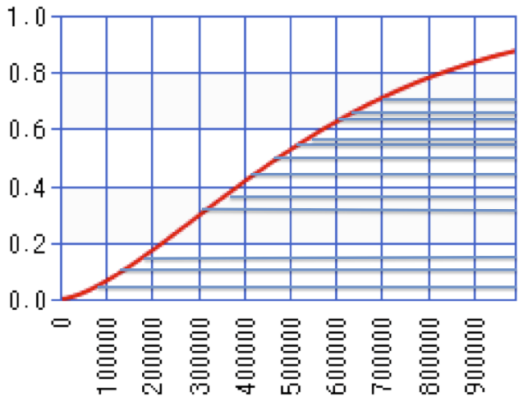


FIGURE 2.13 – Firms Boundaries en t=300 - income levels on horizontal line - cut off incomes on vertical line. One run

makes the diffusion of the good possible. Learning by doing increases the competences of the firms and decreases the cost of a quality. The productivity in the production of a quality increases, learning being stronger than the increase in the tasks unit prices, and the price declines (figure 2.9). As the incomes are indexed on mean quality adjusted productivity rise, households who were not able to consume the good can start buying it as the diffusion rate shows (Figure 4.24). We obtain a feedback loop decrease in cost-increase in consumption based on dynamic increasing returns which characterizes mass consumption ([Matsuyama, 2002]). We are even able to reproduce the standard S shape of diffusion after t=200. Households with incomes above the average can buy new and more costly qualities. A novel feature of the model influences the results. The dynamic increasing returns of each firm are constrained to some degree by the competition of other firms in the baseline scenario. The distribution of tastes for quality (based on incomes heterogeneity) sustains this competition. Yet the whole structure of tastes evolves with the increase of incomes. This favors determines the demand for new more costly qualities.

Result 4 : In the baseline scenario, characterised by a persistent heterogeneity of firms competences and the formation of numerous alliances which determine a high and broadly distributed innovation rate, the interaction of dynamic increasing returns in production and mean income growth in a context of incomes heterogeneity yield a competitive market structure and the diffusion of the good.

The model then appears as the first to take into account the necessary roles of income rise and demand as well as supply in the diffusion of new qualities, in a dynamic setting.

Some supplementary results should be noted. Firms had a low mark up at he beginning of the simulation that constrained their innovation capacity, but this mark up (figure 2.7) rises to a comfortable mean level of 60 to 80% in the second half of the simulation. This high mark up also explains why innovation can be sustained until the end of the simulation,

when diffusion becomes slow because saturation is close. Firms are very heterogeneous in terms of mark up. Innovating firms have a much higher mark up than non innovating firms. Figure 2.8 shows an average difference of 30%. This comes in the model from the fact that by innovating they reduce the number of their close competitors, and can increase their mark up according to the mechanism introduced in 2.42. This rule design, based on bounded rationality, proves profitable and justifies our choice. The distribution of market shares is highly skewed. The largest firm covers 47% of the market, the 3 largest firms cover 72% of the market and the 10 largest firms 94% of the market. The market looks as very concentrated. This should not be a surprise since quality is the only characteristic of the good and all consumers agree on the ranking, and differ only in income. Many real markets appear to have leaders with very high market shares, and the model is able to capture in a endogenous and natural way (without introducing frictions) this strong asymmetry which persists over time. Moreover the firms with the highest market share are able to obtain a much higher mark up than most other firms. The largest firm has a mark up of 75%, the 3 largest reach 66%, and the 10 largest 57%. Our result on the extremely asymmetric distribution of marks up is very consistent with the findings on US and the positive correlation with market shares as by [De Loecker and Eeckhout, 2017]. They find an average mark up of 60% , and even higher marks up of 130% for the 90th highest percentiles, computed like ours on marginal costs. This appears as a major and new stylised fact in recent years, with acknowledged important macroeconomic implications for the labor share that will not be exploited here in a model without workers as agents.

To summarize :

Result 5 : In this quality co-opetion model with dynamic increasing returns, the distribution of firms shares and marks up are highly skewed. The marks up are positively correlated with the market shares of firms.

2.3.2 Experiments

In order to assess the effects of the interactions between the alliances and the main variables of the model such as innovation, diffusion, and competition intensity, we need to vary some important parameters. Because of space constraints, we will present here two types of experiments. The first changes the proportion of strategic competences, the second changes the rate of transfer of competences between partners for the non strategic competences in the baseline scenario.

2.3.2.1 Effects of the proportion of strategic competences

While the baseline simulation has an equal number of strategic and non strategic innovation competences, we study now the two extreme cases, one in which all competences are non strategic and one in which they are all strategic.

(1) All competences are non strategic ($\rho = 0$).

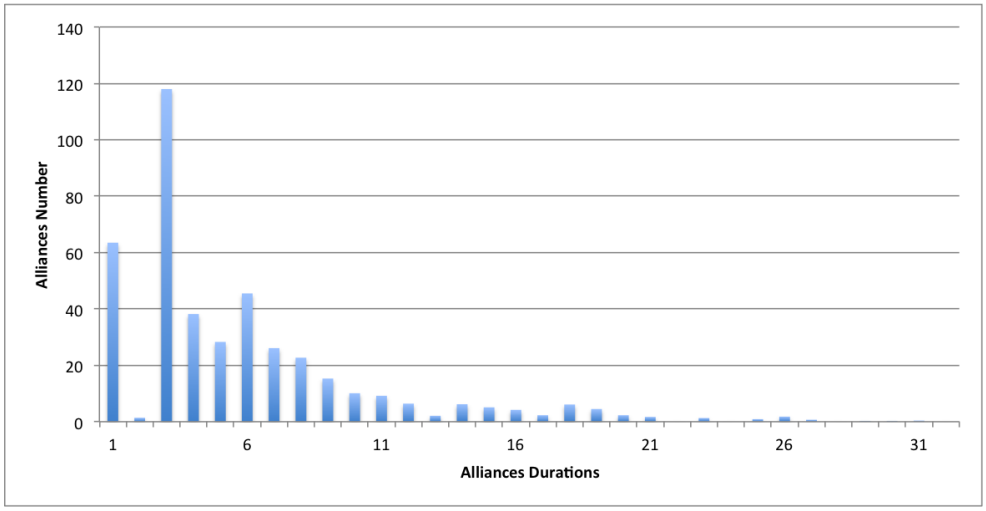


FIGURE 2.14 – Distribution of alliances durations - all competences non strategic

When all competences are non strategic, each partner, for each competence, transfers the extra quantity of competence he has to the partner, at a rate of 50% per year. Convergence is fast, and alliances are less persistent in comparison to the baseline scenario (figure 2.14). The mean is only 5 years and many alliances end after 1 year (61 alliances) and 3 years (almost 120 alliances). When we exploit ther information on alliances terminations in table 2.3, we find that the main motive is firms bankruptcy. this corresponds to the high rate of entry and exit that we will study below. The complementarity motive is also significant, as could be expected since all competences are transferred. Firms, when they innovate, do not renew their alliance 5 times more often than in the base scenario, since they are no longer complementary but similar. The giant component of the network is only 15 instead of 67, and does not deserve further analysis (see table 2.1).

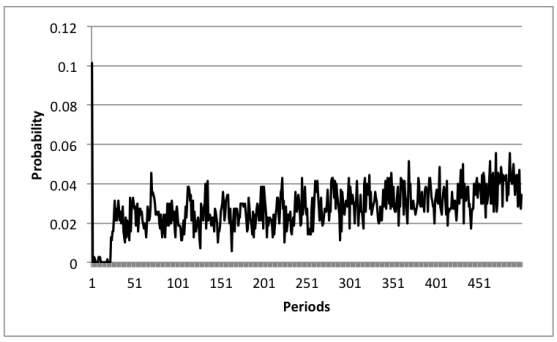


FIGURE 2.15 – Innovation Probability-all competences non strategic

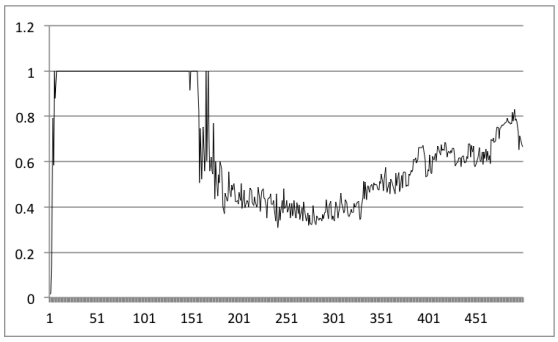


FIGURE 2.16 – Herfindahl Index-all competences non strategic

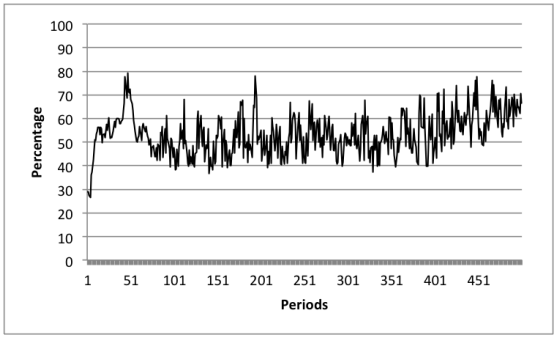


FIGURE 2.17 – Diffusion Rate-all competences non strategic

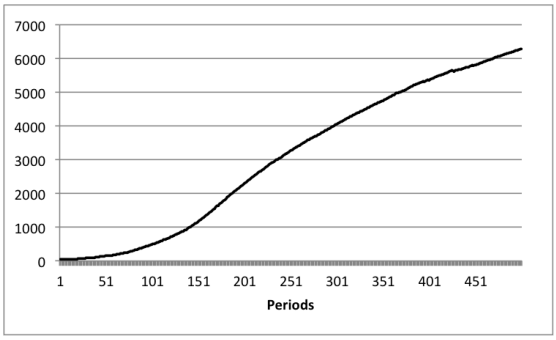


FIGURE 2.18 – Average Quality-all competences non strategic

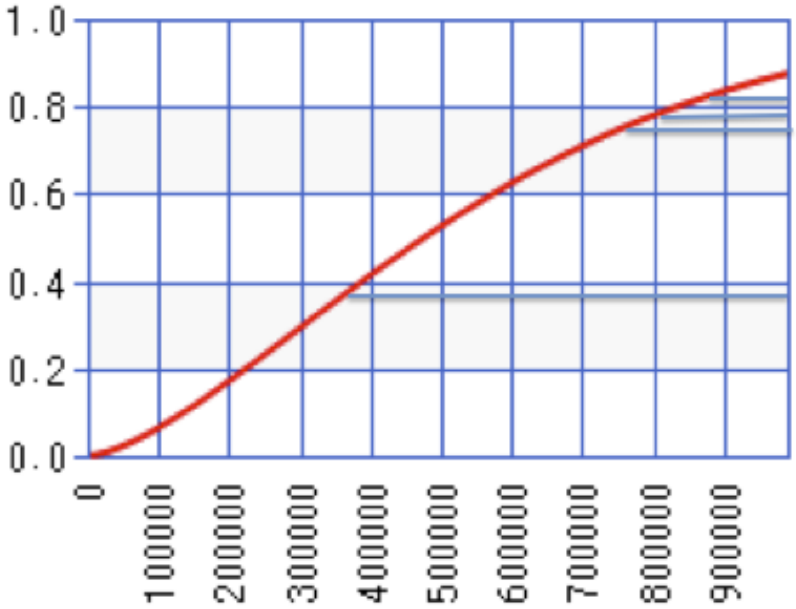


FIGURE 2.19 – Firms Boundaries en t=300 - cut off incomes in euros on vertical line - All competences non strategic. One run

The dynamics of the market are then completely different from the those of the baseline scenario. The market structure changes considerably. First a monopoly takes over the market in the first half of the simulation (Figure 2.16)[46]. The emergence of a monopoly is made easier by the fast convergence of firms. Then a small advantage leads one firm to the domination of a large part of the market through a virtuous feedback between sales and R&D. The other firms are small and the mean innovation rate is around 3% against 17% in the baseline scenario (Figure 2.15). This monopoly is successfully challenged by new firms, but remains dominant. With an average Herfindahl ranging between 0.4 and 0.8, there is much more concentration than in the baseline scenario. When looking at the micro data simulated, it appears that the dominant firm innovates a period out of two. Less alliances make firms autarkic and small firms enter and exit with a low quality since they do not have the means and the time to innovate. Then the dominant firm (and some firms caring for high income niches), raises its quality considerably but the other firms not, so that looking at the high average quality in figure 2.18 masks the high heterogeneity of quality. There is little competition, and lower income households do not find firms which offer a quality/price ratio high enough to provide them net utility, and do not buy (figure 2.19). This is likely to explain that the diffusion rate rapidly reaches a ceiling at 60% instead of 100% in the baseline scenario (Figure 2.17). To summarize, the convergence of competences determines a market structure with few alliances and a dominant firm, yielding little innovation and choice and consequently a partial rate of diffusion to households with heterogeneous incomes and tastes.

(2) All competences are strategic ($\rho = 1$).

When all innovation competences are strategic, alliances have a mean duration of only 3 years (figure 2.20). Half of the alliances last only one year, almost no alliance lasts more than 9 years. Besides the standard innovation failure motive, the termination motives table 2.3 indicates a high rate of terminations by the absence of similarity. This corresponds to the unequal benefit that the two partners have obtained from the alliance since no sharing is done. Bankruptcy of one partner is also high and could be seen as an extreme case of asymmetry in the alliance benefits. The network has a small giant component of 18 and low clustering (2.1). Clearly alliances are not favored by firms when competences are all strategic.

The dynamics is again different from the baseline simulation. A few firms with a high endowment in some complex competences specialise and raise their competences further. They take over most of the market as shows a Herfindahl of 0.7 (figure 2.22). The innovation rate is as high as in the baseline but fluctuates considerably, which corresponds to innovation obtained essentially by the leading firm (figure 2.21). The average quality increases extremely slowly when compared to the two previous experiments, reaching one tenth of the formers (figure 2.24). Figure 2.25 shows, at least in the run displayed, that the dominant firm serves the upper and middle market, and since it is not challenged by firms

46. This evolution of the Herfindahl is an average over the 50 runs. It means that a monopoly emerges in each the 50 runs.

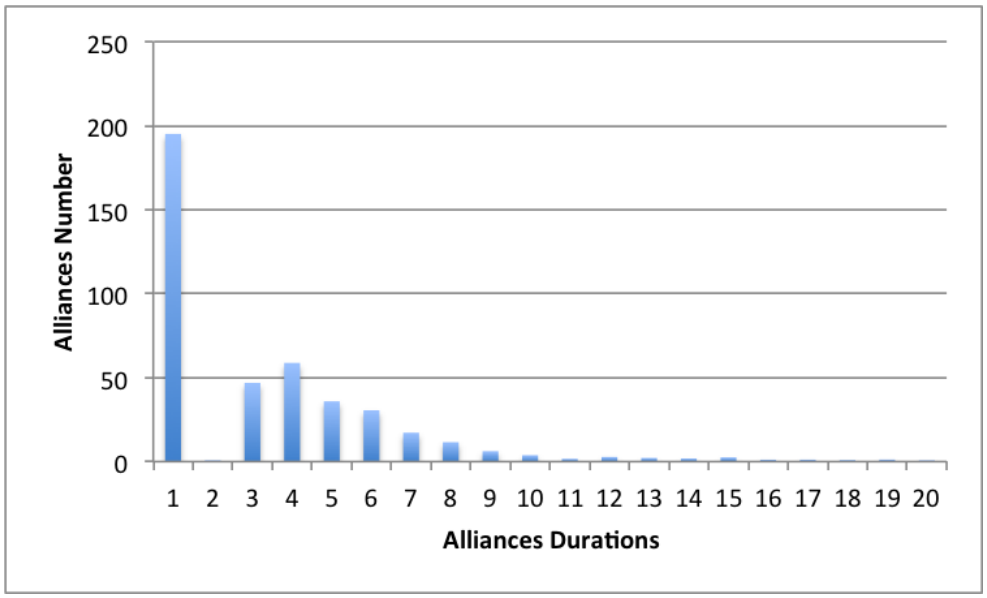


FIGURE 2.20 – Distribution of alliances durations - all competences strategic

higher up, and the price must be affordable for the middle class, its quality needs not be very high[47]. The intensive entry (and exit) of firms with an average low level of quality is reflected in the fluctuations in quality, and also contributes to a low average quality. The diffusion does not go beyond 70% since the quality/price ratio is too low for the low income households (figure 2.23). To summarize, when all competences are strategic, the best endowed firms only use alliances to increase their R&D capacity, and take over most of the market. Then the economy is trapped in a monopolistic situation with little increase in quality and choice.

The two extreme cases present strong analogies and lead to conclusions on the need of both integration and specialisation as in the baseline scenario to obtain the result 4 presented above.

Result 6 : The presence of both integration and specialisation is necessary for alliances to have a substantial existence, and leads to a strong competition and a high innovation rate sustained by many firms (and not only a dominant firm) with diffusion of the product to all income classes.

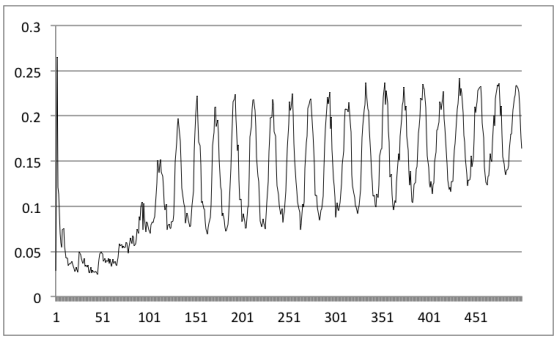


FIGURE 2.21 – Innovation Rate - all competences strategic

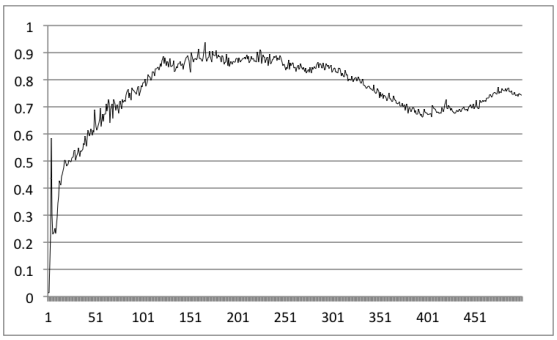


FIGURE 2.22 – Herfindahl Index - all competences strategic

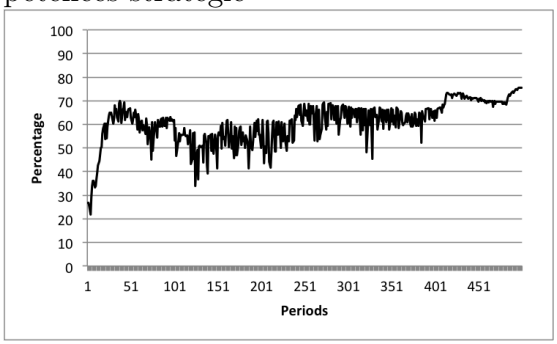


FIGURE 2.23 – Diffusion Rate - all competences strategic

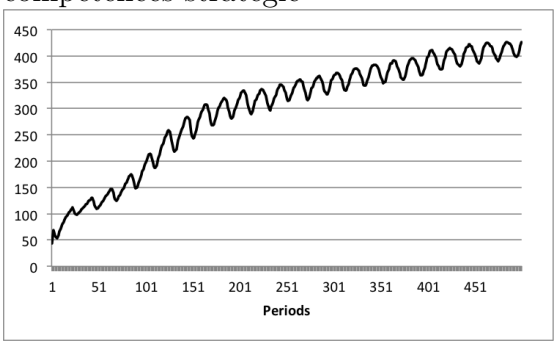


FIGURE 2.24 – Average Quality - all competences strategic

2.3.2.2 Competences Transfer Rate

We then test the sensitivity of our results to the competence transfer rate per period Υ for the non strategic competences. We keep the mix of strategic and non strategic competences of the baseline scenario. With the baseline scenario at $\Upsilon = 0.5$, we only compare this rate of transfer with a complete transfer $\Upsilon = 1$ since a low transfer rate would

47. This market characteristics do not result from sophisticated strategies which are not in the model, but from competition. If the dominant firm was not serving the upper class in some other runs, the reasoning would not be fundamentally altered, since the innovating firms are few, and competition weak.

Alliance Termination Motive	$\rho = 0$	$\rho = 0.5$	$\rho = 1$
Bankruptcy Motive	1.205	0.238	1.28
Complementarity Motive	0.736	0.297	0.997
Innovation Failure Motive	0.395	2.728	1.592
Global Competence Similarity	0.496	1.916	1.1533

TABLE 2.3 – Alliance Termination Motives

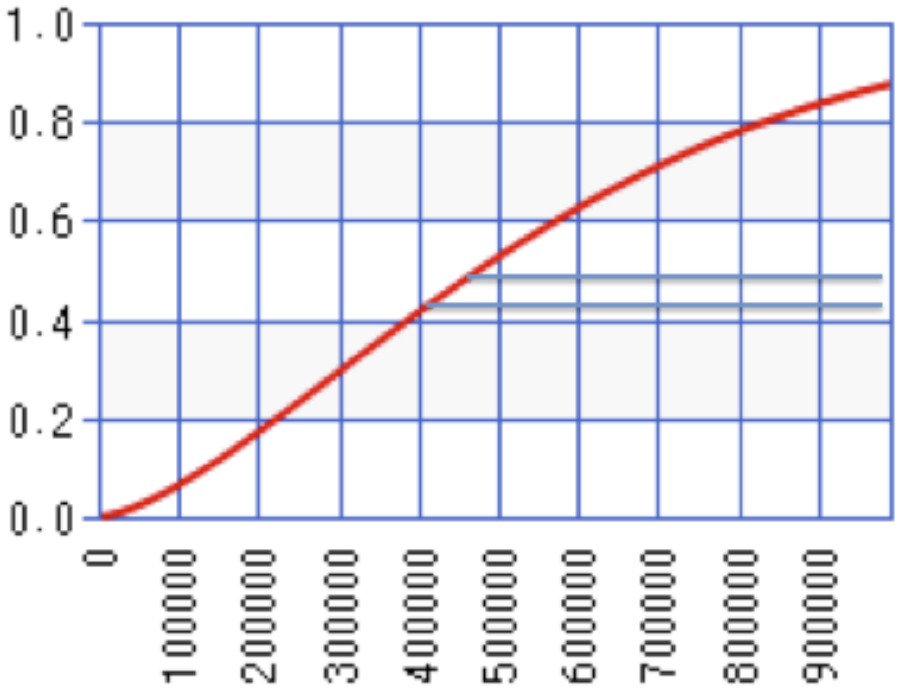
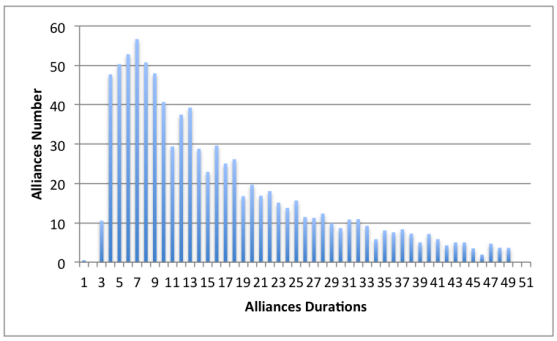
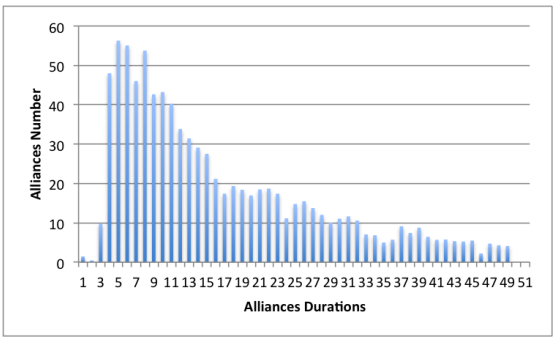


FIGURE 2.25 – Firms Boundaries en t=300 - cut off incomes in euros on vertical line - All competences strategic. One run

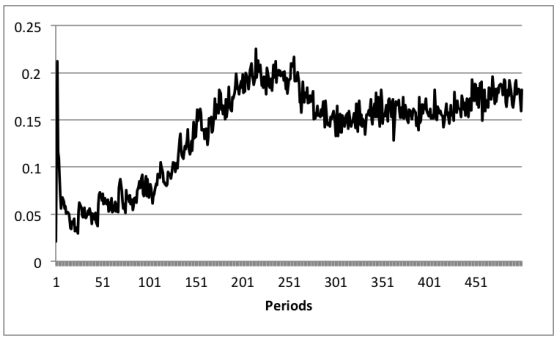


$\Upsilon = 0.5$

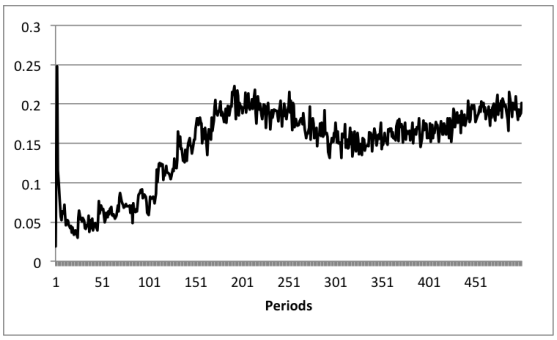


$\Upsilon = 1$

FIGURE 2.26 – Alliance Duration Distribution



$\Upsilon = 0.5$



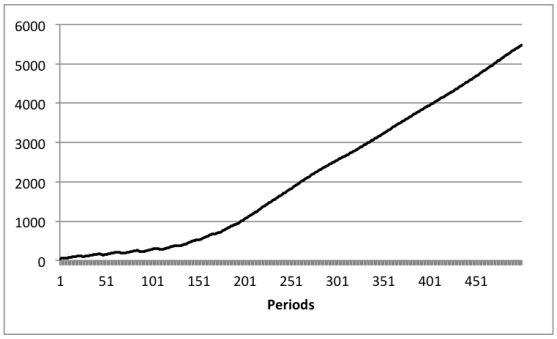
$\Upsilon = 1$

FIGURE 2.27 – Innovation Probability

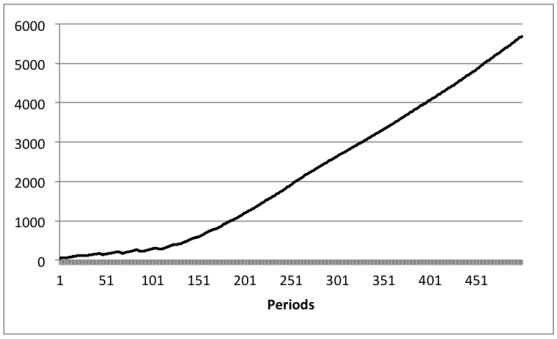
be contradictory with a situation of joint work when using the non strategic competences. The distributions of alliance durations observed in the baseline scenario does not change very significantly when the speed of transfer is increased to a complete transfer at the end of the period (figure 2.26). The innovation rate (figure 2.27) and the increase in the average quality (figure 2.28) are very similar. The market structure (fig 2.29) and the diffusion rate (fig 4.27) are similar, confirming the results are not very sensitive to this parameter.

2.4 Conclusions

The paper investigates R&D alliance formation and destruction in a model based only on competences and shows that a network of alliances can persist in the long run, solving a paradox since convergence in competences should occur in the long run and make alliances useless (result 2). In the model alliances are heterogeneous in duration as in the real markets, which hints to some differentiation between firms behaviors in alliances (result 1). The model solves the paradox by considering that, in accord with management specialists such as [Mowery et al., 1998], firms become specialists in some competences that they do

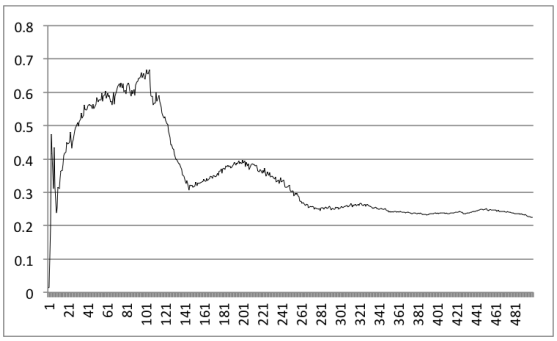


$\Upsilon = 0.5$



$\Upsilon = 1$

FIGURE 2.28 – Average Quality



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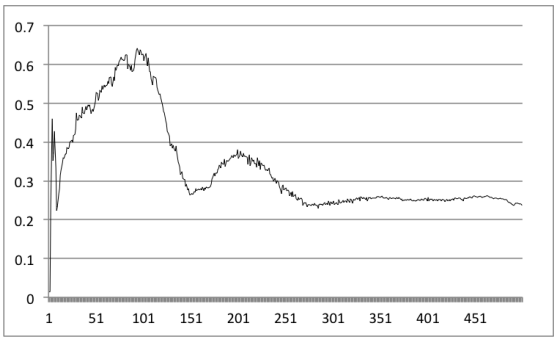


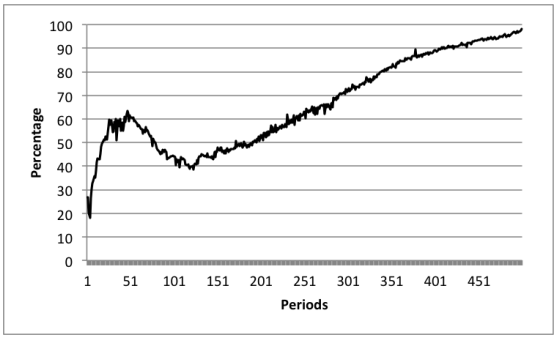
$\Upsilon = 1$

FIGURE 2.29 – Herfindahl Index

not want to share with their partners in the alliance, even though they use them for the joint project. Then the partial specialisation maintains an heterogenity in competences and avoids convergence in the long run. The network has small world properties (result 3).

A contrario in a variant in which all competences are considered as non strategic and shared, firms converge. Moreover important market consequences occur. Some firms with a slightly higher endowment in competences take over the market. Diffusion is then partial, since the lack of competition makes the quality/price ratio too high for low income households. In another opposite variant in which firms do not transfer their knowledge because they consider it as strategic, and specialise, alliances rapidly break because a partner becomes more competent globally. Some firms take over the market and the diffusion is also partial. A mix of integration and specialisation is then key to the persistence of an alliance network in the long run, when based on knowledge (result 6). It is also crucial for the diffusion of a good on a market on which competition is in quality and price.

Our model proposes a new theoretical framework to dispense with problems in the two existing approaches that we surveyed in the introduction, relational embeddedness and new competences. It avoids first to recur to the addition of relational embeddedness



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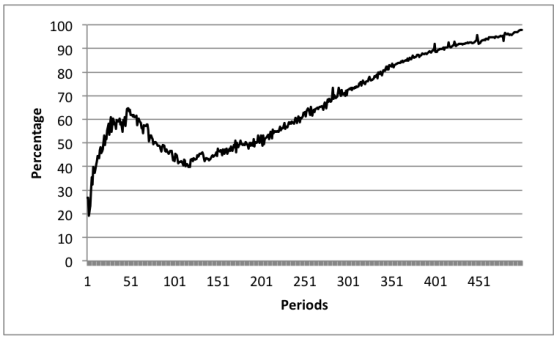

$\Upsilon = 1$

FIGURE 2.30 – Diffusion Rate

to competences sharing that the first approach makes. In other words, the first approach imposes the tendency of some firms to renew alliances they have worked with. This latter motive is usually explained by the accumulation of trust, but this motive can only be a condition of knowledge sharing, which we can assume fulfilled in the model without any need to model it. When all knowledge has been shared, trust is enable to save an interest for firms to pursue alliances based on knowledge sharing. Trust is another theory of alliances which can complement motives like co-operation in R&D effort independently from sharing knowledge, with renewal based on non opportunistic behavior in previous R&D projects. Our theoretical approach is then distinct from the management literature on networks, as developed, to quote a modelled version, by [Cowan et al., 2007]. Second, in contrast to the new competences framework, our approach, through the introduction of a product market closure built so as to integrate competition by competence building and innovation, provides more coherence than these models which avoid convergence on the basis of new competences, as developed by [Baum et al., 2010] and [Caminati, 2016].

The elaboration of this market closure is another novelty of our paper. We jointly model, in a dynamic framework, the co-operation in R&D and the competition on a product market differentiated in quality. The market structure is endogenous and feeds back on R&D, innovation rate, and diffusion of the product. The distribution of market shares and marks up is highly skewed and positively correlated, a major feature of advanced economies in the XXIth century (result 5). We then offer a realistic story of such a dynamic competition by quality. Innovations generate new qualities which are sold to high income households, then diffuse to lower income households through productivity rise with learning proportional to quantity (learning by doing) (result 4). This diffusion process includes the possibility that the market is not covered completely and low income households do not buy the product if the market displays too little competition and firms can survive with low quality/price ratios. Finally the mean income is endogenous to the system through the productivity increases that the learning by doing induces.

One limit of the model is that it considers the market for one product and assumes that

households buy one unit or none per period, although this is a fairly common situation for many products in advanced countries, and a significant share of total consumption. An extension of this work is to add types of innovation which open new sectors (new products which are not substitutes) to desaturate demand, a condition to ensure permanent real growth, which has been little studied. Another limit of the model is that it does not integrate a supply constraint on competences, which is of interest specially for the most difficult to acquire and build. With complementarities between competences in the production process, such a supply constraint on high competences can constitute a major obstacle to growth, a still less studied topic. This implies a labor market to match (or not) supply and demand of competences, and determine the income distribution shape, which remains exogenous in the present model.

Symbol	Description
A_{01}	The initial coefficient of production for a simple task
A_{01}	The initial coefficient of production for a complex task
A_{Pl}	A production coefficient of production task l
a	Parameter of the innovation probability function
B_I	Innovation budget
B_I^R	Real innovation budget
B_I^{min}	Minimum innovation budget
C_A	Exogenous alliance cost
C_P	Production labor cost
C_T	Total cost
GC_f	Global competence level of firm f
I_K	Capital investment
k	quality
k^1	The coefficient of the effect of local competition of innovation budget
k^2	The share of previous sales to innovation budget
l	Task
L_C	The number of non strategic competences
L_I	The total number of innovation competences
L_P	The total number of production competence
N_{LC}	Number of local rivals
p_f	Price of firm f
p_K	Price of capital good
Pr^I	Probability of innovation
R_i	Income of individual i
T_I	Total innovation effort
T^{Il}	The contribution of the research effort of task l
t	Period
uc_f	Unit cost of firm f
V_{Il}	Productivity of the innovation task l
V_{Pl}	Productivity of the production task l
v_i	Utility of individual i
w_{Il}	Wage of the innovation task l by efficient unit
w_{Pl}	Wage of the production task l by efficient unit
$\overline{x}$	The efficiency floor to distinguish strategic and non strategic competence
x_{Il}	Unit efficiency of the innovation task l
x_{Pl}	Unit efficiency of the production task l

Symbol	Description
X_{Il}	Firm stock level of the innovation competence l
X_{Pl}	Firm stock level of the production competence l
y_I	The minimum similarity level between two firms
z	Exogenous parameter of local competition
Y_f^K	Production capacity of a firm f
Y_f^D	Demand of firm f
Y_f^S	Supply of firm f
α_a	Number of complementary competences
$\underline{\alpha_a}$	The minimum number of complementary competences
Ω_{ft}	Sales of firm f at t
γ_I	Substitution parameter of the innovation function
δ_I	The elasticity of substitution between innovation tasks
ζ_A	The adjustment rate
$\underline{\zeta}$	The minimum complementarity level between two firms
ζ_l	The complementarity index between two firms in task l
θ_i	Preference of individual i for quality
κ	Lifetime of capital good
Λ	The similarity level between two partners
$\underline{\Lambda}$	The minimum similarity level
μ_f	Mark-up of firm f
σ_K	Productivity of an unit of capital
τ_{Il}	Quantity of the innovation task l
τ'_{Il}	The percentage of the R&D devoted to labor in task l
τ_{Pl}	Quantity of the production task l
Υ	Competence transfer rate
χ	Learning function
ω	Productivity index

Symbol	**Description**	Baseline
A_{01}	The initial coefficient of production for a simple task	30
A_{01}	The initial coefficient of production for a complex task	50
a	Parameter of the innovation probability function	0.001
k^2	The share of previous sales to innovation budget	0.1
L_C	The number of non strategic competences	25
L_I	The total number of innovation competences	50
L_P	The total number of production competence	50
N	The total number of firms	100
T	The total number of periods	500
$\overline{x}$	The efficiency floor to distinguish strategic and non strategic competence	3.65
y_I	The minimum similarity level between two firms	0.5
z	Exogenous parameter of local competition	0.8
$\underline{\alpha_a}$	The minimum number of complementary competences	20
γ_I	Substitution parameter of the innovation function	1.2
δ_I	The elasticity of substitution between innovation tasks	0.455
ζ_A	The adjustment rate of capital	0.5
$\underline{\zeta}$	The minimum complementarity level between two firms	0.3
κ	Obsolescence rate of capital good	0.05
Φ	The number of individuals	26000000
$\underline{\Lambda}$	The minimum similarity level	0.9
σ_K	Productivity of an unit of capital	2
Υ	Competence transfer rate	0.5

3 Competences, product innovation, growth and employment

3.1 Introduction

In this chapter we present an endogenous growth model based on the concepts of competence and (consumption) product innovation, SIMECO 2. In SIMECO 1, we had only quality innovation in one consumption product market. Each firm sold one quality which was result of its previous quality innovation. Cost increased convex with quality at innovation introduction, and at entry was more costly than the preceding variety. Each individual did not have the same ability to pay and preference for quality and chose a variety which gives him the highest net utility. However, we had assumed that he could buy only one unit of this product. In the long term, demand in this sector could become be saturated when the diffusion rate reaches 100%, and the model converged to a stationary state. In the present model, we introduce two new types of innovation : sector innovation and imitation innovation. Firms may try to innovate by creating a new sector. A sector is defined as a new product which has not existed yet in the market and it allows to satisfy new need to consumers, for which existing sectors cannot care for. When demand in a sector becomes saturated, if individuals have a residual consumption budget after buying the first product, they will continue to buy new products. Demand in quantity can increase indefinitely at the aggregate level. Imitation innovation is introduced in order to allow other firms to enter new sectors. A firm may be mono product or multi-product.

In the production process, we have a learning by doing effect which, in SIMECO 1, increases the firms competences stocks, and decrease the unit price. In SIMECO 2, it increases the workers' competences stocks. Prices per unit of product will not decrease because the wage pays each unit of competence, and the workers' wages are increased accordingly. For the second model, we introduce process innovation from capital sector. There exists a capital firm which sells capital goods to consumption firms. Each new generation of capital is assumed to be more efficient and it then lowers the demand for the labor factor. Process innovation decreases the price of existing sectors and raises the purchasing power of households. It allows then these households to buy more rapidly new products also.

In the first model, individuals are represented by an income distribution function, yet the demand for the varieties (or no purchase) are done on rational decisions based on the position in this distribution. In this model, they are heterogeneous individual agents : each is altogether a worker and a consumer, and the decisions on the different markets are then specific to each of them. They buy products of consumption firms and work for an identified firm. A labor market is built where individuals and firms interact with each other. Since individuals work for firms, we move from firms competence level to individual competence level where individuals bring some efficient units to realize tasks. Each individual owns a competence portfolio which allow him to do different tasks. However, we assume that he can only do one task in each period and competences are not substitutable. The realization of one task requires one specific competence. For this reason, there exists different competence classes in the labor market and individuals will interact with firms in the class where they try to look for a job.

This model has several aims. First we build an endogenous growth model based on competences supply and product innovation, with financial constraint, R&D and saturation of demand. Second we want to study the influence of the main factors on growth and employment, through experiments. A focus is on the future evolution of the demands for different competences, under different assumptions of technical progress : bias towards more or less high demand for complex competences in case of quality innovation and sector innovation for instance. experiments with the competence supply side, will since space and time are limited, will stay on the agenda of research beyond : study the adjustment of labor supply, under different assumptions of changes in initial education level, continuous training by firms to obtain competences that are difficult to obtain on the market, and different wage settings. The confrontation between competence supply and demand may lead to competences bottlenecks if demand by firms exceeds supply by individuals. It has effects on employment and unemployment on different categories of employees according to the degree of complexity of competence[1]. Finally change in the employment structure has effects on the evolution of wage inequality over time.

Theoretical framework

SIMECO 2 is an AB-SFC model with many agents which interact on different markets : firms, individuals, government, banks, unemployment fund and investment fund. The model is Keynesian-Schumpeterian in the tradition originated by [Eliasson, 1977] with the endogenous growth model MOSES (calibrated on the Swedish economy), and pursued since by his team in many papers (for instance [Ballot and Taymaz, 1997]. This theoretical framework has been developed since by ([Dosi et al., 2010]) and his team in many papers. The Schumpeterian label fits however more fully to SIMECO 2 than to the endogenous growth approach initiated in neoclassical models by [Aghion and Howitt, 1992], and in

1. This is a theoretical model with a qualitative focus : competences are not identified with real competence inventories. However the hierarchy of competences and wages in the model has been initialised by the distribution of employees according to socio-professional categories. The initial distribution is derived from actual data on the distribution of wages in France in 1996.

ABM by [Dosi et al., 2010], since here firms innovate in products, both in quality and in new sectors, and these generate entry and exit as much as process innovation does. Product innovation looks an essential element of the creative destruction concept developed by [Schumpeter, 1934].

As for the Schumpeterian content, the model installs a rich competition framework. Firms compete by their costs, by their products, and by their qualities in these products. They even compete on the labor market by raising their wage if they need to attract workers. Exit is the fate of any non competitive firm ([Klette and Kortum, 2004]. As for the Keynesian approach, several features are included. Firms anticipate their demand in order to determine their expected production and can always make mistakes. They advance wages before selling and receiving revenues. Nominal wages are downward rigid. Individuals have precautionary saving. They do not determine their consumption according to the profitability of saving. Once they have set aside precautionary saving, they determine their accumulation saving, the latter so as to set their propensity to consume relatively to their neighbors in income (and increasing in their position on the income distribution. Households cannot borrow. Then fires or a diminution of the real wages trigger a Keynesian crisis. Firms can also be financially constrained, and they are more or less prone to innovate in sector according to the aggressiveness. They have different strategies, and this is in accord with Keynes' views the role of animal spirits.

Simeco 2 is also an endogenous growth model with different types of product innovations. A firm of any size can expand into new markets by realizing different types of innovation project, but in any period such growth depends on the firm's internal resources (especially financial resources and workers'competences). The conception of the firm is SIMECO 2 then related to the competence based view of [Penrose, 1959]. The availability of competences may determine the speed of expansion of firms or it can constraint their development. The model emphasizes competence resources which depend on the evolution of individual competences supply (by initial education, continuous training, task allocation in firms, learning by doing) and of competences demand (by quality innovation, sector innovation and process innovation). A firm of any size may increase the quality of its existing variety or create a new sector. However in any period its likelihood of success depend on its R&D department innovation with two factors : the innovation competences of its workers built over time, and the R&D expenditures, cummulated and current.

This model allows to study some problems that are not or very little discussed in the literature in general and in the agent-based model literature in particular.

First we build an endogenous growth model based on different types of innovation and their relation with the concept of competence. We explore the emergence and the role of human resources constraint the the competences set on the employment structure and aggregate growth in a detailed framework for product innovation, demand and technical progress. Product innovations are modeled under the forms of quality innovation and sector innovation. Varieties of a good have increasing costs and prices in quality and the

income distribution, itself based on competences structure of workers, plays a key role in growth, through demand. The competence structure determines supply. Weak preferences for good by historical order are assumed in the baseline experiment. [Matsuyama, 2002] considers quasi-lexicographic preferences, meaning that consumers should start to buy the first sector before moving to the second one. A consumption order is fixed. For [Saviotti and Pyka, 2013], initial sectors are considered as the necessities goods while new sectors are the luxury ones. We will do different tests on the preference for consumption to study their impact on our results.

Second, at the best of our knowledge, SIMECO 2 is likely to be the first to offer an endogenous growth model in a Stock Flow Consistent framework with heterogeneous competences of workers, and a role for demand. It has a labor market with different levels of competences but possibilities to move up or down. The introduction of labor market may change results obtained in the literature. Many endogenous growth model gives importance to the demand side, under the assumption that existing firms can always provide the total quantity demanded by consumers. Sector innovations are proven beneficial to the economy because it helps to desaturate the market and increases demand in a long term. However, we will show later in this model that there exists many conditions under which growth is not balanced. For instance, sector innovations cannot take off if we do not have both conditions :

(1) Consumers should have enough residual consumption budget to buy new goods, otherwise innovation firms cannot survive for long time and go bankruptcy. New sectors can disappear.

(2) Firms in new sectors should be able to recruit to produce. This is conditioned by process innovation in existing sectors. If there is not process innovation, old sectors do not free up labor force to new sectors. In the history of the first industrial revolution, industrial sectors cannot take off if there were not productivity gain in agricultural sectors. Old farmers move to city to work in factories. However, if process innovation is too strong, it can lead to rise of the unemployment rate and in turn it has keynesian effect on demand and production. The stability of the unemployment rate is obtained by two opposing forces : tasks destruction in old sectors due to process innovation and tasks creation due to increase in demand.

Third we try to explain the phenomenon of increasing wage inequality observed since many decades. By building a competence market, change in competence demand is not homogeneous among different competence classes. Excess in task demand raises more quickly wage of a competence class. Additionally we want to show the role of wage differentiation according to competences in the emergence of new qualities and new goods. Because a new sector does not take advantage many process innovation, its initial price is high and it it is usually consumed by the richest individuals who have large residual consumption budget for new goods. When demand increases, existing firms can expand their production and take more advantage of process innovation. New sectors are more diffused in the economy.

Methodological contributions

The second model is an ABM-SFC model. The introduction of the Stock Flow Consistency framework ([Godley and Lavoie, 2006]) provides a comprehensive and fully integrated representation of the real and financial sides of the economy. This method helps to track all the monetary flows taking place in an economy and the way they accumulate, allows for a consistent integration of the real and the financial side of the economy. Additionally, the fully integrated structure underlying the accounting matrices give account for the inter-relatedness of agents' balance sheet.

We build aggregate balance-sheet, transactions-flow matrix and integrated matrix which comply with rigorous accounting rules based on the quadruple entry principle developed by [Copeland, 1949]. To build these tables, each transaction by one sector should have an equivalent transaction by another sector. Or every financial asset owned by one sector haves a counterpart liability owed by some other. SFC models usually consists of two main components : an accounting part and a set of equations describing the laws of motion of the system. The consistency of the accounting is ensured by the use of three matrices : the aggregate balance sheets (initial state), the transactions flow matrix and the stock revaluation matrix.

Section 2 will present the model, and section 3 the initializations.

3.2 The Model SIMECO 2

3.2.1 Overall Structure

In this section we will survey the overall structure of the model before presenting in detail the behavioural equations of each agent. We first review the different types of agents and their characteristics. Second we present the six markets on which they interact. Third the sequence of events of all agents is described. Fourth we set the tables of balance-sheet accounts and the transactions flow matrix respecting the SFC principles.

3.2.1.1 The Agents

3.2.1.1.1 The Individuals

Let Φ_H a set of individuals. Each individual provides different units of labor. He is also a household and consumes at most one unit of each consumption product. Introducing households with several individuals would have raised the complexity of the model considerably, specially in a SFC framework[2]. It would be necessary for modeling the activity rate, but our long run perspective and interests do not make it fundamental to endogenise it. It would also be important to calibrate the model on income distribution, but we do not intend to go beyond the evolution of incomes inequality. The individual is characterized by some variables which can evolve :

2. SIMECO 2 shares this assumption with the macroeconomic agent based models such as [Caiani et al., 2016], and Eurace@unibi ([Dawid et al., 2016])

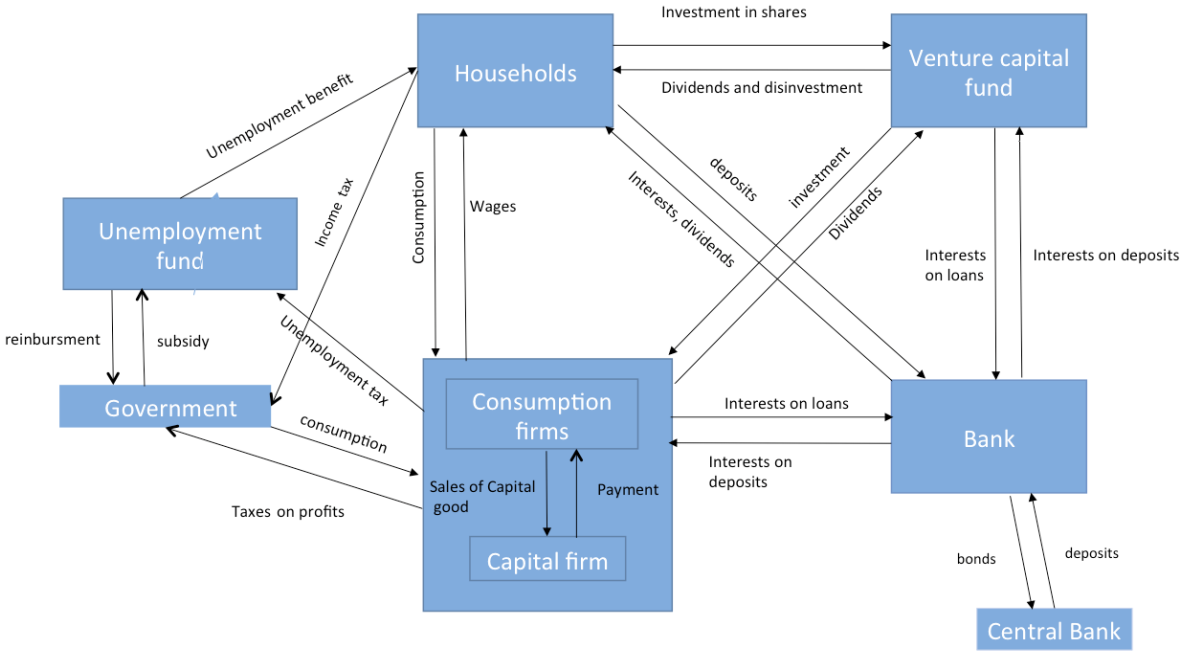

FIGURE 3.1 – Flow diagram of the model.

i) Age

Age is an important variable since workers can accumulate competences over their career, and are then differentiated along this dimension, a novel feature in macro agent based models. This variable is an integer number between [18 ; 62]. For the sake of simplicity, we take assume that all individuals between 18 and 62 are active, and do not consider students and retired workers[3]. Since the period is a year, in each period, we add one year to their age. If they reach 63, they leave the model and are replaced by new 18-year-old individuals. The model considers them as dead, and new individuals inherit their wealth (in order to respect the SFC principles). For the sake of simplicity, we consider the number of individuals remaining constant over the model. Then economic growth -if present - does not depend on change of the population size.

ii) Competences

3. We do not try to model the life cycle theory of consumption (Modigliani, 1966), where the consumption behavior of individuals depends on their income and wealth which change with their age. Additionally, our "individual" agents are individuals, not households. For this reason, we do not take into account teenagers because this requires to introduce social relations like parental relationship. Since teenagers do not work, their parents should transfer a part of their income and/or wealth and it impacts also their consumption behavior. The balance-sheet matrix of teenagers is not in equilibrium without financial flows of other agents. It turns out to be complicated for us to model this interaction between individuals and that would let the consumption behaviors and consumption results more difficult to explain.

We distinguish two types of competences : innovation competence and production competence. We assume that each individual can have only one type of competence. Since competences are not substitutable, each competence type has a distinct labor market. This may look as a strong assumption, but mobility between research jobs and production jobs is certainly weaker than within each type of jobs with adjacent competences requirements. Workers possess several competences within their type. In the simulation, there exist 10 innovation competences and 30 production competences, and in each type, they are vertically ranked by their unitary efficiency (and unit base wage). As in SIMECO 1 a competence yields positive services to contribute to one task only.[4]. Each individual is initialized at entry with a set of 3 adjacent production or innovation competences. This gives some degree of adjustment to the individuals, especially when demand in some competences is depressed for structural reasons and they could be unemployed for a very long period. Another flexibility feature is that this competence portfolio may increase according to different mechanisms like training or promotion since they can acquire a competence new to them. Each competence in their portfolio is characterized by a stock level. It determines the workers' efficiency in realizing a task. In the following, if an individual is working in one task, the stock level of the competence he uses increases with learning. If he is unemployed, this level remains unchanged[5]. Chapter 1 has presented how and why these assumptions differ from the mainstream of the tasks approach.

iii) Professional State

Since all individuals are considered as active, they are employed or unemployed. We assume that there exists only one type of employment contract : permanent and full time contract. If individuals are employed, they normally provide one unit of labor which corresponds to one year of full-time work (964 hours). However the employer may ask them to do some extra hours and they cannot refuse, within the limit of 20%.

iv) Income Level

In each period, individuals receive incomes from different sources. These may be a wage paid by firms or unemployment benefit from the unemployment fund, deposit interest from their deposit in bank, dividends paid by firms and bank. After paying the income tax, they allocate their disposable income between consumption and saving.

v) Wealth

4. Competences are not only distinct, but are also ranked in terms of efficiency (per unit of competence stock). More efficient competences allow to do the tasks which bring a higher contribution to production. In this model based on workers' competences, this hierarchy corresponds implicitly to more initial education, required to obtain a higher competence, and raises the wage that workers are able to require to pay back their investment, according to human capital calculus. Other factors such as rare talents required (manager,researcher...) can raise the contribution of a competence class. Outsourcing would reveal the efficiency as it would be priced on the market.

5. Loss of competence would be a realistic feature, but this would have major consequences for the long run growth, since all competences are embodied. Introducing such an assumption would probably require that some competences are (or become) embodied in firms and not workers, and we leave this complex question to future work.

Individuals' wealth comprises their deposits in a bank account (including precautionary saving), and shares of the investment fund which holds the capital shares of the bank and all the firms.

3.2.1.1.2 The Firms

Let Φ_C a set of consumption firms and Φ_K a set of capital firms. We assume that $\Phi_K = 1$ since we do not focus on process innovation. One firm is enough to obtain several and improved capital generations, yet this firm is regulated to avoid monopolistic behavior.

The Capital Firm

The capital firm uses only labor inputs to produce capital goods for consumption firms. In each period, a new generation of capital is assumed to have a higher productivity, based on an exogenous technical progress trend. This trend is labor saving. Less innovation tasks quantities are required to produce one unit of capital. For the sake of simplicity, we assume that the capital firm can only produce one type of capital per period and cannot turn back to its previous generation. The capital firm is created in initialization. The firm has issued shares bought by the households through the investment fund. The capital firm uses these financial resources to advance wages and other financial transactions. If it goes bankrupt, the investment fund will bail out. However, the risk is low because it incurs mainly labor variable costs and there exists only one capital firm. To avoid monopoly power, we can consider a regulated firm in which the mark up is limited.

The Consumption Firms

Consumption firms use capital and labor inputs in their production function. We assume, in this model, that they can undertake three types of innovation projects or R&D expenses : quality innovation, imitation innovation and sector innovation. The first allows to increase their existing quality within a sector (the commercialisation of the corresponding product is a market). The second is made to enter an existing market, the third to discover a new product and create a new market. Each firm can sell one or several consumption products, but they have only one quality in a given sector. It buys capital goods from capital firm. This decision depends upon its capital stock which determine its production capacity in each period. Each firm has only one capital stock for all its products. If it produces different consumption products, it assigns the capital stock proportionally to each product department.Then it gives to each department the right to use this equipment during one period[6]. All decisions of buying new equipment depends on the firm, not the department. For the sake of simplicity, we assume that firms do not have an operating cost of capital, so that variable costs are labor costs only.

6. Although there is only one type of capital, it is differentiated vertically by age which determines its efficiency, and there is no reason to prevent reallocation between the production departments. It could be argued that after implementation, equipment cannot be moved without incurring a high cost. However all products may also be done within the same plant, and the moving cost is then low. The model has no spatial dimension

3.2.1.1.3 The banks

The commercial bank

Let Φ_B a set of commercial banks. For the sake of simplicity, and since our interest in not focused on monetary crises and the role on bank failures in these crisis, but growth, we assume in this base version of SIMECO 2 that $\Phi_B = 1$. This bank is considered as a regulated private bank. It is created in the initialization period by households who bring some financial capital, via the investment fund. The bank uses deposits of all agents in order to grant loans to firms. Only firms can borrow to advance wages or buy new physical capital goods. Households and the investment fund must respect their budget constraint. The bank pays interest on deposit to other agents according to their deposit level and receive interest on loans from firms. As there exists only one bank, there is no competition when setting the interest rate in order to attract deposit flows. We fix consequently an exogenous interest rate over the model. The bank may ask for cash advances to the Central Bank in order to restore the mandatory liquidity ratio. Cash advances are a loan extended by Central Bank to the bank which is matched by a temporary increase of banks' reserve (a liability for Central Bank). Conversely, cash advances repayments extinguish the loan while reducing bank's reserve accordingly. Interest payments give rise to the same type of transfer, reducing bank's reserves.

The Central Bank

The Central Bank is a public bank held by the government. It has two roles : provide liquidity to the economy if the banking sector is constrained by the liquidity ratio ; buy government's bonds, especially during depression periods where government does not have enough liquidity for some expenses. Bonds are a liability for the government and an asset for Central Bank. We assume that the commercial bank cannot buy the government's bonds. Central Bank's purchases increase its liabilities while also increasing the government account at the Central Bank. For the sake of simplicity, we assume that the value of each bond is one euro. If the bank does not have enough liquidity, it issues bonds which will be bought by the Central bank and pays some interest. When the liquidity level remains too high, it can buy back the bonds in order to reduce the amount of interest. For the government, we use the same rule. It issues bonds usually in recession and buys back during growing periods to reduce its debt level. As the Central bank is held by the government, at the end of each period, its profit or loss will be transferred to the account of the government.

3.2.1.1.4 The Unemployment Fund

France has an unemployment insurance system which relies on firms and employees taxes, and not on government funding. The system is evolving in the late 2010's to the more common government funding, yet the period covered starts in 1996, and we wanted to take into account its economic characteristics, such as the exclusion of long term unemployed of this system, and the relative pressure of a balanced budget target, with cyclical consequences. In the model, firms pay a contribution to the unemployment fund[7]. Then

7. We assume that only firms pay this contribution, not households for the sake of simplicity. Other

the fund uses this contribution to pay the unemployment benefits to unemployed, only when their unemployment duration is not more than 2 years. If it exceeds this duration, unemployed receive the *minimum allowance* from the government (In french the RSA, or *Revenu de Solidarité Active*). The determination of the contribution rate takes place in the end of preceding period and will be used for the current period. However this time lag can lead to some disequilibrium between its revenues and its expenditures. If the unemployment fund does not have enough liquidity to pay the RSA, the government will help him. For instance, if the total amount of the RSA is 1 million euros but the fund has only 800.000 euros of liquidity, the government will transfer 200.000 euros. Next period the fund should raise the contribution rate. However during recession periods, the unemployment rate can increase quickly. In order to be in equilibrium, the contribution rate would rise also quickly.This worsens the economic situation since it leads to substantial increases of firms' production cost and their price. We fix a cap for the target contribution rate. If the actual rate reaches this maximum level, the government will pay the difference. The debt is never repaid, as seems to be the case.

3.2.1.1.5 The Investment Fund

The investment fund participates with the bank in the financing of firms : it finances R&D and the creation of new firms. These decisions are based on some fixed criteria. For the sake of computational cost in the model, we assume that only the 10% wealthiest individuals (around 2000 households) can buy capital shares issued by firms. For the rest of the population, they let the residual income (not used for consumption or precautionary saving) on their bank account and receive an interest, a behavior which is not contradictory with evidence[8]. As mentioned, the shareholders own the investment fund (which is transparent) which in turn owns firms and bank. If the investment fund gets a net profit, it transfers these net dividends to the shareholders according to a proportional rule (percentage of shares of each household in the aggregate sum of shares of the bank and the firms)[9]. As it holds shares of firms, if the seconds go bankrupt, it has impact on the net worth of the investment fund because its total stock of capital shares decreases. In turn the net worth of households decreases because they hold the investment fund. This operation is considered as a variation of capital shares stock, and not as a flow of monetary transaction.

3.2.1.1.6 The Government

Its principal tasks consists of collecting the income tax from households, pay the minimum allowance to unemployed and bail out the unemployment fund. In each period, the Government determines the income tax rate with the target of an equilibrium between its

agents do not use labor factor and consequently do not pay an unemployment contribution.

8. In France non risky investment is privileged by most of households below the 10% wealthiest

9. It obtains dividend flows, new households investments, after deducting the loss capital of firms which have failed (after resale of second hand capital equipment), and new investments

revenue and anticipated expenses. To simplify, we use a flat tax rate for different income groups[10]. When the revenue cannot cover all its expense in one period, the Government issues bonds which will be bought by central bank. To avoid anti-cyclical tax increase in recession, as for the unemployment fund, the Government will not raise dramatically its tax rate which can damage its return. However, during periods of growth, it takes into account its debt level and chooses a tax rate higher than in equilibrium in order to buy back its bonds.

3.2.1.2 Markets

In this model, agents interact with each other on six markets : labor market, capital good market, consumption goods market, deposit market, credit market and capital share market.

i) Labor Market

Labor supply

Interactions take place between firms and individuals. Firms try to hire unemployed workers and workers apply for a job[11]. Since we distinguish two types of competence (production competences and innovation competences), each of the two markets is subdivided in as many sub-markets than there are competences, namely 30 for the production competences, and 10 for the innovation competences. As stated above, workers can only realize tasks which correspond to one of the competences in their competence portfolio. Since competences are defined at the economy level, they are transferable between firms. Standard human capital theory considered only two types of human capital, general and firm specific. There is now a large evidence that human capital specific to the occupation or to a task -transferable between firms - is a large fraction of total human capital (Kambourov and Manovskii, 2009). Competences in SIMECO 2 are none of the formers, but correspond to the latter[12]. Since competences are transferable, the worker can offer them on the labor market. The competence class is common knowledge, and the services from the stock level in a competence class have the same value for all the hiring firms.

A worker's efficiency level in one task depends on 3 factors : i) his stock level in the corresponding competence *and* ii) the task (or competence) efficiency) iii). the ratio of his number of yearly on the legal number of hours in case of extra hours. As each individual may hold different competences, he can search for a job on different sub-markets but during

10. Most macroeconomic agent base models have such a flat tax, and, moreover, in SIMECO 2, government expenditures are very low, so that progressivity would not be real.

11. Employed workers do not search for a job. This gross flow is not more than 5% of employed workers in France, and since we do not calibrate the gross flows, does not justify the modeling complication in this model.

12. We do not deny that general human capital is important, but it can be assumed to be included in the competences in the model, as a uniform fraction of their unit efficiency (defined below), more general human capital being associated with higher classes. Human capital specific to the firm is not likely to be extremely important, although decisive measurements are difficult to obtain.

one period, we assume that he can only search in one competence market. The choice of the competence class in which to apply depends on his expected individual wages (wage by competence unit multiplied by the number of units) in the different competences of his portfolio, and of the market situation for this competence class. He may change of competence market if he cannot find a job after some periods, and since he has ranked his expected wages, it justifies search in only one competence market at a time.

Labor demand

Both consumption-good and capital-good firms need labor in their production function. However, the first ask for both types of competence while the second asks only for production competence because technical progress is exogenous and the capital firm does has no R&D department. From their production function, we can determine the demand of efficient units in each competence class.

Interaction between labor supply and demand

On the labor market, firms need labor, expressed by the number of efficient units while individuals provide them. For the sake of simplicity, there does not exist any transaction costs in this model like recruitment cost, redundancy cost, nor fixed costs per worker. Then firms are indifferent between two individuals providing different number of efficient units because they have the same cost by competence unit. An individual with a stock level of 10 has the same cost than two individuals with a stock level of 5 in the same competence[13]. However, each firm does not have the same wage level by competence unit because it depends on other factors like firms' excess of demand in a competence, and the profit rate, since it gives a premium to workers. If it meets difficulties in hiring, the next period it will increase its offered wage. On the supply side, each individual has a reservation wage. When a firm looks for workers in a competence class, the set of possible candidates is the unemployed who searches this competence market and whose reservation wage is lower than the total wage proposed by the firm to this worker (taking the number of competence units into account). Then firms choose randomly individuals in this set until they find enough workers or the set is empty.

ii) Capital Good Market

Capital good demand

Each consumption firm has a production capacity which is determined by its capital stock and the productivity of its capital units. When it anticipates a strong increase of demand or when its utilization rate of production capacity reaches the maximum threshold (80% in our model), it will order new capital good. The consumption firms cannot adjust

13. This assumption takes into account the major stylised fact on wages for our purpose, namely that wages are increasing in the competence level in a class. it also corresponds to the common sense observation that a firm which has less competent workers will need more employees to produce the same amount. The main alternative approach would be a posted wage for the job, setting a hiring norm corresponding to the minimum productivity that would give the firm a non negative return, as in a firm side search model ([Pissarides, 1976]). Then the firm would select the most productive worker or randomly any worker above the norm, but in this setting, the workers ranked low may stay unemployed lifelong, a too extreme result. Then a more complex mixed modeling would be needed as in WorkSim ([Goudet et al., 2017]).

their production capacity at once, meaning when they learn their true demand.

Capital good supply

The Capital firm provides the capital good to consumption firms at the beginning of the next period. In order to satisfy this demand, the capital firm will use its labor resources to produce, trying to adjust them if necessary.

Interactions between capital good supply and demand

In case of labor constraint, the capital firm may not deliver all the ordered equipment. We use the proportional rule of rationing. For instance, if it can provide only 90% of the aggregate capital demand, each customer receives only 90% of its order. We also build a second hand market in our model. If a consumption firm goes bankrupt, its creditors or shareholders will try to sell its capital stock on the second hand market. In case of rationing, consumption firms may go on the second hand market to buy the capital good. The price of the second hand capital is set so as to be equivalent to new capital in efficiency terms. We assume that this takes place after the transactions between capital and consumption firms, and for this reason the second hand market cannot impact the sales of the capital firm. On the second hand market, we pick randomly firms among those who want to buy more capital goods. They can accept or deny the deal. We continue until there does not exist anymore demanding firms or capital equipment for sale. The introduction of this second hand market, which could be a novelty in ABM, is done in order to avoid large losses to the bank and to the investment fund and shareholders in case a firm represents a large share of the economy would go bankrupt.

iii) Consumption good markets

Consumption good supply

Each consumption firm sells one or several consumption products. Each product is characterized by a quality and price, and the sector it belongs The aggregate supply in a sector is then not homogeneous.

Consumption good demand

Each household has a consumption budget which is related mainly to his income level and other factors (see below). Income also determines its preference structure over qualities. They consume 0 or 1 unit of the good, considered as a good durable during the whole period (a year).

Interactions between consumption good supply and demand

households have two choices : the sectors and the quality of each variety in a sector. First they have a utility function. It helps to determine the possible utility if they consume a variety. For each sector, they eliminate choose all varieties except the one which maximizes their net utility (deducting the price) among possible varieties. The they compare the best choices in the existing sectors. Because of the budget constraint and binary decision for each sector, their first choice is the sector which gives them the maximum utility between different sectors. We have then two maximization processes : first the best variety between different varieties in one sector and the best product between different best varieties. However for the ranking between sectors, in the reference scenario, we give some

advantage to the first sectors which are considered as the most basic goods. Sectors are ranked by creation date, and new sectors are more considered as luxury and have a decreasing weighting coefficient in their net utility. They check their consumption budget before buying. Then they consider the second ranked sector in terms of net utility and repeat the process. If this firm is out of stock, they may report on next product. We will detail the algorithm later in the section of consumption market description.

iv) Deposit Market

Deposit supply

As there exists only one bank in our model, agents do not have the choice and leave their liquidity in the bank's account.

Deposit demand

Bank uses deposit of other agents to grant loans to firms. It pays them interest on deposit.

Interaction between deposit supply and demand

Since there is no competition in the deposit supply and to avoid monopoly power, we fix the interest rate on deposit as constant over the model[14].

v) Credit Market

Credit supply

The bank uses the deposits of all agents to grant loans to firms. It has a liquidity ratio constraint which determines its financing capacity in each period.

Credit demand

Firms may do not have enough liquidity for some activities. We assume that the bank can finance their purchase of physical capital and wage advance. In fact, the bank refuses to finance the R&D activity because it considers it as too risky. As there is no patent market in the model, in case of bankruptcy, the creditors cannot sell firms' innovation results in the market. With physical capital, if indebted firms are unable to repay their debt, bank can sell its capital stock in the second hand market. Firms who wish to borrow send a request to the bank with their desired amount. It determines the total demand of credit.

Interaction between credit supply and demand

The bank decides according to some criteria and in the end, it has a list of accepted candidates. However, it must cope with its actual financing constraint which may not allow to finance all the firms loans demand. In this case, it ranks firms from the best to the worst and grants loans until it does not have enough liquidity to finance the rest of candidates.

Capital shares market

Capital shares supply

Firms issue capital shares in order to finance their R&D activity if they do not have enough liquidity. Contrary to bank, the investment fund has less risk aversion. The decision to invest in a firm is based on the expectation of getting more dividends in the future. The Investment fund finances two activities of firm : innovation activities of existing firms and

14. This is feasible because we checked that inflation is low in the model. Negative real interest rates on deposits are common in France

creation of new firms. In the latter case, entrepreneurs try to create new firms. They ask the investment fund, and if it accepts, new firms are created. New capital shares are issued which helps these firms to pay some activities in the first periods of their existence when sales are still low. Capital share supply is the total number of capital shares issued by existing firms and new firms. Each share has a nominal value of 1 euro.

Capital shares demand

Households save part of their disposable income, according to a behavioral set of rules detailed below, on the basis of precautionary saving (put as a deposit on the bank account), and of a distinct yet aggregated motive corresponding to retirement needs and bequest. We assume that only 10% of the wealthiest individuals invest in capital shares market savings which is possibly left after setting precautionary saving. They do not hold directly the capital share stock of firms and bank but though investment fund. They buy capital shares issued by the investment fund which use its liquidity to buy capital shares issued by firms and bank. The capital share demand is a major determinant of the financing capacity of the investment fund.

Interaction between capital shares supply and demand

The investment fund first decides to invest in the R&D of existing firms. Since it had already invested in the past, if existing firms go bankrupt, it can loose its investment. However, it has some criteria for the decision. If it still has some financing capacity, it finances the creation of new firms. Financing stops when there are no new profitable investment opportunities or the investment fund does not have any financing ability left in this period.

3.2.1.3 Sequence of events

Agents interact with each other according to the following sequence :

1. Labor market for researchers.
2. Innovation effort and results.
3. Expected demand for consumption goods.
4. Labor market for capital firm.
5. Production of capital firm and second hand market of capital goods.
6. Labor market for production department of consumption firms.
7. Production of consumption firms.
8. Wage advance. Mark-up and then price settings.
9. Payment of unemployment contribution by firms.
10. Payment to unemployed by Unemployment fund and government.
11. Payment of income tax by individuals.
12. Determination of saving and consumption of individuals.
13. Demand for consumption goods.
14. Payment for purchase by individuals to consumption firms and payment for capital goods by consumption firms to capital firm.

15. Debt refunding by firms and interest payment.
16. Profit or loss of firms. Possible bankruptcies and their consequences.
17. Price setting of capital firm.
18. Expected budget for capital investment by consumption firms.
19. Expected budget for R&D and budget allocation between different innovation projects.
20. Demand for credit and venture capital.
21. Supply of credit and bank's decisions. Investment fund' decisions.
22. Real budgets for capital investment and R&D.
23. Dividend payment.
24. Effectiveness of layoffs. Layoffs by bankrupt firms.
25. Determination of reservation wage of unemployed.
26. Contribution rate setting by unemployment fund.
27. Determination of minimum wage level (smic) by the Government.
28. Setting of the base wages by firms.
29. Demography.
30. Death and inheritance.
31. Creation of new firms.

3.2.1.4 Balance-Sheets and Transactions-Flow Matrix

The use of the SFC method allows to make certain the coherence between all agents' financial transactions flows. First we establish an aggregate balance sheet of the economy. Then we introduce the transactions-flow matrix. We add different transactions flows to the initial balance-sheet to obtain the final balance-sheet. Our economy contains the four following sectors : the individuals' sector (made up of individuals and investment fund), the production sector (made up of consumption and capital firms), the financial sector (bank), the Government sector (made up of the Government, unemployment fund and Central Bank, which constitute sub-sectors). Before describing the balance sheet matrix of all these sectors, called the sectoral balance sheet matrix, we will look at the balance sheet of one agent of each type, with numerical examples.

Individuals Balance Sheet			
Assets	Total = 700	**Liabilities**	Total = 700
Capital Share Stock, Investment fund Deposit	$E_{IF} = 400$ $W_H = 300$		
		Net Worth	$NW_H = 700$

We assume that individuals do not hold tangible assets such as real estate or durable goods (lasting more than one period) because it requires to model all these consumption

sectors which are not the aim of our model. They hold financial assets like deposit and capital shares of the investment fund. For liabilities, we assume that they cannot borrow from bank in our model. For this reason, their net wealth is the sum of their assets.

Consumption Firms Balance Sheet			
Assets	Total = 700	**Liabilities**	Total = 700
Physical Capital	$K_C = 100$	Loans	$D_C = 200$
Intangible Capital	$K_f = 100$	Capital Share	$E_C = 800$
Deposit	$M_C = 500$		
		Net Worth	$NW_C = -300$

Firms have two types of capital : physical capital and intangible capital (the R&D stock). Physical capital is evaluated at current production prices and intangible capital at the past flows of investment in R&D. Their financial assets contain the deposit in their bank account. On the liabilities side, they may have loans with bank and they have as a debt their shares held by the investment fund. Their net wealth is the difference between total assets and liabilities.

We use the same reading with the balance sheet of the rest of agents where the left side represents agents' assets and the right side their liabilities. Their net wealth is the difference between two sides.

Capital Firm Balance Sheet			
Assets	Total = 500	**Liabilities**	Total = 500
Deposit	$M_K = 500$	Loans	$D_K = 200$
		Capital Share	$E_K = 800$
		Net Worth	$NW_K = -500$

Bank Balance Sheet			
Assets	Total = 1000	**Liabilities**	Total = 1000
Debt Stock	D = 1000	Deposit	M = 800
		Capital Share	$E_B = 700$
		Net Worth	$NW_B = -500$

Unemployment fund Balance Sheet			
Assets	Total = 300	**Liabilities**	Total = 300
Deposit	$M_U = 300$	Debt	$D_U = 200$
		Net Worth	$NW_U = 100$

Government Balance Sheet			
Assets	Total = 500	**Liabilities**	Total = 500
Debt	$D_U = 300$		
Deposit	$M_G = 200$		
		Net Worth	$NW_U = 500$

Investment fund Balance Sheet			
Assets	Total = 800	**Liabilities**	Total = 800
Deposit Capital shares, firms Capital shares, bank	$M_{IF} = 400$ $E_F = 200$ $E_B = 200$	Capital shares, households	$E_H = 400$
		Net Worth	$NW_{IF} = 400$

3.2.1.4.1 Initial Balance-Sheets

All assets appear in the balance sheet with a plus sign while liabilities, including net worth, are assigned a negative sign. The matrix should follow one single rule, as in [Godley and Lavoie, 2006] : all the columns and all the rows that deal with financial assets or liabilities must sum to zero. However, [Godley and Lavoie, 2006], note in their matrix, that the only row that may not sum to zero is physical capital because it appears in a single entry of the sectoral balance sheet. This is in contrast to financial assets and liabilities. As our model is an innovation model, we introduce, and this is likely to be a novelty in SFC modelling, a row for intangible capital which plays the same role as physical capital because both are investment of consumption firms. The cumulated R&D expenditures influence the research effort. In the column of each sector, the sum of all components represents its net worth. This guarantees the coherence of the balance sheet matrix because all the sector components of the last line of the total are zero.

	Indiv	Firms C	Firm K	Bank	UF	Gouvernment	Central bank	IF	Total
Physical Capital		$+K_C$							$+K_C$
Intangible Capital		$+K_I$							$+K_I$
Loans		$-D_C$	$-D_K$	+D					0
Debt to government					$-D_U$	$+D_U$			0
Capital shares, firms		$-E_C$	$-E_K$					$+E_F$	0
Capital shares, bank				$-E_B$				$+E_B$	0
Capital shares, IF	$+E_H$							$-E_H$	0
Deposit	$+M_H$	$+M_C$	$+M_K$	-M	$+M_U$	$+M_G$		$+M_{IF}$	0
Bills						-B	+B		0
Reserves				+H			-H		0
Net worth	$-NW_H$	$-NW_C$	$-NW_K$	$-NW_B$	$-NW_U$	$-NW_G$		$-NW_{IF}$	0
Total	0	0	0	0	0	0	0	0	$-K_C - K_I$

FIGURE 3.2 – Initial Balance-Sheet

Notes : Indi = individuals, Firms C = consumption firms, Firm K = capital firm, UF = Unemployment fund, Govt = government, IF = investment fund.

Lines

- Lines 1 and 2 : physical and intangible capital.
- Line 3 : bank uses money from the agents' deposit to grant loans to firms.
- Line 4 : the Government is responsible for the debt of the unemployment fund.
- Line 5 : the investment fund holds capital shares of firms.

- Line 6 : the investment fund holds capital shares of bank.
- Line 7 : individuals holds capital shares of the investment fund.
- Line 8 : agents deposit their liquidity in their bank account. The bank will use this money to grant loans to firms. For firms and other agents, the deposit corresponds to their liquidity. For individuals, it includes liquidity and precautionary saving.
- Line 9 : government issues bills which will be bought by the central bank.
- Line 10 : the central bank provides cash to commercial bank.
- Line 11 : the net worth is sum of all previous transactions in the same columns. It can make sure that the following total (line 12) is equal to 0.

Columns

- Column 1 : individuals' net worth is composed of their deposit in bank account and their capital share stocks on firms and bank.
- Column 2 : consumption firms' net worth is the difference between their assets and liabilities. Their assets include physical and intangible capital stocks and their liquidity in the bank account. Their liabilities depend on their total loans held by bank and their capital shares stock held by individuals (see the following table of balance sheet of one consumption firm).
- Column 3 : the asset of the capital firm is only its bank deposit. Its liability includes loans and capital share stocks. Its net worth is the difference between assets and liabilities.
- Column 4 : the asset of the bank is its debt from firms. Its liability is its deposits because bank uses deposits of other agents and its capital share stock hold by individuals in order to grant loans to firms.
- Column 5 : the unemployment fund has debt to the Government, especially when it does not have sufficiently liquidity for the payment of the minimum allowance. Its net worth is the difference between its debt stock and deposit.
- Column 6 : the Government holds debt of unemployment fund. Its net worth depends on its debt and deposit.
- Column 7 : the Central bank buys bills issued by the government and provides cash to bank.
- Column 8 : the investment fund has some deposit in its bank account. It owns capital shares of firms and bank and it is owned by individuals.

3.2.1.4.2 The transactions flow matrix

As in the balance sheet matrix, the coherence of the transactions flow matrix is built on the rule that each row and each column must sum to zero.

Lines

- Line 1 : individuals consume.
- Line 2 : consumption firms buy capital goods from capital firm and pay.
- Line 3 : firms pay employees their wage.
- Line 4 : firms pay the unemployment contribution to the unemployment fund. For consumption firms, we distinguish employees in the production and the research depart-

	Households	Firms C		Firm K		Bank		UF	IF	Central bank	Gouvernment	Total
		Courant	Capital	Courant	Capital	Courant	Capital					
Consumption	$-C$	$+C$										0
Investment			$-I_C$	$+I_C$								0
Wage bill	$+WB_H$	$-WB_P$	$-WB_R$	$-WB_K$								0
Unemployment contribution		$-UB_P$	$-UB_R$	$-UB_K$				$+UB_F$				0
Debt to government								$+D_U$			$-D_U$	0
Unem. benefit	$+UB_H + RSA$							$-UB_H$			$-RSA$	0
Tax	$-T_G$										$+T_G$	0
Profit, firms C		$-F_C$	$+FU_C$						$+FD_C$			0
Profit, firm K				$-F_K$	$+FU_K$				$+FD_K$			0
Profit, bank						$-F_B$	$+FU_B$					0
Dividends	$+FD_H$								$-FD_H$			0
Interest on loans		$-r_lD_C$		$-r_lD_K$		$+r_lD$						0
Interest on deposit	$+r_mM_H$	$+r_mM_C$		$+r_mM_K$		$-r_mM$		$+r_mM_U$	$+r_mM_G$		$+r_mM_G$	0
Change in loans		$+\Delta D_w$	$+\Delta D_C$	$+\Delta D_K$			$-\Delta D$					0
Investment, IF			$+\Delta K_{IF}$						$-\Delta K_{IF}$			0
Investment, H	$-\Delta K_H$								$+\Delta K_H$			0
Change in deposit	$-\Delta M_H$	$-\Delta M_C$		$-\Delta M_K$	$-\Delta M_{K,C}$		$+\Delta M$	$-\Delta M_U$	$-\Delta M_G$		$-\Delta M_G$	0
Change in bills										$-\Delta B$	$+\Delta B$	0
Change in reserves							$-\Delta H$			$+\Delta H$		0
Total	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE 3.3 – Transactions Flow Matrix

ment. We consider innovation investment as having the same nature with physical capital investment. Firms use their capital account to pay researchers' wage and the corresponding unemployment contribution while they use their current account to pay employees in the production department.

- Line 5 : the unemployment fund may have debt to the Government.
- Line 6 : the unemployment fund pays unemployment benefit to individuals.
- Line 7 : individuals pay income tax to the Government.
- Line 8 : the profit of consumption firms is the difference between their sale (C) and total variable cost (wage bill and unemployment contribution in the production department). They pay dividends to the investment fund. The residual profit will be used to invest in physical capital and R&D.
- Line 9 : the profit of the capital firm is the difference between its sales and production cost. It pays dividends to the investment fund and lets its residual profit in its deposit account.
- Line 10 : bank receives interest on loans from firms and pay interest on deposit to other agents. Its residual profit is the undistributed profit (profit left after paying dividends).
- Line 11 : the investment fund collects dividends from the firms and the bank then pays to individuals.

- Line 12 : firms pay interest on loan to the bank.
- Line 13 : bank pays interest on deposit to other agents.
- Line 14 : firms borrow from the bank.
- Line 15 : the investment fund issues new equities of consumption firms in order to invest in R&D.
- Line 16 : Individuals invest in firms though investment fund.
- Line 17 : bank uses deposit of other agents to grant new loans later.
- Line 18 : the Central bank buys bills issued by the government.
- Line 19 : the Central bank provides cash to commercial bank.
- Line 20 : the total of all lines should be (and is) equal to zero.

Columns

- Column 1 : income of individuals comes from the wages (for employees), unemployment benefit or the minimum allowance (RSA) (for unemployed), dividends and interests on deposits. They pay then the income tax to the Government, increase or decrease their deposits as a result of precautionary saving and rationing in consumption. Some individuals (10% of the wealthiest wealthiest) will invest in firms. The rest is consumption.
- Column 2 : for consumption firms, we distinguish current and capital accounts. In the current account, firms receive money from sales and pay wages, the unemployment contribution to unemployment fund, debt and interest repayment. They can have some interest on deposit. If firms cannot have enough liquidity to advance wage in the next period, they have to borrow from bank (change in loans). The rest in their deposit account will be used by bank.
- Column 3 : in the capital account, firms use their residual profit to invest in physical capital and make innovation expenditures. For the second, the innovation cost includes wage paid to researchers and their corresponding unemployment contribution. If firms do not have enough liquidity, they borrow from the bank to invest in capital and issue new equities to invest in R&D.
- Column 4 : the capital firm receives money from sales of capital good in order to pay wages and the unemployment contribution. It can receive interest on deposit from bank and repay the principal and interest on loan to bank. If it does not have enough liquidity, it will borrow from bank. The rest of its deposit will be used by bank.
- Column 5 : capital firm's residual profit will be left in its account and used by bank because the capital firm does not invest.
- Column 6 : the bank's profit is the difference between interest on loans and interest on deposit.
- Column 7 : the bank uses its residual profit and variation of deposits of other agents to grant new loans to firms.
- Column 8 : the unemployment fund collects unemployment contribution from firms and pays short-term unemployed. If it does not have enough liquidity, it can ask the Government to pay the difference. However, this debt will disappear after one period and it will be considered as government's debt.

- Column 9 : the investment fund receives dividends from firms and bank and returns them to individuals. The investment fund issues capital shares which are bought by individuals. Then it uses this money to buy capital shares issued by firms.

- Column 10 : the Government collects the income tax to pay the minimum allowance to long-term unemployed and debt of unemployment fund.

- Column 11 : in the last column, the total is the sum of previous columns. For the reason of coherence, it should all be equal to zero.

3.2.1.4.3 Full-integration matrix

We are now in a position to integrate fully the transactions flow matrix to the balance sheet. In the following table, we make use of the (-1) time subscript whenever beginning-of-period wealth is referred to. The first row represents th initial net worth of each sector (the network in the beginning of each period, before adding new transactions flow). As in [Godley and Lavoie, 2006], we assume that the net worth of the central bank is equal to nil because any profit of the central bank is returned to government. The sum of the first row is equal to the value of tangible and intangible capital $K_{C-1} + K_{I-1}$, as showed in the balance-sheet.

Change in net assets of any sector is made up of two components : changes from new transactions and changes from revaluations of existing stocks (usually from changes in the prices of assets or liabilities).

		House.	Firms C	Firm K	Bank	UF	IF	CB	Govt	Sum
	Net worth, end of previous period	NW_{H-1}	NW_{C-1}	NW_{K-1}	NW_{B-1}	NW_{U-1}	NW_{IF-1}	0	NW_{G-1}	K_{-1}
Change in net assets arising from transactions	Change in loans		$-\Delta D_C$	$-D_K$	$+\Delta D$					0
	Change in loans (government)								$-\Delta D_U$	0
	Change in reserve				$+\Delta H$			$-\Delta H$		0
	Change in deposit	$+\Delta M_H$	$+\Delta M_C$	$+\Delta M_K$	$-\Delta M$	$+\Delta M_U$	$+\Delta M_{IF}$		$+\Delta M_G$	0
	Change in bills							$+\Delta B$	$-\Delta B$	0
	Change in capital shares		$-\Delta E$				$+\Delta E$			0
	Change in tangible capital		$+\Delta K.p_K$							$+\Delta K.p_K$
	Change in intangible capital		$+\Delta I_C$							$+\Delta I_C$
Change in net assets arising from revaluations	Capital gain in tangible capital		$+\Delta p_K K_{C-1}$							$+\Delta p_K K_{C-1}$
	Net worth, end of period	NW_H	NW_C	NW_K	NW_B	NW_U	NW_{IF}	0	NW_G	K

FIGURE 3.4 – Full-integration matrix

The first component of the change in net assets arises from the transactions flow matrix. The rows "change in loans", "change in cash", "change in deposit", "change in loans (government), "change in capital shares" are equivalent to corresponding rows of the transactions flow matrix "change in loans", "change in cash", "change in deposit", "debt to government" and "investment, IF". For the last operation, the total number of capital shares increases when the investment fund invests in existing firms or creates new firms. It can decrease if some firms fail. The total variation is result of both operations. All these rows reflect the financial transactions that occurred during the period. The only difference between two tables is their sign. All minus signs in the previous table are replaced by a plus sign here, and vice versa as in [Godley and Lavoie, 2006]. The last two rows of the first component comes from investment of consumption firms on physical capital and research activity. It corresponds to the row "investment" and "wage bill of researchers" in the transactions flow matrix. The second component of the change in net worth arises from capital gain. The value of firms capital stock depends on the actual price of capital firm. Addicting both components to the net worth of the previous period, we obtain the net worth at the end of the current period. The integration of the flow of funds financial transactions and the balance sheet with the national income accounts is complete.

3.2.2 Agents Behavior

This section describes the behavior of each types of agent in the model, and presents the specifications of the equations.

3.2.2.1 Consumption Firm Behavior

We distinguish two departments in each consumption firm : the research department and the production department. In the research department, firms use a staff endowed with competences specific to R&D activities. If many are researchers, the research departments also uses technical and clerical staff as well as some managers, and these populate parts of the lowest and highest of the 10 competence classes. The results of an innovation in SIMECO 2 may be a higher quality of their existing varieties (quality innovation), a sector new to the firm (imitation innovation) or a sector new to the economy (sector innovation). This step determines the number of products and their quality which have an impact on the production function in the production department. For the sake of clarity, we first present the production department because innovation results will have impact on the production process. It avoids to present two times the production function.

3.2.2.1.1 Consumption firms production department

Production planning

Each firm has a production capacity which depends on its stock of capital. In the beginning of the period, it receives capital good from capital firm. This determines the

new production capacity of firms. We call it Y_{ft}^{PC} (the function will be introduced later in the sub section of capital investment).

In the same time, they have a desired quantity which is the demand expressed by consumers in the previous period. In fact, firms may be constrained by the capital or labor factor in the previous period and should produce a lower quantity than their real demand. In this period, they try to satisfy this demand.

As firms may be constrained by their production capacity at t, their expected production is :

$$Y_t^E = min[Y_{ft}^{PC}, Y_{t-1}^e] \tag{3.1}$$

where Y_t^E the expected production at t, Y_{t-1}^e the demand expressed by consumers at t-1.

With the expected production, firms will determine their demand of labor. They may have human resources constraint and it determines their real production :

$$Y_t^R = min[Y_t^E, Y_t^L] \tag{3.2}$$

where Y_t^R is the real production, Y_t^L the production level determined by firms' employees.

Production function

We present for a firm who has only one product. Multi-product firms have as many production departments as the number of products.

The production function of a consumption product is :

$$Y = min[A_{P1}T_{P1}, ..., A_{Pl}T_{Pl}, ...A_{PL_P}T_{PL_P}] \tag{3.3}$$

Under the capacity constraint and also a human resources constraint which will be described later, the production function of a consumption product has the same form as in SIMECO 1 :

$$Y = min[A_{P1}T_{P1}, ..., A_{Pl}T_{Pl}, ...A_{PL_P}T_{PL_P}] \tag{3.4}$$

where Y is the quantity produced, L_P is the number of production competences, A_{Pl} the coefficient of demand for task l, T_{Pl} the *quantity* of task l defined in efficiency units. Each worker brings the following quantity in efficient units :

$$V_{ilt} = x_{Pl}X_{il}\tau_{il} \tag{3.5}$$

T_{Pl} is measured as follows :

$$T_{P1} = \sum_{i=1}^{L_{Pl}}(x_{Pl}X_{il}\tau_{il}) \tag{3.6}$$

where L_{Pl} the number of workers in the firm owning the competence l of production, x_{Il} the unit efficiency of the production competence l, X_{Iil} the stock level of worker i belonging

to L_{Pl}, τ_{il} the number of working hours of worker i. We normalize the legal number of hours of work to 1. When firms need a higher quantity of a task, they can ask existing workers to work overtime. In this case, the value of τ_{il} can increase to 1.2. For the sake of simplicity, we assume that τ_{il} can be only 1 or 1.2.

3.2.2.1.2 The Research Department

Sequence of decisions in the research department

1. Determine the number of innovation projects and their type.
2. Determine the global budget of R&D of firms.
3. Allocate the global budget to different innovation projects.
4. Determine the total innovation effort and innovation effort of each project.
5. Calculate the innovation probability of each project.
6. Determine innovation results of each project.

Innovation Projects

In the research department, first consumption firms determine the number of innovation projects in the actual period. We distinguish three types of innovation project : quality innovation, imitation innovation and sector innovation.

(i) Firms invest in quality innovation research in order to raise the quality of their existing varieties[15].

(ii) Imitation innovation allows firms to enter a new market which already exists in the economy[16]. For example, if a firm f is producing one product in the sector 1, it can try to enter in the sector 2. Producing a new good requires a new technology. Imitation innovation allows firms to acquire the required technology to enter this sector[17].

(iii) Sector innovation creates a new sector which does not exist in the economy. Innovators can take advantage of being the first and only firm in this sector until other firms succeed imitation innovation projects or entry of newly created firms.

Each firm has a product portfolio. It can produce one or several products. We call respectively mono-product firm or multi-products firm. In the second case, firm can produce different products belonging to different sectors. In period t, the product portfolio of a firm f is called S_f, with $S_f \geq 1$. The firm may decide to leave one sector if it is not profitable

15. We assume (a) that firms always try to innovate, (b) and always adopt their innovation. Not trying to innovate is very risky since we assume an environment in which products can be improved considerably (as digital goods). Moreover they adopt their innovation since they cannot anticipate if the profit will be higher or lower than for their present quality variety, since they do not know the R&D expenditures of their rivals. They can reasonably expect that in the long run, higher quality products will be put on the market by rivals, and will become also less costly than their own product.

16. It means only this and not the imitation of the technology of a given firm.

17. This assumption constitutes an entry barrier to the sector. Without this condition, all markets are open. Each firm can enter any market without any cost. Competition becomes too tough and this decreases quickly the sector profit. It can also favor the emergence of a monopoly in all the economy because it can take more advantage of the scale effect on R&D.

during a number of periods (3 periods in the present setting). If the number of sectors falls to zero, the firm fails and lays off all workers at the end of the period. Investing in quality innovation is mandatory in the innovative and competitive environment of the model. However, since a firm has only one product and quality by sector, it can have only one quality innovation project by sector. Then firms may decide to produce a good in a sector new to them (by imitation or by innovation) or not. To make a decision, they look at their operating margin[18].

Let π_f the operating margin of firm f.

$$\pi_f = \Pi_f / \Omega_f \tag{3.7}$$

where Π_f is the operating margin of firm f, Ω_f its sales.

When looking at this margin, a firm can adopt one of two different strategies : defensive and offensive. Adopting the defensive strategy means that they try to enter a new sector when the operating margin decreases under a critical threshold. Since their operating margin in their existing sector is lower than their competitors' operating margin, they try to find a new opportunity in other sectors. If a defensive firm has a higher operational margin, it does not try to enter a new sector. In the offensive strategy, when the operating margin is higher than a certain threshold, the firm tries to diversify its product portfolio. These two opposite strategies can both find some justification, . Firms in difficulty react to survive, and firms which are successful have resources to try to grow and prepare the future. In the baseline simulation, we assume that each firm has an equal probability (50%) of adopting the offensive or the defensive strategy. It adopts one or the other. Then if a firm has adopted a strategy it acts accordingly. This setting aims to capture the heterogeneity of firms strategies.

If a firm decides to enter a new market, it has to choose between imitation and sector innovation R&D investments. As sector innovation is risky and costly, a firm considers first the choice of imitation. The condition for imitation innovation is the existence of another profitable sector in the economy. We calculate the average operating margin of all sectors different of S_f, called $\pi_{S_{-f}}$.

- If $\exists s \in S_{-f}$ where $\pi_{-f} > \overline{\pi}$, the firm considers this sector as profitable. If many sectors are profitable, the firm chooses the most profitable one. It has one imitation innovation project and no sector innovation project.

- If $\nexists s \in S_{-f}$ where $\pi_{-f} > \overline{\pi}$, it has no imitation innovation project and one sector innovation project.

For the sake of simplicity, we assume that all firms have the same $\overline{\pi}$. Each innovation project lasts at most 3 years. After failing 3 times, the firm abandons the existing project and starts a new one. If there is no profitable sector, it tries to do sector innovation.

To summarize, a firm making S_f products has S_f quality innovation projects. Then it decides to enter or not a new sector If there exists any profitable sector in the economy, it

18. The profit rate may look a more standard criterium. However it is a somewhat narrow view to take it as the indicator of performance. Performance relies mainly on competences and intangible capital.

will try to enter the most profitable one by an imitation investment. Otherwise, it starts one sector innovation project.

Research Budget

Global budget of R&D

First firms determine their global expected R&D budget which is a percentage of total sales of the previous period. Yet they respect a minimum R&D budget envelope in the case of too low sales.

$$B_{It}^{E} = max(b_I \Omega_{t-1}, B_{It}^{min}) \tag{3.8}$$

where B_{It}^{E} is the desired innovation budget at t, b_I a parameter which corresponds to a percentage of global sales, Ω_{t-1} firm's total sales at t-1, B_{It}^{min} the minimum R&D budget. The minimum of global budget depends on the number of innovation projects and the minimum budget of each project.

$$B_{It}^{min} = \sum_{s=1}^{S_f} B_s^{min} \tag{3.9}$$

where B_s^{min} is the minimum budget of the project s. For the sake of simplicity, we assume that B_s^{min} is identical for all firms and all types of innovation project[19]. B_s^{min} is not randomly chosen. Since the R&D budget allows to pay the wages of the research staff, and since we assume that the innovation effort function is a Leontief, we need at least one researcher by category of innovation competence. B_s^{min} is the sum of the average wage and its unemployment contribution in each of the categories of innovation competence.

After setting the desired R&D budget, a firm, if it does not have enough liquidity, tries to be funded by the investment fund and in fine by the households. The households'savings available for buying shares and the investment decision determine the real R&D budget.

As a firm may have several innovation projects, we then allocate the total innovation effort to the different projects as shares of the total real innovation budget, rather than the research staff itself[20].

Budget allocation between innovation projects

If firms have any sector or imitation innovation project, they first allocate the budget to this project and then distribute equally to other quality innovation projects.

19. It may look unrealistic to assume that it is independent of the size of the firm. However the result of the innovation effort depends only on the absolute level effort and not a R&D/sales ratio, so that very low research expenditures are almost useless

20. The other way of labor allocation consists of distributing ex ante researchers in different projects. However, for computational reasons, the size of the research department is relatively small because since researchers occupy only 10% of total employees. There are 10 innovation competences. allocating the research staff into different projects would make it still smaller in each competence class.

- In case of sector innovation :

$$B_{IP} = b^{IP} B^R \text{ where } b^{IP} = 0.2 \tag{3.10}$$

where B_{IP} is the budget for sector innovation, b^{IP} the proportion of total budget allocated to sector innovation (it is assumed to be 20% of the total budget), B^R the real total budget (after decisions of investment fund).

- In case of imitation innovation :

$$B_{II} = b^{II} B^R \text{ where } b^{II} = 0.1 \tag{3.11}$$

where B_{II} is the budget for imitation innovation, b^{II} the proportion of total budget allocated to imitation innovation (it is assumed to be 10% of the total budget).

- For quality innovation projects, the budget is the remaining budget and allocated equally between the projects. For the product s it is :

$$B_s = (1 - b^{IP}) B_I^R / S_f \text{ or } B_s = (1 - b^{II}) B_I^R / S_f \tag{3.12}$$

Innovation Functions

Innovation effort

Let L_I the number of innovation competences. In each firm, we call T_{Il} the total of efficient units supply in task l or, to make short, the innovation effort in l . We use the type of equation that was used in SIMECO 1. However here workers bring their individual contribution :

$$T_{Il} = \sum_{i=1}^{L_{Il}} (x_{Il} X_{il} \tau_{il}) \tag{3.13}$$

where L_{Il} the number of researchers utilising the competence l in the firm , x_{Il} the unit efficiency of the innovation competence l, X_{Iil} the stock level of worker i belonging to L_{Il}, τ_{il} the number of working hours of worker i, normalized to 1, since the time unit is the year.

The total innovation effort function in the R&D department is given by a Leontief function over all the contributions T_{Il} [21].

$$T_I = min[T_{I1}, T_{I2}, ...T_{IL_I}] \tag{3.14}$$

Allocation of innovation effort

- For the sector innovation project, the innovation effort is :

21. Unlike in SIMECO 1, firms can recruit or train to increase the number of researchers in a competence which is a bottleneck. For the sake of symmetry with the production department, we then assume a Leontief rather than a CES.

$$T_{IP} = \frac{B_{IP}}{B_I^R}.T_I \tag{3.15}$$

- For the imitation innovation project, the innovation effort is :

$$T_{II} = \frac{B_{II}}{B_I^R}.T_I \tag{3.16}$$

- For each quality innovation project s, its innovation effort is :

$$T_{Is} = \frac{B_s}{B_I^R}.T_I \tag{3.17}$$

Innovation functions

The innovation functions are similar to the function used in SIMECO 1, with the specification being Bernouilli. The probability of a sector innovation project is given by :

$$Pr_{IP} = 1 - e^{(-\Psi_{IP}T_{Is})/S_t} \tag{3.18}$$

where Ψ_{IP} is the parameter of the sector innovation probability function. The sector innovation probability is an increasing function with its innovation effort and decreasing with the number of sectors in the economy. This latter assumption has similar foundations to the effect of a higher quality in a sector. The number of innovation competences is fixed in the model. The set of existing varieties of competences represents a finite potential for innovation. This is formally expressed in the models which represent innovations as a recombination of existing competences ([Katila, 2002], [Taylor and Greve, 2006]). We adopt a reduced form that considers that in absence of new competences, as new sectors are invented, the future sector innovation potential for one firm declines. This does not mean that in the model the sector innovation rate declines to zero, since the number of firms can increase as the economy grows, and the total number of sector innovations may then increase or decrease[22].

The probability of an imitation innovation project is :

$$Pr_{II} = 1 - e^{(-\Psi_{II}T_{II}/\overline{k_s})} \tag{3.19}$$

where Ψ_{II} is the parameter of the imitation innovation probability function, $\overline{k_s}$ the average quality level of the sector the firm wants to enter. The probability is increasing with innovation effort and decreasing with the average quality. If the average quality is low in

22. Introducing new competences is a more complex matter than it looks, yet feasible in our framework, that we leave for future work. The recombination models do not represent individual researchers and consider that firms have binary levels in a competence, 0 or 1. This cannot be assumed in a model in which workers learn and increase progressively their levels in their competences

a sector, it means that this product was recently created. It will be easier to enter and challenge incumbents.

The probability of a quality innovation project is :

$$Pr_s = 1 - e^{(-\Psi_s T_{Is}/k_s)} \tag{3.20}$$

where Ψ_s is the parameter of the quality innovation probability function, k_s the quality of existing variety s. The function is the same as in SIMECO 1. The probability is increasing with the project's innovation effort T_{Is} and decreasing with its level of quality k_s. This property implies that in long term, it becomes more difficult for a firm to innovate in quality. Since the quality keeps increasing, the firm needs to make more effort to get the same innovation rate.

Innovation outputs

Innovation is stochastic. In the computation, for each innovation project of each firm, we randomly select a number between 0 and 1 according to a rectangular distribution. If it is lower than the innovation probability, the firm succeeds in its project. Otherwise, it fails.

Each innovation project last at most 3 years. After 3 failures, they stop actual project and start a new one. Under 3 years, the innovation effort is accumulated after each failure. If it succeeds, the innovation effort restarts from 0. If this assumption was not made, R&D effort T_I would increase indefinitely and the probability would ten to 1.

Quality innovation results

The success of a quality innovation project gives innovators a higher quality level, with the same specification than in SIMECO 1. At t, we call the quality level of firm k_t. In case of innovation success, its new quality becomes :

$$k_{t+1} = k_t + \Delta k \tag{3.21}$$

with Δk chosen from a Pareto distribution.

$$P(\Delta k > a) = (\frac{a}{2\Delta k})^n \tag{3.22}$$

with n = 1.

We present again the consequences of the specifications since they justify the switch of firms to new products with time. We have made three assumptions for the determination of the increases in quality, embodied in the equations 3.21 and 3.22. First quality change is modeled as an improvement over the present quality, and not the attainment of a certain exogenous quality level (as could be obtained by buying a patent). This improvement view of technological progress is a widely accepted contribution of evolutionary economics since [Nelson and Winter, 1982], and based on path dependence. Second increases in quality are drawn in a distribution of absolute increases, meaning a decrease in relative terms. Third, the Pareto specification (with adequate parameters choice) means that the distribution

makes the probability of high jumps rare. The decline in relative improvements in quality is not an issue for a realistic modeling of a market it which demand can become saturated[23]. The decrease of the return of effort in terms of innovation rate and the decline in the relative improvements in quality are both incentives for firms to switch to the innovation of new products. New sectors have a low initial average quality so that the quality improvements can be high again for a while. Therefore quasi-constant returns to the R&D effort are possible at the aggregate level.

A fundamental assumption of the model, the same as in SIMECO 1, is that a new higher quality leads to a change in the demand of tasks hence production competences. We assume that higher quality requires more complex tasks at the expense of simple ones. This quantity increase of complex tasks is however followed by learning by doing, taking the form of an increase in the workers'competences, and the demand for all workers decreases continuously afterwards. The increase in complex tasks is then not be a permanent phenomenon for a given quality, for a level of output. To complete this summary view, when the innovation takes place, more physical capital is required to produce the good, as assumed in SIMECO 1 (see equation 3.33 below), and this leads first to a capital - complex labor complementarity, and a capital - simple labor substitution, in accord to many econometric studies (see [Vivarelli, 2014] for a survey). Then, later in the life of the quality, new more productive generations of capital are acquired, and the quantity of capital decreases as well as the demand for all types of workers by learning. The question of substitution between capital and the labor types in the course of the life of a quality then depends on the parameters, which can be varied in experiments.

At the moment quality rises, the demand for complex tasks increases, and simple tasks. To remind, tasks are ranked in order of increasing x_{Pl} (the efficiency of the service of a competence unit). A floor $\bar{l}$ is set under which tasks are labelled as simple, and at and over which they are labelled as complex. In the production function, (equation 3.3), the coefficient A_{Pl} of a task determines how many (efficiency) units of each task are necessary to produce one unit of consumption product. Firms need $1/A_{Pl}$ efficient units in task l to produce one unit of product. The change in the value of A_{Pl} leads to a change in demand for the competence l.

For $l^P \leq \bar{l}$,

$$A_{Pl} = A_{01}.e^{u(k,l)} \tag{3.23}$$

with A_{01} the initial coefficient of production for simple tasks. First $u_l(k,l) < 0$, the simpler the task (lower l), the higher the coefficient, and the higher the demand. Second $u_k(k,l) > 0$. When the quality rises, the coefficient increases and demand for this task type decreases.

For $l^P > \bar{l}$

23. Moreover high jumps could favor the emergence of monopolies too easily compared to the real world since consumers decide only on quality and price.

$$A_{Pl} = A_{02}/e^{v(k,l)} \tag{3.24}$$

with A_{02} the initial coefficient for complex tasks. First, $v_l(k,l) > 0$, hence the more complex the task type, the lower is the coefficient and the higher the demand. Second, $v_k(k,l) > 0$. When the quality rises, the more complex the task, the faster the coefficient decreases, and demand increases accordingly[24].

Imitation innovation results

If a firm succeeds an imitation innovation project, it enters this sector. We draw randomly its initial quality level belonging to the 70% lowest existing qualities in the market (like in SIMECO 1) since otherwise there would be the risk that they dominate immediately all the incumbents. Their initial vector of task requirement is :

$$A_{Pl} = A_{0l}/e^{v(k,l)} \tag{3.25}$$

with $v'_k > 0, v"_k > 0, v'_l < 0, v"_l > 0$. Firm's initial quality level determines the demand of each production task.

Sector innovation results

Sector innovation allows to create a new sector which has not existed yet in the economy. First we need to determine its initial characteristics, especially the initial coefficients of production for all production tasks. We assume that all sectors should start by the same quality level k_0, since otherwise, this would affect the consumers preferences over the different products in an arbitrary way. Consumers utility functions have the quality in their arguments.

We call Θ the complexity degree of a new sector. It will determine the initial vector A_{Pl} in the production function. In fact, it represents the initial quantity of each task to produce one unit of product. If A_{Pl} is low, the production requires a high quantity of this task.

Θ determines the initial coefficients of task demand.

$$A_{0l} = A_{0l}(\Theta), A'_{0l}(\Theta) < 0, A''_{0l}(\Theta) > 0, A'_{0l}(l) > 0, A''_{0l}(l) > 0 \tag{3.26}$$

If the new sector is complex, the value of Θ is high. As A_{Pl} is a decreasing function with Θ, A_{Pl} is lower. It means that the production of one unit of product asks for a higher quantity of this task. New sectors requires more simple tasks than complex tasks. Consequently A_{0l} is increasing with l because each unit of final product requires $1/A_{0l}$ units of tasks l.

24. Functions u(k,l) and v(k,l) are adjusted so that $u(k,l) < v(k,l)$. The decrease in simple tasks is weaker than the increase in complex tasks which have a higher unitary cost. Therefore the new quality is more costly to produce

3.2.2.1.3 Price Setting

Firms set the price by adding a mark-up on unit variable cost (or marginal cost), as in SIMECO 1. Since we consider only variable cost, it concerns total wage bill and unemployment contribution per production unit[25].

$$uc_f = [\sum_{l=1}^{L_P}(1+\eta_U)(w_{Pl}T_{Pl})]/Y_f^S \tag{3.27}$$

where uc_f is the unit variable cost of firm f, w_{Pl} unit wage of production task l (which will be defined with the other wage variables below), T_{Pl} the quantity of production task l in efficient units, η_U the unemployment contribution rate, Y_f^S the supply of firm f. The contribution rate is a percentage of total wage bill because it is uniform for all categories of workers.

$$p_f = (1+\mu_f)uc_f \tag{3.28}$$

where μ_f is the mark-up of firm f, p_f the price of firm f. Like in SIMECO 1, we add a mark-up to the unit variable cost to determine price. The mark-up helps to cover fixed costs, especially capital purchase and research expenditures.

$$\mu_f = \mu(N_{LC,s}) \tag{3.29}$$

where $\mu'(N_{LC,s}) < 0$, $\mu_f \geq 0$, N_{LCs} is the degree of local competition in the sector s.

The mark-up depends on local competition of the sector. The local competition is defined as the distance between their quality-adjusted price with their nearest competitors' quality-adjusted price. On the scale of quality-adjusted price, each firm copes with two nearest competitors (one in its right side and another in it left side). If this distance decreases, both firms sell more similar products. Their differentiation decreases and price competition leads to lower the mark-up rate[26].

3.2.2.1.4 Firms' profit

The revenues of the consumption firms come from their sales and interests on their deposits. They use revenues (sales and interest on deposit) to pay different expenditures (wage bill and unemployment contribution in the production department, capital investment, research expenditure, repayment of debt and its interest).

$$\Pi_f = p_f Y_f^R + r_m M_f - (1+\eta_U)[\sum_{l=1}^{L_P}(w_{Pl}T_{Pl}) + \sum_{l=1}^{L_I}(w_{Il}T_{Il})] - I_f^R - B_f^R - \sum_{t\in\beta} D_{tf}/\beta - r_l D_f \tag{3.30}$$

25. For the sake of simplicity, we assume that the operating cost of capital is zero. There exists only acquisition costs of capital.

26. The specification is different from the one in SIMECO 1. There can be less rivals fo a given product, so that taking into account the two nearest competitors is here a better choice than a fixed distance and all the competitors within this distance.

where Π_f is the profit of firm f, $p_f Y_f^R$ its real sale, r_l interest rate on debt, D_f debt stock of firm f, r_m interest rate on deposit, M_f deposit stock of firm f, β the duration of loan and D_{tf} the initial debt amount when the firm started to borrow. If the firm borrows an amount of D_{tf} at t, we assume that the bank sets the same debt duration β to all firms. Each year, it has to repay an amount of D_{0f}/β to bank.

If firms obtain a profit, they use a percentage of their profit to pay a dividend.

$$FD_f = max[0, \rho_f \Pi_f] \tag{3.31}$$

where ρ_f is the dividend rate of firm f, FD_f its dividend flow. We assume that all firms adopt the same dividend rate.

3.2.2.1.5 Capital Investment

Consumption firms determine their production capacity before deciding their investment in physical capital. If their actual production capacity does not allow them to satisfy their future demand, they will buy new capital in order to increase their production capacity.

We assume that each generation of capital good lasts κ periods (in the reference simulation $\kappa = 10$). During its lifetime, the capital productivity remains unchanged. After κ years, it is worn out.

The production capacity of firm f available for production in period t is :

$$Y_{ft}^{PC} = \sum_{T=t-\kappa}^{T=t} (\sigma_{KT} \Delta K_{fT}) \tag{3.32}$$

where Y_{ft}^{PC} is the production capacity of firm f for period t, σ_{Kt} the capital coefficient at t, ΔK_{fT} the number of additional units of capital of period T and still available for production in t (and ordered at the end of year before). Firms may order capital equipment each year. Each period, the new generation of capital has a higher productivity.

$$\sigma_{Kt} = \sigma_{Kt-1}(1 + g_t) \tag{3.33}$$

where g_t is exogenous technical progress of capital factor with time which reflects the advance of science[27]. However, the productivity of capital decreases with the quality level of product $\sigma'_{Kt}(k_{ft}) < 0$, $\sigma''_{Kt}(k_{ft}) > 0$. Without capital technical progress, the demand for capital good would explode in the long term since it is fueled by several factors : replacement for physical wear, the creation of new firms, the appearance of new sectors, by the continuous increase of quality in all sectors of our economy. The size of the capital sector would increase too fast in comparison with the consumption sector and distort the economy.

27. This is done since SIMECO 2 is targeted to focus on product innovation rather than on process innovation, although we endogenise somewhat process innovation in the consumption firms, which depends on the rate of investment.

A firm decides to invest at the end of a period t if the demand exceeds the production capacity during the period. In each period, the generation of capital which was bought κ periods ago will disappear. We recalculate the production capacity of firm at the end of the period :

$$Y_{ft}^{PCs} = \sum_{T=t-\kappa+1}^{T=t} (\sigma_{KT} \Delta K_{fT}) \tag{3.34}$$

Desired supplement in production capacity is a ratio of the gap between demand and capacity, after scrapping worn out capital :

$$\Delta Y_{ft}^{PC} = \zeta_A (Y_{f,t}^{D} - Y_{f,t}^{PCs}) \tag{3.35}$$

where ΔY_{ft}^{PC} the desired supplement of production capacity, ζ_A the adjustment rate of production capacity ($\zeta_A \in [0, 1]$), $Y_{f,t}^{D}$ the demand for firm f product in t. If at t, demand for consumption goods has been higher than production capacity, firms order new capital.

The demand for new investment comes as :

$$\Delta K_{ft}^{E} = [\zeta_A (Y_{f,t}^{D} - Y_{f,t}^{PCs})]/\sigma_{Kt} \tag{3.36}$$

where ΔK_{ft}^{E} is the demand for new capital in units, σ_{Kt} the productivity of one unit of capital new in t.

The value of the demand of capital can be obtained by multiplying the capital demand by the price of each unit of capital.

$$I_{ft}^{E} = p_{Kt} \Delta K_{ft}^{E} \tag{3.37}$$

where p_{Kt} is the price of new unit of capital in t, I_{ft}^{E} the value of the desired capital investment of firm f in t.

This function determines the expected amount of capital investment. However, firms may cope with the budget constraint and not have enough liquidity to finance their desired investment. They then ask external sources - the bank in our model. The decision of the bank determines the realized capital investment.

We assume that new generation of capital substitutes labor factor. For the production of each unit of product, at the same quality level, a firm needs a lower quantity of all production competences. It means that the production coefficient A_{Pl} increases at the same pace for all production tasks. In each period, if a firm receives a new generation of capital, its A_{Pl} will increase at the rate :

$$\alpha_{Kft} = min[\frac{(Y_{ft}^{PC}/\sum \Delta K_{ft}) - (Y_{f,t-1}^{PC}/(\sum \Delta K_{f,t-1})}{Y_{ft,-1}^{PC}/\sum \Delta K_{f,t-1})}; 0.05] \tag{3.38}$$

where $\sum \Delta K_{ft} = \sum_{T=t-\kappa}^{T=t} (\Delta K_{fT})$ is defined as the sum of the capital units of all the generations available for production. The ratio in t is then the average productivity of the stock of capital. In this equation, the increase of production coefficients is proportional to

the increase of the average productivity of the stock of capital between the two periods. As new generations of capital have always a higher productivity, the value is always positive. However We limit the increase to 5%, since it the increase could be too high for new firms, which have very few generations of capital, and a small number of units in each. When they are created, they do not have an initial capital stock $\sum \Delta K_{f,t-1} = 0$. Additionally, if A_{Plt} varies too quickly, price also changes too quickly and the competitive structure is not stable.

The new production coefficients are :

$$A_{Plt} = A_{Pl,t-1}(1 + \alpha_{Kft}) \tag{3.39}$$

3.2.2.1.6 Firms finance

At the end of each period, firms set aside an amount of their liquidity for wage advances because in the sequence of events, they pay the wages and the unemployment contribution before receiving sales[28]. If they do not have enough liquidity to pay the wages, they ask two external finance : bank and investment fund. Each of them takes its decision and it determines firms' realized budget. [Myers and Majluf, 1984] presented a pecking order theory of finance : in the presence of imperfect capital market such as information asymmetries, the cost of external finance is usually high. Consequently firms resort to external financing when internal funding possibilities have been completely exhausted. However, for precautionary reasons ([Fazzari et al., 1988], [Caiani et al., 2016], firms will not arrive to the point of exhausting their internal resources and desire to hold a certain amount of deposits, expressed as a share of the total wage bill.

We consider three financial operations : wage advance, capital investment and research expenditure. The first operation is the most important. If a firm does not have enough liquidity for this operation and the bank refuses a loan, it will go bankrupt immediately since a negative liquidity is excluded in order to respect the SFC principles[29]. If the firm cannot pay the employees, we prefer to close it immediately as a precaution. For wage advance, firms ask the bank. If it accepts a loan, the firm continues. If it refuses, the firm fails immediately.

If firms' residual profit (after setting aside for wage advance) is positive, they will decide to invest in capital and research activities. We assume that firms ask the bank for capital investment and investment fund for research investment. This distinction is based on the ability to recover a loan. As bank does not want to take risks, it always chooses a safer

28. This is a necessity in a SFC model. Sales cannot take place if workers have not been paid

29. Individuals cannot have a negative or zero liquidity in our model because by assumption, they cannot borrow. However they can receive unemployment benefits as long as they have not been fired. a Firms may choose to fire employees. However this operation requires a notice period of one year in the model. Although the notice period is in France less than a year, our elementary period, the delay before a worker can receive the unemployment benefits here contains also the delay between the day the firm has made the lay off decision for economic motive, and the day it can legally lay off, and this can easily exceed a year

way. It accepts to finance capital investment because if firms cannot pay, it can seize their capital stock and resells on the second hand market. This sale allows to recover some of their debt amount. As for the investment fund, it accepts to take more risk and finance research investment even if it does not have a counterpart. Its revenues come from future flows of dividend. As innovations lead usually to higher profit and consequently higher dividend, the investment fund accepts to take this risk. Firms will issue capital shares which will be bought by investment fund and for this reason, it becomes their owner (for the sake of households).

To conclude, firms have three sources of financing : self-financing, bank and investment fund. We call IC_t the self-financing capacity of one firm at t. It depends on its residual profit at the end of the period, after removing an amount for precautionary deposits and wage advance. B_I^E is its expected innovation budget and I^E its expected capital investment budget.

$$\text{If } B_I^E + I^E \leq IC_t, B_I^R = B_I^E \text{ and } I^E = I^R.$$

If the self-financing capacity of a firm is higher than the total amount of investment, the real innovation budget and real capital investment budget correspond respectively to their expected budgets.

If $B_I^E + I^E > IC_t$, the firm first allocates its own funds by a proportional rationing of the two investments. Then it asks the external sources. Since each source has an independent decision, the bank may accept but the investment fund may refuse or inversely. We assume that the answer of each institution is 0 or the amount demanded. Then :

We call φ the self-financing rate of firm.

$$\varphi = \frac{IC_t}{(B_I^E + I^E)} \tag{3.40}$$

If $\varphi \geq 1$, the firm has enough liquidity to finance its investment. If $\varphi < 1$, the firm needs to find from external sources an amount of $(1-\varphi)(B_{If}^E + I_f^E)$. It asks the bank for the amount of $(1-\varphi)I_f^E$ and the investment fund the amount of $(1-\varphi)B_{If}^E$.

If the bank and the investment fund accept, $I^R = I^E$ and $B_I^R = B_I^E$. If both refuses, $I^R = \varphi I^E$ and $B_I^R = \varphi B_I^E$. If one accepts and the other refuses, we do not want a strong disequilibrium between two types of investment, especially if the investment fund refuses, firms can fail if they cannot advance wage to their researchers. In this case, they will change their initial internal source allocated to each investment to obtain a parallel rationing.

3.2.2.2 Capital Firm Behavior

The capital firm sells capital goods to consumption firms. It uses only the labor factor in its production function. We call L_K the number of competences to produce the capital good.

Its production function is :

$$Y_K = min[A_{K1}T_{K1}, ..., A_{Kl}T_{Kl}, ..., A_{KL_K}T_{KL_K}] \tag{3.41}$$

where A_{Kl} are the fixed coefficients of labor in capital production for each task l, T_{Kl} the total of efficient units supply in the task l of the capital production function.

$$T_{Kl} = \sum_{i=1}^{L_{Kl}} (x_{Kl}X_{il}\tau_{il}) \tag{3.42}$$

where L_{Kl} the number of workers in the capital firm owning the competence l of production, x_{Kl} the unit efficiency of the capital production competence l, X_{Iil} the stock level of worker i belonging to L_{Pl}, τ_{il} the number of working hours of worker i. The stock of competence increases by learning effect and the productivity increases (paragraph 3.2.2.4.2). For the sake of simplicity, we assume that the set of production competences is identical for the consumption sector and capital sector. Each competence class has the same unit efficiency ($x_{Kl} = x_{Pl}$).

In order to set up the price, we first determine the unit variable cost of capital.

$$uc_K = [\sum_{l=1}^{L_K} (w_{Kl}T_{Kl}) + \eta_U \sum_{l=1}^{L_K} (w_{Kl}T_{Kl})]/Y_K \tag{3.43}$$

where uc_K is the unit variable cost of capital, w_{Kl} the unit wage of task l, η_U the contribution rate.Then we add a mark-up :

$$p_K = (1 + \mu_K)uc_K \tag{3.44}$$

where p_K is the price of one unit of capital, μ_K the mark-up of capital firm. Contrary to the consumption sector, the capital firm does not have competitors. This monopoly situation can lead to a constant increase of mark-up. We assume that capital firm is a regulated one. It can increase its mark-up but cannot excess a ceiling threshold.

Capital firm has a fixed mark-up over the model. When its profit is negative, it will increase its mark-up next period by n% but always under the ceiling threshold. When its debt level downs to 0, it returns to its fixed long-term level. When $\Pi_{Kt} < 0$:

$$\mu_{K,t+1} = min[\mu_{K,t}(1 + n), \overline{\mu_K}] \tag{3.45}$$

The profit of the capital firm is :

$$\Pi_K = p_K Y_K^R + r_m M_K - (1 + \eta_U) \sum_{l=1}^{L_K} (w_{Kl}T_{Kl}) - r_l D_K - \sum_{t \in \beta} D_K/\beta \tag{3.46}$$

where Π_K is the profit of capital firm, Y_K^R number of sold capital units, r_l interest on debt, D_K debt stock of capital firm, r_m interest on deposit, M_K deposit of capital firm, D_K/β debt repayment.

Dividends are computed as a constant share ρ_K of firm's profit :

$$FD_K = max[0, \rho_K \Pi_K] \tag{3.47}$$

where FD_K is the dividend paid by capital firm, ρ_K dividend rate of capital firm[30], Π_K the profit of the capital firm.

At the end of each period, the capital firm sets aside an amount of liquidity for precautionary reason (a percentage of its total wage bill) and for wage advance next period. If it does not have enough liquidity, it can borrow from bank. For the sake of simplicity, we assume that bank always accepts because there exists only one capital firm in our model.[31]

3.2.2.3 Task Allocation And Wage Setting

3.2.2.3.1 Supply and demand of competences

Firms hire individuals in order to realize innovation (only consumption firms) and production tasks. Each individual owns a competences portfolio and may can realize different tasks according to their corresponding competences. We remind that each task requires only one competence. As exposed, even if individuals hold many competences, in each period, they look for a job only in one labor market. They choose the competence market where they expect to get the highest wage among other competences market. Firms express their demand in terms of efficient units in each competence and individuals supply different units. We have described the labor market, but not wage setting by firms.

3.2.2.3.2 Wage concepts

We need several concepts to measure wages. First we define the concept of *wage by efficiency unit of task* which corresponds to the efficiency units in the innovation effort or the production function. Second we define the *individual wage* which is the wage paid for a worker (which differs from the total compensation received since the premium corresponding to profit sharing is not included) . Third we need an intermediate concept which is the *competence wage*, which is the wage by unit of competence, and this is the wage posted by the employer on the labor market. Fourth *competence reservation wages*, and, fifth, *individual reservation wages* are derived from the formers and presented.

Task wage

In initialization, the *wage by efficiency unit of task*, or, to make short thereafter*task wage*, is determined on a single basis for all types of tasks and competences. w_{10}, the task wage at time 0, is paid for one unit of task 1. It is the anchor of the wage setting and the hierarchy of individual wages. It is determined so as to ensure the minimum wage for

30. We assume this rate constant over the model and identical to the rate of consumption firms.

31. If it goes bankrupt, both capital sector and consumption sector will disappear in our model. As capital firm is a regulated one, it is guaranteed by the Government and for this reason, bank always accepts.

an 18 years old worker working full time, and entering the labor market, hence having no experience (see the Initialization section below).

The task wage after t=0 may become specific to each firm, and is accordingly indexed in the task class, the firm number, and time, hence w_{lft}. This divergence takes place because we make the fundamental assumption that for any l. The evolution of the task wage depends on a firm's excess demand of efficiency units in this task and the corresponding competence.

Individual wage

A Worker is paid according to the number of efficient units of tasks he brings. His wage level is :

$$W_{ilt} = w_{lft} V_{ilt} = w_{lft} x_l X_{ilt} \tau_i \tag{3.48}$$

where W_{ilt} is the wage level of individual i in task l at t, w_{lft} the task wage of firm f in task l at t, V_{ilt} the number of efficient units provided by individual i. It is however more instructive to develop V_{ilt} in its components of equation 3.5.

Workers' individual wage level within a competence class then differ according to their competence stock level and time worked. Workers' individual wages differ between competence classes because the number of efficiency units that a competence unit brings differ according to the hierarchy of the x_l, which are fixed.

$$x_l / x_{l-1} = (1 + a_l) \text{ for } l \in L_P \tag{3.49}$$

It is assumed that productivity per unit of task is increasing convex in l, as in SIMECO 1. Then a_l is the efficiency ratio between two consecutive classes and a_l is positive and increasing in l. $a_l > 0$, $a'(l) > 0$. These parameters and x_1 are set in the Initialization section. The individual wages are therefore increasing convex in l, for a given competence stock X_{it}. This convexity has some empirical validation when looking at the hierarchy of wages within a firm [Lemieux, 2006] [32]. It can be explained in various ways, including a hierarchical production function ([Rosen, 1982]), where the higher the number of operators at the bottom of the hierarchy, hence the higher the individual is in the hierarchy, the higher the effect of his talent (efficiency) on the firm's total productivity. We have assumed that each worker can use only one competence l to do one task l even if he owns different competences. In the following, he may do another task which requires a competence different to l.

Competence wage

The *competence wage* is an intermediate concept between the concepts of task wage and individual wage. If an worker has a competence stock level X_{ilt}, his wage by unit of

32. Convexity is a useful assumption for quality increase to increase the cost of production ([Shaked and Sutton, 1982]). However, since complex labor replaces simple labor, the quantity of labor could decrease, and if the higher price of the complex labor does not compensate, the labor cost per unit of product may decrease. In that case the firm which innovates in quality may take the whole market.

competence, to make short, *competence wage* w^C_{ift}, is the individual wage divided by the number of competence units :

$$w^C_{ift} = (w_{lft} x_l X_{ilt} \tau_i)/(X_{ilt} \tau_i) = w_{lft} x_l \tag{3.50}$$

We need such a concept for two purposes. First it determines the competence wage that firms post on the market, since the firm pays for each unit of competence, and not a fixed wage for a job. Second it is the base of the worker's reservation wage per competence unit on the labor market, since demand and supply must be measured with the same concept of wage to allow for a matching. However a worker can apply to work in different competence classes, and the choice must be modelled.

Individuals' competence portfolio

For an individual, we name his competence portfolio s_i. We have assume that each individual owns three adjacent competences at entry in the labor market, such as $[C_1, C_2, C_3]$, $[C_2, C_3, C_4]$, ..., $[C_{28}, C_{29}, C_{30}]$. This assumption is based on two reasons :

(i) The difference between two consecutive competences is weak and their corresponding tasks share some degree of similarity. It avoids the situation that an individual is able to realize two very different tasks in terms of productivity, such as security and chief executive tasks. In th real world, one of these competences is unlikely to have been acquired since the expected wage is too low compared to the other one.

(ii) Since the difference in productivity between two consecutive competences is low, so is the difference between two competence wages. It gives the possibility for individuals to change their competence market during their lifetime.

However, the competence portfolio of an individual can evolve with time if he is trained by firms and acquires new competences (see below for the training algorithm).

Competence reservation wage

The reservation wage per competence unit of an unemployed individual in class l, or to make short, his *Competence reservation wage* is, at the time T of entry in unemployment, his last competence wage :

$$w^{CR}_{ilT} = w_{lfT} x_{ilT} \tag{3.51}$$

It is assumed that the competence reservation wage decreases with seniority of unemployment due to their information that after two years, they will loose the unemployment benefits for the minimum allowance which is lower. It only drops in the class in which he is looking for a job.

$$w^{CR}_{ilt} = max[w^{CR}_{ilT}.g(t-T); smic^C_t] \tag{3.52}$$

where (t-T) is the seniority of the dismissal, g(t-T) a logistics function which takes the

value 1 when L=0 and then makes the wage decrease to about 80% of the previous wage[33]. However, the competence reservation wage cannot fall below to $smic_t^C$. This competence minimum is such that the lowest competence level worker with the lowest endowment of 5 units obtains the minimum wage. Even if he never held a job in these competences, we set an initial competence reservation wage based on the $smic_t^C$ and his stock in this competence.

An unemployed worker has as many *reservation wages per competence unit* as he has competences. However he is only a candidate in the class where he has the highest *individual reservation wage*. An *individual reservation wage* is obtained by the multiplication of the reservation competence wage and the number of competence units. Let w_{it}^R be his individual reservation wage.

$$w_{it}^R = Max_{l \in s(i)}[w_{ilt}^{CR} X_{ilt}] \tag{3.53}$$

He chooses the competence class l which gives the maximum value for w_{it}^R. The competence class in which he is searching may therefore change, even if the level accumulated in the last competence exercised leads to a lot of inertia[34].

3.2.2.3.3 Recruitment and assignment process

The market is composed of L segments, where $L = L_P + L_I$. On a segment (or competence class), each firm requires a number of task units if necessary. Demand of firm f for each competence class is :

$$L_{lft}^D = Y_{lt}^D / A_{lt} \tag{3.54}$$

Its supply for each competence class :

$$L_{lft}^S = \sum_{i=1}^{L_{Pl}} x_{Pl} X_{Pl} \tau_{il} \tag{3.55}$$

where L_{Pl} is the number of employees in the firm doing task l.

Demand excess for each competence class of firm f at period t :

$$ED_{flt} = L_{lft}^D - L_{lft}^S \tag{3.56}$$

For a competence, when demand exceeds supply, firms have many options in order to increase their supply of efficient units. This variety, which exists in the real world, is necessary in the model since workers have task specific competences and the production

33. Several studies show a decrease in the reservation wage in France and elsewhere. For France, see [Pouget et al., 2010], although some other studies indicate that such a decrease does not appear [Addison et al., 2009].

34. [Gathmann and Schönberg, 2010] show that a laid off worker, if he does not find a job in his occupation class, will accept a job in an occupation class which is close, and obtain a wage which falls according to the distance to the former task class. The two facts are modeled here.

function is Leontief. These mechanisms follow the following order of priority : i) extra hours ; ii) reclassification ; iii) promotion or downgrading of overstaffed tasks ; iv) hiring ; v) promotion of non overstaffed tasks ; vi) training and promoting. This order corresponds to a presumed increasing cost for the firm. i)Extra hours can be implemented quickly, and in the model are paid at the same rate[35].ii) reclassification may take more time. iii)Promotion or downgrading of overstaffed has only the possible cost of paying a wage which can be higher than the normal wage paid in the job when the employee is downgraded.iv) hiring is an uncertain process if the market is under tension. v) Promotion of non overstaff may yield a chain of promotion of workers who will have a low competence level in their new job. vi) training to promote an employee in the job has a double cost : training, and having to fill the job of the promoted worker.

We describe the algorithm of task assignment and recruitment process in the production department of consumption firms. We use the same algorithm with the innovation department and capital firm. To assign production tasks, we start by assigning the most complex tasks. L_P is the number of production tasks. We start with the most complex task l = L_P. Let L_{lf} be the number of individuals in the firm f with the corresponding L_P competence to do the L_P task. As everyone has a different level of competence stock X_{il}, we start by assigning to the best individual. If its supply of efficiency units is less than the firm's demand for efficiency units, the task continues to be assigned to the second best performing individual. And we continue until all the efficiency units of this task are completed. The last individual may not work full time but receives the same wage per efficient unit as his colleagues performing the same task.

i) Extra hours

If firms lack a number of efficient units in a competence l, they ask existing workers in task l to do extra hours. For legal reason in France, the number of extra hours cannot exceed 20% of legal working hours. In the computation, we choose randomly one worker among firms' workers in task l to do extra hours. We recalculate the excess demand in this competence until firms do not have anymore excess demand (equations 3.55 and 3.56). If all workers in task l should do extra hours but the excess demand in l is still positive, firms move on to the second possibility.

ii) Reclassification

If firms are multi-sector, for a competence l, they can have a excess demand in one product department but supply excess in another product department. In this case, they will transfer workers between product departments and we assume no other extra costs. Workers continue to do the same task and receive the same wage level as before. We recalculate firms competence supply and demand excess (equations 3.55 and 3.56).

iii) Promotion or downgrading of overstaffed tasks

An individual holds several competences. We look at promotion first. If firms have a excess demand in competence l, they may look among their workers realizing task (l-1) if

35. In France they are normally paid at a supplementary rate. However there are exceptions, since there is no choice by the employees to model, we have made this simplifying assumption.

they have competence l in their portfolio. If it does and under the condition that there exists an excess supply in competence (l-1), they will promote this worker to do higher task. Workers may have a lower stock level in competence l. If the individual wage in new task l is lower than their previous individual wage in l-1, firms will compensate for the difference.

$$W_{ilt} = Max[w_{l-1,f,t-1}x_{l,t-1}X_{i,l-1,t-1}\tau_{i,l-1,t-1}; w_{lft}x_{lt}X_{ilt}\tau_{ilt}] \text{ where } \tau_{ilt} = 1 \tag{3.57}$$

If many workers in class (l-1) are in this case, firms will choose randomly one worker to do task l until excess demand in l disappears or excess supply in (l-1) is not anymore met. Second, we use the same mechanism with downgrading when an individual realizing task l has to do a new task l-1. As with promotion, firms will compensate the difference in individual wage if the new wage level is lower.

$$W_{ilt} = Max[w_{l-1,f,t}x_{l-1,t}X_{i,l-1,t}\tau_{i,t}; w_{lf,t-1}x_{l,t-1}X_{il,t-1}\tau_{i,t-1}] \text{ where } \tau_{it} = 1 \tag{3.58}$$

Steps 1 to 3 are iterated on all l classes and all firms.

We recalculate firms competence supply and demand excess (equations 3.55 and 3.56). If firms still have demand excess at least in one competence class, they move to the next solution.

iv) Hiring

For $\tau_i = 1$, the firm offers a competence wage :

$$w^C_{lft} = w_{lft}x_l \tag{3.59}$$

In the segment l, the firm contacts the unemployed at random, and recruits the first unemployed person who has a competence reservation wage lower than the competence wage offered (equations 3.50 and 3.51) :

$$w^{CR}_{ilt} \leq w_{lft}.x_l \tag{3.60}$$

This worker individual when hired brings $V_{ilt} = \tau_{it}x_lX_{ilt}$ and will be paid according to equation 3.48. We recalculate firms competence supply and demand excess (equations 3.55 and 3.56).

Small steps algorithm

The firm 1 has an excess demand in a competence class l. It starts recruiting in the class l where the need is proportionately the most important since the production function is a Leontief, and the excess demand blocks. It recruits one worker in this class if it can. It then recalculates the production enabled by the recruitment, and its new excess demands on all the V_{lft}. It then recruits in the class where he need is now the most important. This process goes on until the firm has recruited on e worker in each class it wanted to, but

it cannot pursue to start again recruiting in a class in which he has recruited before all other firms have a chance. So this is only a first round for firm 1. Then comes the turn of firm 2, which does the same process. When all firms have recruited one worker (or tried to), the complete process is repeated. This is done until recruitment is no longer desired or possible, due to the lack of applicants. Since hiring can only be sequential, this algorithm restricts severely the extent to which the first firms to recruit have an advantage over the rivals on the labor market, a bias the competition .

v) Promotion of non overstaffed tasks

The firm has not succeeded in hiring in class l. It wants to promote a worker from class (l-1). However, there is, unlike in iii) no excess supply in task (l-1). A promotion will increase excess demand in (l-1). The employer will then need to promote a worker from task (l-2) to do the task (l-1) and so on. we assume that the firm decides to fill the job in l by a promotion only if at most the two inferior classes (l-2) and (l-3) are in excess demand. If (l-4) is in excess demand, it does use this solution. We recalculate firms competence supply and demand excess (equations 3.55 and 3.56).

vi) Training

Training is a last solution to fill a job : it requires to promote a worker in class (l-1) who does not have the competence l in his portfolio and train him in that competence. It has a cost. The training costs function is :

$$CF_l = f(l) + CF[(l - max(l_i))^2] \tag{3.61}$$

where CF_l is the training cost to acquire a new competence l[36], $\max(l_i)$ the highest competence among the competences in a worker i's portfolio.

The training cost depends on the competence that firm wants to acquire f(l). $f'(l) > 0, f''(l) > 0$. The more complex the competence to be acquired, the higher its acquisition cost. It also depends on the difference between the competence l to be acquired and the highest competence possessed by this employee. The worker will acquire an initial stock level in the new competence X_{il} which is the average national level in this competence. His wage is the max of this wage and his preceding wage.

3.2.2.4 Competence development and dynamics of wages

3.2.2.4.1 Competence development

At the end of the period, only workers have learned and improved its competence stock. The others (unemployed) keep the same competence level. A worker's competence stock increases with the quantity of task performed in the previous period.

$$X_{ilT} = X_{il,T-1}[1 + [\chi(\sum_{t=1}^{t=T} \tau_{ilt}) - \chi(\sum_{t=1}^{t=T-1} \tau_{ilt})]] \tag{3.62}$$

36. We assume the same training cost function to all firms.

where X_{ilT} is the competence stock level of individual i in competence l at T, χ the learning function, $\chi' > 0, \chi'' < 0$. It is increasing and concave in the cumulative quantity of task l performed by the worker since he has entered the competence class in the firm. For an individual, $\tau_{ilt} = 1$ or 1.2 if he has performed the task l in t and $\tau_{ilt} = 0$ otherwise. When an individual changes firm and starts to work in a new firm, the level reached before is kept in accordance tot he concept of task based competence but the experience starts again at 0 ($\tau_{il,t-1} = 0$), since the new environment is likely to stimulate the accumulation of experience again.

3.2.2.4.2 Dynamics of wages

a/ wages at initialisation

In initialization, all firms in all sectors have the same wage per efficient unit. We will describe the wage distribution according to age, competence type and competence level in the section of initialization description. As we know the minimum wage in France in 1996, we consider that it is paid to a 18-year-old individual having the lowest production/innovation competence. Since we know his wage level and the number of efficient units we have attributed to him in order to set an appropriate scale, we calculate his wage per efficient unit and use the same for all firms and all competences. Other age or competence classes have different nominal wage level set by equation 3.48, but they all have the same wage per efficient unit. Their difference is explained by difference in competence stock level X_{il} and in competence unit efficiency x_l.

b/ Dynamics of wage

We have four assumptions :

-i) The minimum wage is totally indexed to the CPI (consumer price index) once a year.

- ii)We consider that the task wage in each firm (or wage per efficient unit) is partially indexed on the increase in Smic, as the result of negotiation which takes place once a year (required by the law Auroux in France).

-iii) Firms increase their wage if they have difficulties in hiring in a class of competence. More precisely the wage depends on firms' excess demand in a competence class. It explains an evolving and possibly increasing wage heterogeneity between competences and between firms with time.

- iv)The nominal wage cannot decrease (an accepted fact in France even if recent changes in Labor Law allow for decreases corresponding to the same pay for more hours).

If the excess demand remaining when the firm has finalized its labor force adjustment for production during the period is positive or zero :

$$\frac{\Delta w_{lft}}{w_{lft}} = \xi \frac{\Delta Smic_{t-1}}{Smic_{t-1}} + (1-\xi) g(max[Ł_{fl}^D - L_{fl}^S]; 0]) \tag{3.63}$$

where $\frac{\Delta w_{lft}}{w_{lft}}$ is the rate of increase of the task wage in competence l at t, $\frac{\Delta Smic_{t-1}}{Smic_{t-1}}$ is the rate of increase of Smic at t-1, ξ the parameter of wage sensitivity to the Smic, $L_{flt}^D - L_{flt}^S$

the difference between supply and demand (in efficient units) of firm f in task l at t . $g(0) = 1, g' > 0, g'' > 0$. $g(\infty) = g^{sup}$ is the maximum rate of increase of the task wage[37][38].

In each period, firms pays a premium to their workers if they make profit. We assume that dedicate a fixed and identical percentage of their profit for this purpose. Each worker obtains an amount of premium based on the contribution of its efficient units over the total of the firm's effective units.

3.2.2.5 Bank Behavior

The commercial bank finances capital investment of consumption firms and wage advance of all firms. It uses deposit of all agents to grant loans to firms. When it was created in initialization, it issues capital shares which were bought by the investment fund and for this reason the fund becomes its perpetual owner. If it gets some profit, it pays dividend to the fund (hence households who own the fund).

For the security reason, the commercial bank cannot use too much liquidity of agents. If the commercial bank lacks of liquidity, its will ask the Central Bank. In this case, it will issue new bonds which are bought by Central Bank in exchange of liquidity. By this way, Central Bank can inject liquidity to the economy.

When the commercial bank makes a decision of granting loan to a consumption firm, it will consider its ability to repay debt. And for this evaluation, it needs some firm's indicator like its debt ratio (on sale), its outstanding loan and its profit rate.

The profit function of bank :

$$\Pi_B = r_l(D_C + D_K) - r_m(M_H + M_C + M_K + M_{UF} + M_{IF} + M_G) \tag{3.64}$$

where Π_B is the bank's profit, r_l the interest rate on loans, D_C the loans of consumption firms, D_K the loans of the capital firm, r_m the interest rate of deposits, M_H the deposits of individuals, M_C the deposits of consumption firms, M_K the deposits of the capital firm, M_{UF} the deposits of the unemployment fund, M_{IF} the deposit of the investment fund, M_G the deposit of government.

The bank pays a dividend to the investment fund (transmitted to the households) :

$$FD_B = max[0; \rho_B \Pi_B] \tag{3.65}$$

where FD_B the dividend paid by the bank, ρ_B the dividend rate of bank, Π_B its profit.

37. We set it at 1.2.

38. Task excess demand is not necessarily cyclical, since supply may not respond. For instance, if technical change bias leads continuously to increase in demand of complex task while the education and training system cannot adjust immediately, excess demand in these tasks becomes more and more serious and that explains the increase in wage inequality.

3.2.2.6 Unemployment Fund Behavior

It plays the role of collecting the unemployment contribution of firms and then redistributes it to the unemployed. First, it has to set the contribution rate according to its revenues and expenditures.

The total wage bill of firm f :

$$WB_f = (\sum_{l=1}^{L_P} \sum_{i=1}^{L_{Pl}} W_{il}) + (\sum_{l=1}^{L_I} \sum_{i=1}^{L_{Il}} W_{il}) \tag{3.66}$$

where L_{Pl} and L_{Il} are the number of employees doing the production task l and the innovation task l in the firm.

The unemployment contribution paid by one firm comes as :

$$UB_f = \eta_U WB_f \tag{3.67}$$

$$UB_F = \sum_{f=1}^{\Phi_C+\Phi_K} UB_f \tag{3.68}$$

where UBf and UB_F are respectively the unemployment contribution paid by each firm and the all firms (including the capital firm), $\Phi_C + \Phi_K$ the number of firms and η_U the contribution rate.

Each unemployed receives an unemployment benefit which corresponds to a percentage of his most recent wage. If an individual is unemployed since T years, his unemployment benefit depends on his wage before being fired t-T years ago.

$$UB_{i,t} = \eta_W W_{i,t-T} \tag{3.69}$$

where $UB_{i,t}$ is unemployment benefit of individual i, η_W the replacement rate (set at 0.7 as in France), $W_{i,t-T}$ his most recent wage.

The total unemployment benefit paid by unemployment fund comes as :

$$UB_H = \sum_{i=1}^{N_U} (UB_i) \tag{3.70}$$

where UB_H is the total unemployment benefit, N_U the number of unemployed concerned by the unemployment fund (if one unemployed's unemployment period is higher than two years, he will receive the minimum allowance from the government). The contribution rate is set by the unemployment fund in order to balance expected revenues and expected expenses. Its anticipations are static. Its financial needs are the difference between the expenses last year and its liquidity level. The contribution rate is set as :

$$\eta_{Ut} = \frac{UB_{H,t-1} - M_U}{WB_{t-1}} \tag{3.71}$$

Its profit function :

$$\Pi_U = UB_F - UB_H + r_m M_U \tag{3.72}$$

where M_U is its deposit.

At the end of the previous period while the total number of unemployed and payment of benefits take place at the present period, there may exist a difference between revenues and payment. In this case, the government will finance the deficit.

3.2.2.7 Investment Fund Behavior

The investment fund is owned by households. For the sake of simplicity, we assume that only the 10% wealthiest individuals can buy its capital shares. The fund buys capital shares issued by firms and becomes their owner. In each period, its revenues come from dividends paid by firms and bank.

$$FD_{IF} = FD_C + FD_K + FD_B \tag{3.73}$$

where FD_{IF} is total dividends received by investment fund, FD_C dividends paid by consumption firms, FD_K by capital firm and FD_B by the bank. In case of bankruptcy of one firm, it has an impact on households' wealth though a decrease of their shares in the investment fund. Consequently it will not appear in the transaction flows matrix but in the balance-sheet (variation of capital shares stock).

The Investment fund then transfers the dividends to individuals.

$$FD_H = \rho_{IF} FD_{IF} \tag{3.74}$$

where FD_H the amount of dividends received by individuals, ρ_{IF} dividend rate of investment fund.

FD_H determines the total amount of dividends paid to individuals. The Investment fund has to allocate this global budget to each shareholder according to its parts in investment fund's capital share stocks. To remind, each capital share is considered as having a fixed normalized price of 1 euro.

For instance, if the capital share stock of investment fund is 10000 euros (or units) and an individual i owns 1000 units, he will receive 10% of FD_H. In next period, if investment fund issues 1000 new parts and i buys 50 units, his proportion becomes 1050 / 11000 = 9.5%. If some individuals want to sell their capital share stock, other shareholders buy first these shares rather than buy new shares of the investment fund.

For investment decisions, the investment fund uses its liquidity to buy capital shares issued by firms and bank.

We call ϕ_{C_t} the number of consumption firms at t. The capital shares supply of incumbents is :

$$E_t^S = \sum_{f=1}^{\phi_C} (1 - \varphi_f) B_{ft}^E + \Delta E_{Bt} \tag{3.75}$$

where E_t^S is total capital shares supply at t, ΔE_{Bt} bank's capital shares supply.

The demand of capital shares is the investment fund's liquidity stock at the end of t-1.

$$E_t^D = M_{IF,t-1} \tag{3.76}$$

where E_t^D is total capital shares demand.

However the investment fund will not invest in all firms. To make a decision, it establishes some criteria. In fact, it finances at the same time research activities of existing firms and creation of new firms. For the sake of simplicity, we assume that it gives priority to existing firms because it is does not want to see them fail, and loose its shares. First they want more to increase value of incumbents by investing in innovation than to take risk of creating new firms. Investment in innovation helps to increase firms' profit though higher quality product and new highly potential products. Quality innovation ameliorate the quality price ratio of firm while sector or imitation innovations allow to enter new sectors with high potential of growth. Investment fund will look at firms' return rate of invested capital and their innovation activities (their last period of innovation, their quality level comparing to competitors). This determines total capital shares supply E_t^R.

If $E_t^R > E_t^D$, the supply of capital shares is higher than their demand by the fund, some firms cannot be financed. For incumbents, we use proportional rationing rules. Otherwise, all firms can get their financing.

If the investment fund still has liquidity after investing in existing firms, it may try to create new firms. We use sectors' average profit rate as criteria. It first looks at the average profit rate of existing sectors. If there exists any very profitable sector, the fund will create firms in this sector. We assume that it creates at most one firm by sector by period[39]. If there are multiple profitable sectors while investment fund' investment ability is low, it will give priority to the most profitable ones.

The variation of liquidity stock of investment fund comes as :

$$\Delta M_{IF} = FD_C + FD_K + FD_B - FD_H + \sum_{i=1}^{\phi_H}(S_C) - E^R \tag{3.77}$$

3.2.2.8 Individuals Behavior

3.2.2.8.1 Saving and consumption

Let NI_{it}^A be the total after-tax income of an individual i at t. We call M_{it}^B its deposits level before receiving the wage, M_{it}^A its deposits after receipt of wage, minimum allowance, unemployment benefit, dividends, interests... which constitute W_{it} and therefore after payment of income tax. [Deaton Angus, 1991] defines M_{it}^B as "cash on hand". This is obtained by :

$$M_{it}^B = M_{it}^A + W_{it} \tag{3.78}$$

39. It may seem low but for instance, over 30 periods, it can create 30 firms - a very high number compared to the number of firms in the initializations (20).

This is the maximum consumption. Households take their saving decisions, and this determines the desired consumption budget. They have two kinds of voluntary savings.

A novel savings specification : accumulation saving based on ranking

First they have an accumulation motive, which in the absence of a retirement period, is essentially a bequest motive. This bequest motive is justified by the introduction of inheritance in the model, in order not to have a disappearance of wealth when individuals die, in a SFC model. second, it contributes to the inequality in incomes, although we will not develop in more detail than some homogamic matching, since we do not model the allocation of individuals in hoseholds. . The accumulated wealth will be transmitted to their heir as they retire and die. For an individual household, the accumulation savings rate, is increasing positively in the absolute level of income. Econometric studies show that the saving rate is strongly increasing in the income level in cross section[40]. However introducing in a growth model such a function with savings ratio increasing in income, means that as the real incomes levels rise at the aggregate level, the aggregate saving rate rises continuously. This would have obvious long run consequences. Moreover, the statistics do not show a fall of the aggregate saving rate, but fluctuations. This is the case in France and some other OECD countries [Berger and Daubaire, 2003]. It is then necessary to take into account this stylised fact. Our novel specification considers that the saving rate depends on the rank of the household on the income scale in the period concerned, $s_a(Ra_i)$, and it is increasing in the rank. This ensures a stable aggregate saving rate in the long run. It also models the social aspects of the consumption determinants ([Duesenberry, 1949]) : if my neighbour in income level has an increase in income of 10%, and I have the same increase, my rank does not change and I do not increase my saving rate and decrease my consumption rate as I would have if I had been the only one to obtain such an increase in income. My neighbor does the same. The aggregate saving rate stays stable.

Precautionary motive for saving

Second, households have a precautionary saving, as analysed and modelled by the buffer-stock theory [Deaton Angus, 1991] and [Carroll, 1997][41]. Ω_i is the desired ratio of liquid assets (deposits) to disposable income. In the model, the value of Ω_i is 1.2 times the annual income, which guarantees that if the deposits with income are less than 1.2 times the income, the individual saves for precautionary reasons. 1.2 is not much because it includes the income that has just been received and is not yet spent. In a stationary state this makes a effective precautionary deposit of 20% of income.

λ_s is the period adjustment rate (we have chosen the adjustment of $\lambda_s = 0.5$) . The

40. [Garbinti and Lamarche, 2014] provide the figures for our model, but studies such as [Dynan et al., 2004] come to the same conclusion.

41. The proponents of the precautionary saving as a proportion of wealth consider the problem of the long term stability as solved because wealth increases. However estimates for the precautionary wealth are only around 2 to 10% of total wealth in France according to [Arrondel et al., 2008]. Then the accumulation motive with a specification based on income rank and the novel modelling that we propose seem necessary to keep a stationary aggregate saving rate in the long term.

desired consumption is :

$$C_{it}^{E} = (1 - s_a(Ra_i))NI_{it} - \lambda_s(\Omega_i NI_{it} - M_{it}^{B}) \tag{3.79}$$

where C_{it}^{E} is the desired consumption budget of individual i, $s_a(Ra_i)$ his accumulation saving rate, λ_s the adjustment rate and Ω the desired ratio between deposit and net income.

This formula has included the fact that the average propensity to consume must be decreasing in Ra_{it} and the accumulation savings rate increasing in Ra_{it}. In the figure 3.5, we rank individuals according to their disposable income and according to their position, they have a different savings rate.

For the implementation, we use the savings rate by quintile in [Garbinti and Lamarche, 2014]'s article (Graph II) (figure 3.5) since this corresponds *exactly* to the ranking concept :

a/ The median savings rate is positive and increasing from the second quintile. This has the advantage of giving a savings rate as a function of a relative and not absolute income and solves the problem of the first stylized fact on the constancy (no trend) of the aggregate savings rate.

b/ Since the accumulation savings rate of the first quintile is set to 0, for this quintile :

$$C_{it}^{E} = NI_{it} - \lambda_s(\Omega NI_{it} - M_{it}^{B}) \tag{3.80}$$

Let $C_{it}^{E} = NI_{it} - \lambda_s(\Omega NI_{it} - M_{it}^{B}) = NI_{it}$ if the precautionary savings stock is the desired one, so all the income is consumed. If the deposit with after-tax income is lower than the desired stock, then an individual saves for precautionary reason, and consumes less than his income. If it is higher than the desired liquidity level, he consumes more than the income. He dissaves on a net basis, which should be a common situation for the first decile, compared to current income, and in line with [Garbinti and Lamarche, 2014].

Actual consumption may be lower than C_{it}^{E}, since households may not find some of the goods supplied worth buying.Then an additional involuntary saving may take place as a consequence of the consumption decisions presented below.

3.2.2.8.2 Utility function and demand

Each individual derives a utility from consumption of a product. It depends on its quality and its price. We extend the concept of net utility used in SIMECO 1 to several products in order to compare different qualities inside a sector and between products in the different sectors[42].

We keep the SIMECO 1 assumption of unitary (or zero) consumption for each product i.e. in each sector. Consuming more than one unit brings no additional utility. In a sector

42. The coexistence of different quality levels in a sector is explained by the income distribution (according to its income, each individual does not have the same willingness to pay to acquire a higher quality) and by a higher cost of higher quality. By definition, if all varieties have the same price but different qualities, all individuals will choose the best quality if their budget constraint is respected.

s, the consumption of one unit of a variety j with the quality k_{js} and the price p_{js} leads to the net utility for individual i :

$$v_{ijs} = \theta(R_i)k_{js} - p_{js} \tag{3.81}$$

where v_{ijs} the net utility of individual i when consuming one unit of variety j in sector s, $\theta(R_i)$ the degree of preference of individual i for the quality, $\theta'(R_i) > 0$, $\theta''(R_i) > 0$.

we extend this utility function to all the products the individual consumes. The list of these products is a subset of all existing products, which is to be selected by the individual's choice, under his budget constraint. Preferences being nonhomothetic, following the quality ladders literature (for instance [Grossman and Helpman, 1991]), we assume that the net utilities of the products are linearly additive. The total net utility function of the individual has the general form :

$$U_i = \sum_{s=1}^{S_t} (\epsilon_s v_{is}) \tag{3.82}$$

where S_t is the vector of sectors in the economy at time t, and individual buys effectively only a subset of these sectors. v_{is} is the net utility from the one variety bought in sector s, and ϵ_s is the weight given to the net utility of a product bought in sector s (to be explained below). $v_{is} = 0$ if he doesn't buy the product of sector s. This general form will receive several specifications in the model, since it appears to have important effects on competition and growth.

We develop now an algorithm for the reference simulation to model the choice process between the existing products and qualities at time t. This algorithm has three steps, corresponding, first, to the elimination of all varieties except one (or none) in a sector, second to the choice of the products he *wants* to buy, under his budget constraint, third, the final choices if he is rationed on some varieties and products.

First step. Elimination of all varieties except one or none in each sector.

Φ_{Cs}, the number of firms in the sector s, is also its number of varieties. In a sector s, an individual selects the variety which maximizes his net utility. This is the rational way to do, which is used in quality ladders models. It can be none, since in some case, the value of net utility may be negative, if the quality has a low value for the individual and the price is high. The participation constraint $v_{ijs} > 0$ must be respected.

$$v_{is} = max_{j \in \Phi_{Cs}}[v_{ijs}, 0] \tag{3.83}$$

This process is repeated for each existing sector in t, and the individual then has a list $[v_{i1}, v_{i2}....v_{iS}]$ of preferred varieties over all existing sectors.

Second step. Choice of the products desired.

However, the individual is likely to face the budget constraint and may not be able to buy a product in each of all sectors. He is aware of this and ranks all the products in order to make the selection. A preliminary remark is that we make the assumption that each

new sector, when invented, has his first product start at the same level of quality than other products when they started the preceding sectors. Since quality determines the gross utility, this avoids biases in comparisons between different products. A very high starting quality would give a strong advantage to a product, which need not be compensated by a high price, since the price depends on the costs of production, and these are different between sectors. They depend on the complexity of the new product, a parameter that we will study in chapter 4.

The simplest ranking algorithm consists in starting by selecting first the product with the highest net utility in step one, and check that it matches the budget constraint. It is then put on the list of the products demanded. Then the algorithm is iterated to select the product which brings the second best net utility, check the remaining consumption budget, and so on, until the budget constrains. We will use this algorithm which does not put a hierarchy on products in an experiment in chapter 4. However, for the baseline experiment, we have chosen to put some hierarchy on the products net utilities. The economic literature has a long tradition of a distinction between necessity goods and luxury goods, and formalises this with different elasticities of the consumption of the goods to income. Necessity goods would have a negative elasticity beyond some threshold, while luxury goods would have a positive elasticity. However, introducing elasticities to income cannot be done since our households consume one unit or none. Yet the idea of a order in the consumption of the goods determined by the individual income appears as an important stylised fact. We find an order in the diffusion of the durable goods in the table 3.6. The number of households having a microwave increases from 54,2% in 1996 to 89% in 2016, cellphone from 16.2% to 93.6%, microcomputer from 18.7% to 81.1%. The rates of equipment progress with real income, but also are not the same, implying some order rather than differing tastes among individuals.

Recent literature on consumption rejects the simple dichotomy between necessity and luxury goods, and emphasizes the idea that, as income rises and new goods are invented, these are viewed as a fulfilling a social need, for example the smartphone (see [Saviotti and Pyka, 2013] and [Matsuyama, 2002]). New goods are often luxuries since they are expensive to produce, and furthermore the inventor has a monopoly. Later mass production brings lower prices and access to lower income households. First this view waves the possibility of satiation. Second it allows for a continuous ranking.

Then we consider that there two ways to model this ordering. One is a lexicographic order : households try to consume the goods in their order of appearance, since the first ones are viewed as fulfilling more basic needs. The second gives a decreasing weight to the net utilities, and is a hierarchic order[43]. The first solution assumes that there is a complete ordering of the preferences on the goods, and that it follows the order of invention with no possibility of substitution except possibly for budget constraint or rationing. We find the assumption too strong for the baseline, yet it must be studied, and we keep it for an experiment. We adopt the second for the reference simulation. We are conscious that it

43. [Foellmi and Zweimüller, 2006] use such a hierarchic utility function

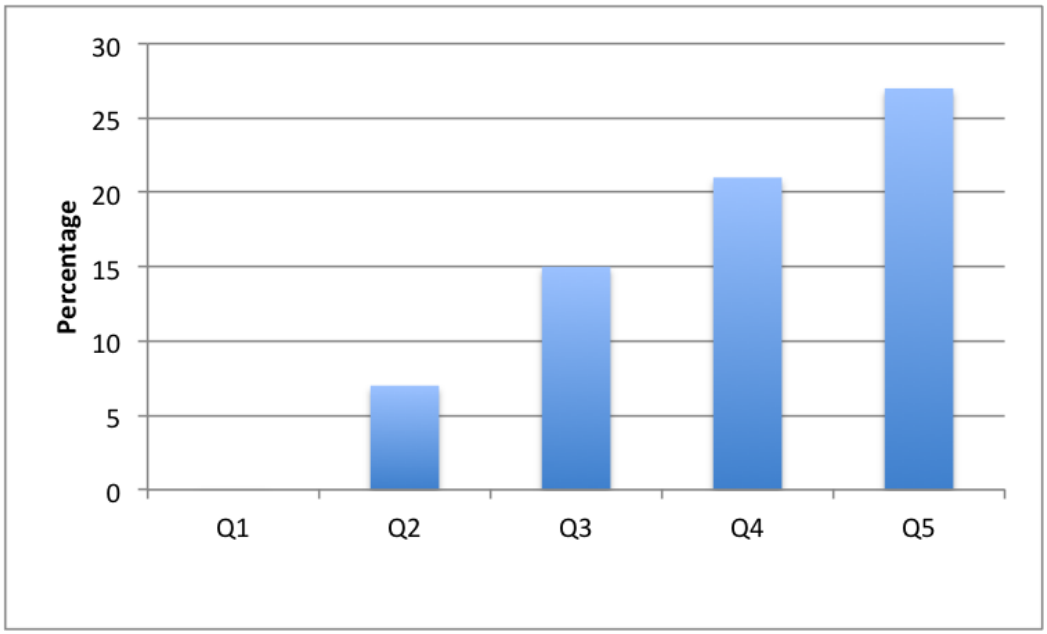

FIGURE 3.5 – Savings rate by disposable income quintile

Year	Refrigerator	Freezer	Microwave	Washing machine	Dish washer	TV set	TV channels	Video recorder	Landline phone	Cell phone	Microcomputer	Internet connexion	Car
1996	nd	nd	54,2	nd	42,6	94,1	nd	69,8	nd	nd	18,7	nd	nd
1997	nd	nd	nd	nd	41,8	94,2	nd	nd	nd	16,2	19,7	nd	nd
1998	nd	nd	61,2	nd	42,5	nd	nd	nd	nd	nd	24,8	nd	nd
1999	nd	nd	nd	94,4	45,0	94,3	nd	75,5	nd	32,0	29,5	7,7	nd
2000	nd	nd	67,8	94,5	nd	94,5	nd	nd	nd	50,9	34,7	14,8	nd
2001	nd	nd	nd	nd	46,5	95,5	nd	78,5	89,4	62,5	40,4	22,1	nd
2002	99,3	82,7	75,2	nd	nd	96,2	nd	nd	90,0	69,5	45,5	28,4	nd
2003	99,2	83,1	nd	95,3	51,7	96,3	nd	79,5	88,5	73,6	50,1	33,9	nd
2004	99,4	85,0	80,7	95,9	nd	95,8	nd	78,0	88,5	77,4	54,6	37,0	nd
2005	99,7	84,1	78,9	93,5	46,2	96,8	nd	79,8	87,2	71,6	49,6	35,5	80,5
2006	99,6	84,0	80,8	93,9	47,4	97,0	nd	82,1	87,6	74,3	54,3	41,8	80,6
2007	99,8	84,8	83,3	93,8	47,3	97,2	33,2	84,5	86,1	77,7	59,6	48,6	81,3
2008	99,8	86,1	83,7	94,2	48,8	97,1	36,0	83,3	88,1	78,9	62,8	54,7	81,2
2009	99,8	87,3	85,2	94,9	51,6	97,5	39,1	83,6	89,2	80,4	66,7	60,5	81,7
2010	nd	90,1	86,6	95,0	51,5	97,8	43,9	82,1	89,3	84,5	69,7	64,6	81,7
2011	nd	89,9	87,0	95,1	54,1	97,4	45,9	79,9	90,2	85,9	73,0	69,2	82,8
2012	nd	90,4	87,6	95,1	55,7	97,1	49,1	79,5	90,9	87,5	75,2	73,0	83,2
2013	nd	91,6	88,6	95,8	57,1	97,2	51,1	77,2	91,3	88,8	77,1	75,3	83,6
2014	nd	91,4	88,6	96,0	58,4	96,9	53,1	74,5	90,2	90,5	78,8	77,9	84,1
2015	nd	92,2	88,6	96,0	59,6	96,6	55,4	73,1	89,0	92,0	79,9	79,7	84,5
2016	nd	92,7	89,0	96,4	60,8	96,3	59,2	69,9	87,1	93,6	81,1	81,7	84,7

FIGURE 3.6 – Equipment of French households with durable goods between 1996 and 2016 (Insee)

abandons the idea that there are necessities, but mixed utility functions would obscure the model, which does not intent to reproduce with precision the evolution of our economies.

The choice between products is then formalised in the reference simulation as follows. The individual i has a consumption budget C_i. As there exists S_t sectors in the economy at t, he decides to buy the sector numbered m which provides him with the maximum net weighted utility :

$$v_{im} = max_{s \in S_t}[\epsilon_s v_{is}] \tag{3.84}$$

where ϵ_s is the weight coefficient of a sector s, declining in the number of the sectors, which are labeled in the order of appearance. The first sector is initialized has the highest priority and has a weight value of $\epsilon_1 = 1$[44]. For other sectors :

$$\epsilon_S = \epsilon_{S-1}(1 - \beta_w) \tag{3.85}$$

where β_w is the rate of decrease of the weight. $\beta_w = 0.02$ in the baseline simulation[45]. More generally :

$$\epsilon_S = 1 - {\beta_w}^{s-1} \tag{3.86}$$

After selecting the product in sector m with the maximum net utility, the individual checks his remaining budget. If the chosen product fits it, the individual puts it on the list of its demands. If not, he forgets about this product. In the two cases, the sector is removed from the set S_t, and the individual continues to use the selection function (3.84) to find the sector (m-1) which offers the second best weighted net utility. The loop continues until each product in the set S_t has been demanded (or rejected), or when the individual finds he has not enough residual budget to buy the last product he has selected.

Third step : Final choices, rationing cases. If in step two, one variety demanded is no longer available because other consumers have bought all the units produced, the individual goes back to step one, and in the sector concerned chooses the second best. Then he makes again step two, with a comparison between the second best and the best varieties of the other sectors. This process can be iterated 3 times for each product in which the preferred quality is rationed. The individual can then be rationed if he does not find available products during his shopping time[46].

3.2.2.9 Entry and exit of firms

Consumption firms

44. In fact the economy is initialised with 6 sectors, forming a full macroeconomic system. Sector innovation creates a 7th sector, and so on.

45. We will do different tests in the section of results to study its impact on consumption and demand.

46. Running the process without limits for 25,000 individuals would go beyond computer time availability on a small desktop. Yet it is also realistic to put a limit on shopping time.

Entry and exit are endogenous in the SIMECO 2

a) Firms bankruptcies and second hand capital market

Firms fail when their liquidity runs down to zero, since they do not have enough liquidity to pay their anticipated wage bill next year (after the rejection of financial request by bank or the investment fund). They will lay off immediately their employees. In order to respect the SFC principle, we assume that firms anticipate the total wage bill next period and must have the ability to pay the employees, before selling the production. It avoids to have workers unpaid, having in mind that households cannot borrow.

If firms still have a capital stock, it is seized by the bank at the end of the period. The bank then tries to sell it in the second hand market next period. If the bank is completely reimbursed and some fund remains from the capital sale, the investment fund gets the rest. This is a novel feature of the model, or at least one rarely introduced. The reason of the introduction is theoretical coherence. Banks refuse to lend for R&D, but accept to lend for physical investment. We want to give some collateral to the bank to justify that it accepts to lend to firms for investment. Moreover, if entry and exit are important, it avoids a loss of wealth for the bank, and also for the investment fund, and consequently the economy. In order not to induce adverse shocks on the capital firm, which could have macroeoconomic consequences since each firm in an ABM has a significant weight, we assume that the firms use the second hand market as an adjustment only when they are rationed by the capital firm (an infinitely small transaction cost can be assumed).

We must determine the value of their capital stock. Firms have many generations of capital in their capital stock (it lasts κ periods). To determine the price of each generation, we use the price of a current unit of capital set by the capital firm. For each previous generation, we put a discount of $1/\kappa$ on the current capital price (we do not discount for time preference in the model). This discount is justified by the number of periods remaining of a generation of capital. Additionally as the previous generation has a lower productivity, since the capital productivity increases by g%/period, a second discount g is added.

Second hand capital has an age T = 1 to (κ - 1). The price in t of a generation of capital having the age T is set upon the price of new capital :

$$p_{k,t-T} = p_{k,t}(1 - \frac{T}{\kappa})(1-g)^T \tag{3.87}$$

Υ_{ft} is defined as the value of the capital stock of a firm in t :

$$\Upsilon_{ft} = \sum_{T=t-\kappa}^{t} (p_{kT}\Delta K_{fT}) \tag{3.88}$$

For the sake of simplicity, we assume different generations of capital cannot be separated in the second hand market. The candidate must buy all the capital stock of the bankrupt firm. It takes place only during the period after the declaration of bankruptcy. If no firm wants to buy, the capital stock is destroyed. The net worth of bankrupt firms includes now their liquidity stock and revenue from sales of capital good in the second hand market. If

they have a debt towards the bank, they must repay it first, since it is a collateral. Then if they still have a liquidity, it will be transferred to the account of the investment fund. In the balance-sheet of the investment fund, its assets will decrease because its capital shares stock decrease.

b)Firms creation

The investment fund decides to create new firms according to some criteria presented in the previous subsection. If they are created, we should determine their initial characteristics. The investment fund transfers an amount of money in the new firm account, and this liquidity allows the new firm to survive during the first three years. This amount is used to recruit and buy capital goods. The decision of recruitment and capital investment is based on an expected production. For existing firms, to remind, it depends on the demand expressed by individuals last period. For new firms, we set an expected level of 1000 units. Firms calculate the number of individuals they should hire (the expected wage bill is based on the average wage in the labor market) and the quantity of capital good to produce this quantity. The investment fund gives the liquidities on this basis. The capital shares stock of the investment fund in the firm is equal to this amount.

As in SIMECO 1, each new firm is given a quality drawn among the 70% lowest qualities in the existing firms in the sector, with equal probability for each quality. Its characteristics (production coefficients, capital coefficient, production unit wage, average unit wage, initial mark-up) are interpolated between those of the two firms closest on the quality scale to the selected incumbent, in order to avoid head-on competition. If there is no longer any firm in this sector, we assume that they have the initial quality level (all sectors start by the same initial quality level).

3.2.2.10 Cohorts : Entry and exit of Individuals, and the endogenous education system

When an individual reaches 62 years, he retires and is replaced by a new individual who is 18 years old. We replace one by one, the size of the population remains unchanged over the model. In order to respect the SFC principle, we transfer the wealth between them. It can be considered as a inheritance left by a parent to his/her child, chosen randomly, since we do not model households, but within the same competence class. This implements the homogamic feature our our societies where children from educated parents tend to be more educated. This has the consequence that, as more competent individuals tend to get wealthier, their children inherit more wealth. A new individual has also an idiosyncratic competence portfolio. However it is crucial for long run growth, and also a fact, that the education system evolves over time. The increase in quality induces an increase in the demand for the more complex competences, and as is acknowledged (and will be shown the results, an increase in the relative incomes of workers who hold the complex competences (see [Autor, 2013] for instance). Initial education responds at least partially to the structural change in the composition of demanded competences. Modeling this

evolution is crucial since , unlike in an endogenous aggregate growth model, competences accumulated during the lifetime are lost for society when the workers retire. To solve the problem. We use an algorithm which modifies the supply of initial education according to competence demand in the labor market :

In each period, we calculate the demand for each competence in percentage :

$$Z^D = [Z_1^D \ ... \ Z_l^D \ ... \ Z_L^D]$$

The number of new individuals is N_{18}. We call ν the adjustment rate of the education system with labor demand.

If the adjustment is total (ν=1), the number of new individuals for each competence class l is $Z_l^D.N_{18}$.

However, the educational system necessarily lags. Now consider the adjustment is partial ($\nu < 1$), and the preceding cohort t-1 had the structure :

$$Z_{t-1}^{N18} = [Z_{1,t-1}^{N18} \ ... \ Z_{l,t-1}^{N18} \ ... \ Z_{L,t-1}^{N18}]$$

We call Δy_l the rate of change in percentage of the structure of the incoming cohort in competence l, compared to the preceding cohort.

$$\Delta y_l = \nu(Z_l^D - Z_{l,t-1}^{N18}) \tag{3.89}$$

For each competence class l, the increase or decrease of individuals is :

$$\Delta_l^{N18} = \Delta y_l.N_{18} \tag{3.90}$$

The size of the new cohort in a competence class l is :

$$N_l^{18} = N_{l-1}^{18} + \Delta_l^{N18} \tag{3.91}$$

We show a simple example of 5 competences.

$$Z^D = [10\% \ 30\% \ 20\% \ 30\% \ 10\%]$$

The number of new individuals is $N_{18} = 50$.

If $\nu = 1$, the number of new individuals in the first competence class is : $N_1^{18} = 0.1*50 = 5$. We have a vector $N_l^{18} = [5 \ 15 \ 10 \ 15 \ 5]$.

If a < 1, we need to know the structure of the cohort in t-1 :

$$Z_{t-1}^{N18} = [20\% \ 30\% \ 20\% \ 10\% \ 20\%].$$

If the adjustment rate is a=0.2, for the first competence class : $\Delta y_1 = 0.2(0.1 - 0.2) =$ -0.02. We have a vector : $\Delta y_l =$ [-0.02 0 0 0.04 -0.02].

$$\Delta_l^{N18} = [-1 \ 0 \ 0 \ 2 \ - \ 1]$$

The structure of the cohort in t-1 :

$$Z_{t-1}^{N18} = [10\ 15\ 10\ 5\ 10]$$

The structure of the new cohort in t :

$$Z_{t}^{N18} = [9\ 15\ 10\ 7\ 9]$$

For the first competence class, $Z_t^{N18} = Z_{t-1}^{N18} + \Delta_1^{N18} = 10 - 1 = 9$.

In the baseline simulation a=0.2. When computing, if the number of individual is not an integer, we give preference to the competence class where the demand excess is the highest. We round up them first before moving to other competence class. In this example, the forth competence has the highest demand excess, we round up it first. Then we move to the second and third competence, and so on. For the last competence, it corresponds to the difference between the total number of new individuals and the number of individuals already allocated in (L-1) previous class.

We have reasoned as if we gave only one competence l to the new individual. However, when created, each individual has 3 competences. Consequently we give him two other competences (l-1) and (l+1), except for the first and last competence. If l = 1, we give him (l+1) and (l+2). If l = 30 with production competence or l=10 with innovation competence, we will give (l-1) and (l-2)[47].

To each entering 18 years old, we give an initial competence level X_0 for (l-1), and (l+1). In order to allow him to search on the competence class l, we give a higher stock level of 10% for the competence l, therefore $X_0(1 + 0.1)$. For each period, we assume a higher level of competence stock in each l of m%.

$$X_{0,t} = X_{0,t-1}(1 + m) \tag{3.92}$$

To summarize, the initial education system adapts to the changing structure of demand of competences and provides a higher level in each competence. However, it is lagging, and moreover it provides each year only one generation, where all should be trained in order to fit the demanded competence structure. hence lifelong training is essential.

3.3 Initialization process and stationary state

In order to reduce bias from random distribution process on results, we build an initialization stationary state by setting some behavioural functions in order to control the values of some variables or parameters, as has been done only once to our knowledge, by

47. This is a bias, but concerning the competence 30 (or 10 for researchers), most individuals use their highest competence at start, and by accumulation of experience, do not want to use the lower ones. For l=1, the bias is compensated by a higher stock in l=1 to induce him to search in this competence (see below).

[Caiani et al., 2016]. In this system, all markets should be in equilibrium and from this state, we start to run the model. We distinguish three blocks of equations : consumption firms equations, capital firm equations and the rest of the world equations (individuals, bank, investment fund, unemployment fund, government and central bank). In the last sub-section, we will present the process of implement these equations in the computer.

3.3.1 Capital Firm Equations

If the capital market is in equilibrium, capital supply of capital firm should be equal to capital demand by consumption firms. We start by building each side of the capital market.

$$Y_k = K_0/\kappa \tag{3.93}$$

where Y_K is the production of capital, K_0 the initial capital stock of consumption sector, κ the duration of capital good. Since the consumption sector is in equilibrium, in each period, consumption firms pay only for capital replacement investment. There is not expansion investment since demand in consumption sector remains stable. As the capital good lasts for κ years, in each period, $1/\kappa$ of capital stock disappear. This equation means that production of capital firm is equal to outdated capital amount.

$$Y_k = min[(A_{K1}T_{K1}, ..., A_{Kl}T_{Kl}, ..., A_{KL_K}T_{KL_K}) \tag{3.94}$$

This equation is the capital firm's production function we set in the previous part. From the production level, we can determine demand in each task.

The number of employees of the capital sector N_K and consumption sector N_C is given in initialization. It will be described in the last sub-section of implementing in the computer.

The unit variable cost of capital good (and marginal cost as well) is :

$$uc_k = \frac{\sum_{l=1}^{L_K}(w_{Kl}K_l)}{Y_K} \tag{3.95}$$

It is equal to capital firm's total wage bill divided by the quantity of produced capital units.

The price of one unit of capital good :

$$p_k = (1 + \mu_k)uc_K \tag{3.96}$$

The deposit of the capital firm :

$$M_K = \sum_{l=1}^{L_K}(w_{Kl}\tau_{Kl}) \tag{3.97}$$

In the stationary state, the capital firm uses deposit only to pay the wages.

The total wage bill in the economy comes as :

$$WB = \sum_{l=1}^{L_K}(w_{Kl}\tau_{Kl}) + \phi_C[\sum_{l=1}^{L_I}(w_{Il}\tau_{Il}) + \sum_{l=1}^{L_P}(w_{Pl}\tau_{Pl})] \tag{3.98}$$

It is the sum of the wage bill of capital sector and those of consumption sectors (in research and production departments).

The contribution rate is set up as a percentage of total wage bill.

$$\eta_U = \frac{N_U\eta_W}{\phi_H - N_U} \tag{3.99}$$

To remind, N_U is the number of unemployed, ϕ_H the number of individuals, η_W the replacement rate. We obtain this function from the equilibrium condition of unemployment fund. The amount of unemployment tax paid by firms should be equal to the amount paid to individuals in initialisation.

- Unemployment tax : $UB_F = \eta_U.WB$
- Unemployment benefit :

$$UB_H = N_U\eta_W WB/(N_C + N_K) \tag{3.100}$$

In this equation, we calculate the average wage of one worker : $WB/(N_C+N_K)$ is the division between total wage and total number of workers in capital and consumption sectors. For one unemployed, we multiply this average wage with the replacement rate. Finally, in order to calculate the total unemployment benefit, we multiply by the number of unemployed.

In stationary state : $UB_F = UB_H$. That leads to :
$\eta_U = N_U\eta_W/(N_C + N_K) = N_U\eta_W/(\phi_H - N_U)$.
The amount of unemployment tax paid by capital firm :

$$UB_K = \eta_U(\sum_{l=1}^{L_K}(w_{Kl}\tau_{Kl})) \tag{3.101}$$

It corresponds to a fraction of its wage bill.

Profit of capital firm is the difference between its revenues (sale and interest on deposit) and its expenditures (wage, unemployment tax, interest on debt).

$$\pi_K = p_K Y_K + r_m M_K - \sum_{l=1}^{L_K}(w_{Kl}\tau_{Kl}) - UB_K - r_l D_K - \sum_{t\in\beta} D_{tK}/\beta \tag{3.102}$$

Dividend of capital firm :

$$FD_K = Max[0; \rho_K\pi_K] \tag{3.103}$$

Debt of capital firm :

$$D_K = M_K - (\pi_K - FD_K) \tag{3.104}$$

3.3.2 Consumption Firms Equations

Consumption firms use capital goods provided by the capital firm and it helps to determine their production capacity. Since consumption firms are in equilibrium, their production should be equal to their production capacity. They reach the maximum of their production capacity.

$$Y_C = Y_K \sigma_K = (K_0/\kappa)/\sigma_K \tag{3.105}$$

The production level helps to determine demand in each production task.

$$Y_C = [A_{P1}T_{P1}, ..., A_{Pl}T_{Pl}, ..., A_{PL_P}T_{PL_P}] \tag{3.106}$$

In initialization, we assume that all consumption firms are identical. Their unit cost is :

$$uc_C = \frac{\phi_C \sum_{l=1}^{L_P}(w_{Pl}\tau_{Pl})}{Y_C} \tag{3.107}$$

Unit variable cost is the fraction between total wage bill in the consumption sector (only in production department) and its quantity, and is the marginal cost as well.

Price of consumption product :

$$p_C = (1 + \mu_C)uc_C \tag{3.108}$$

Innovation budget function :

$$B_I = b_I p_C Y_C \tag{3.109}$$

Innovation effort function :

$$T_I = min[T_{I1}, T_{I2}, ...T_{IL_I}] \tag{3.110}$$

Deposit of the consumption sector :

$$M_C = \phi_C[\sum_{l=1}^{L_P}(w_{Pl}\tau_{Pl}) + \sum_{l=1}^{L_I}(w_{Il}\tau_{Il})] \tag{3.111}$$

It corresponds to wage advance in both departments.

The number of unemployed :

$$N_U = \Phi_N - N_C - N_K \tag{3.112}$$

It is the difference between population size and workers employed in the consumption and capital sectors.

Total unemployment benefit paid by consumption firms :

$$UB_C = \eta_U \Phi_C[\sum_{l=1}^{L_P}(w_{Pl}\tau_{Pl}) + \sum_{l=1}^{L_I}(w_{Il}\tau_{Il})] \tag{3.113}$$

Profit of consumption sector :

$$\pi_C = p_C Y_C + r_m M_C - \phi_C[\sum_{l=1}^{L_P}(w_{Pl}\tau_{Pl}) + \sum_{l=1}^{L_I}(w_{Il}\tau_{Il})] - UB_C - (K_0/\kappa)p_K - r_l D_C - \sum_{t\in\beta} D_t/\beta \tag{3.114}$$

Dividend in consumption sector :

$$FD_C = max[0; \rho_C \pi_C] \tag{3.115}$$

Debt of consumption sector :

$$D_C = M_C - (\pi_C - FD_C) \tag{3.116}$$

3.3.3 Individuals Equations

Total number of workers :

$$N_{TOT} = N_C + N_K \tag{3.117}$$

Net income of individuals :

$$NI_H = WB + UB_H + FD_H + r_m M_H \tag{3.118}$$

Individuals consumption budget :

$$B_C = (1 - s_a(Ra_i) - \lambda_s(\Omega NI_i - x_i) \tag{3.119}$$

Equilibrium on the consumption market :

$$B_C = p_C Y_C \tag{3.120}$$

As we assume equilibrium on the consumption product market, supply should be equal to demand. Total individuals' consumption budget is equal to total consumption firms' sales.

Net worth of individuals :

$$NW_H = NI_H - B_C \tag{3.121}$$

Deposit of individuals :

$$M_H = NW_H \tag{3.122}$$

3.3.4 Bank Equations

Profit of the bank :

$$\pi_B = r_l(D_C + D_K) - r_m(M_H + M_C + M_K) - FD_B \tag{3.123}$$

Dividend paid by bank :

$$FD_B = Max[0; \rho_B \pi_B] \tag{3.124}$$

Net worth of the bank :

$$NW_B = D_C + D_K - M_H - M_C - M_K \tag{3.125}$$

3.3.5 Unemployment fund Equations

Debt of unemployment fund :

$$D_U = UB_C + UB_K - UB_H + M_U = 0 \tag{3.126}$$

Deposit of unemployment fund :

$$M_U = UB_C + UB_K - UB_H = 0 \tag{3.127}$$

We describe the process of implementing previous behavioral equations in the program. Our starting point is the net wage distribution in France in 1996,. From this variable, we will determine the rest of variables in the initialization.

3.3.6 Description of the process of implementation in the computer

Wage Distribution

- The total number of employees $N_{TOT} = 23\ 880$, where the number of employees in the consumption sector $N_C = 21492$ (2388 researchers and 19 104 workers), and the number of employees in the capital sector $N_K = 2388$.

- The unemployment rate : 7.4%.

- The number of innovation competences : $L_I = 10$. The number of production competences : $L_P = 30$. For the sake of simplicity, we assume that both consumption and capital sectors use the same production competences.

Decile	Average wage by decile	Wage bill	% of total wage bill
D1	11 651	27 822,588	5,31
D2	12 672	30 260,736	5,77
D3	14 092	33 651,696	6,42
D4	15 611	37 279,068	7,11
D5	17 269	41 238,372	7,86
D6	19 223	45 904,524	8,75
D7	21 762	51 967,656	9,91
D8	25 803	61 617,564	11,75
D9	34 131	81 504,828	15,54
D10	47 379	113 141,052	21,58
Total		524 388,084	100

TABLE 3.1 – Annual wage Distribution By Decile in France in 1996

The table 3.1 shows the average annual wage distribution in France in 1996 (obtained from Dares). First we get the minimum wage (for a full time worker over one year) in

France in 1996 which was 10.520 euros. In the model, we have 25 790 individuals. We assume that the unemployment rate is 7.4%. That leads to the number of employees of 23 880 individuals. Since this table shows the average annual wage level, we first take into consideration only employees. As each decile contains 10% of total employees, we have 2388 individuals by class.

Thanks to the average wage by decile and the number of individuals by decile, we deduce from it the wage bill of each class (the third column). In the fourth column, we divide the wage bill of each class to the total wage bill (last line) to obtain the percentage of wage bill of each class in total wage bill.[48]

Wage distribution by competence

In the total number of employees, we assume that 10% of them are researchers and 90% workers in the production department of capital firm and consumption firms. There exists 10 innovation competences and 30 production competences in the model. We assume that each class has an equal number of individuals (a rectangular distribution of competences). Assuming a pyramidal distribution would make the initialisations of the economic system extremely complex with each class of incomes unequal and consequences for the consumption of the different products. However, if one wants to connect classes to the hierarchy of broad occupations, managers, intermediate workers, and blue collars/employees, it is simple to consider that if they occupy a different number of classes, for instance if managers are 20%, they occupy the 6 upper classes in the production hierarchy. For researchers, each class of competence is hold by 10% of total workers and each class of production competence by 3%. For simplicity, we first generalize the average annual wage of each production competence and use it for the corresponding innovation competence. Each production competence is ranked from 1 to 30 and each innovation competence from 1 to 10. As the number of production competences is three times higher than the number of innovation competence, the average wage of the first innovation competence C_{I1} is equal to that of the first production competence C_{P1}. Then the second innovation competence C_{I2} has the same wage level of the 4th production competence C_{P4}, C_{I3} with C_{P7}, C_{I4} with C_{P10},...

An example of calculation : wage assignation for the first production and innovation competences.

The first decile has an average wage of 11 651 euros. The corresponding wage bill is 27 822 588 euros. Since each decile includes 10% of total employees, this is the total wage bill of employees in C_{P1} (3%), C_{P2} (3%), C_{P3} (3%), and C_{I1} (1%).

We name $\overline{W_{P1}}$ the average wage of one average employee owning C_{P1}. This is the individual wage W_{i10}, where 1 is class 1 and 0 is for t=0 (equation 3.48). In the spirit of SIMECO 1, we assume that the average wage distribution function is increasing and convex. For this reason, we use an exponential function. The average wage of one average employee owning C_{P1} is called $\overline{W_{P2}}$ and $\overline{W_{P2}} = \overline{W_{P1}} * (1 + a_1)$ with a_1 a constant. Then

48. In the statistics, there is no D10. We calculate first the % of total wage bill of D10 since the sum is equal to 100%. Then we determne the wage bill of D10 and finally the average wage of D10.

$\overline{W_{P3}} = \overline{W_{P2}} * (1 + a_1) = \overline{W_{P1}} * (1 + a_1)^2$ and $\overline{W_{I1}} = \overline{W_{P1}}$.

$$0.3\overline{W_{P1}} + 0.3\overline{W_{P1}}(1 + a_1) + 0.3\overline{W_{P1}}(1 + a_1)^2 + 0.1\overline{W_{P1}} = 11651 \quad (3.128)$$

We assume that the average wage of $\overline{W_{P1}}$ is 3% higher than the minimum wage level : $\overline{W_{P1}} = 10520 * 1.03 = 10835$ euros

If we replace this value in the equation 3.128, we find the value of $a_l = 0.081$ for l=1. We continue with the same algorithm for the rest of production and innovation competences. This procedure sets the vector of a_l in equation 3.49. The initial competence wage is of a 18-year-old individual owning the first competence. His competence stock level is 5 units. Consequently the initial competence wage is 2104 euros.

Wage distribution by age

The previous calculations help to determine the average wage of each competence. This is the wage level of one average individual in each class. However, each individual has its age. From the average wage level, we determine then the wage distribution of each age class inside this competence class. As we assume that the age is an integer between 18 and 63. We call the average wage level of a 18 year-old individual holding the first production competence $\overline{W_{P1,18}}$. For the sake of simplicity, we assume that the average wage function is linear in age (which implies a decrease in the growth rate, a stylised fact on average). The coefficent will be higher for higher competence classes as is observed. A finer initialisation would use a concave shape as the data tell ([Aubert and Crépon, 2003]). This increase will be endogenous in the model, based on the accumulation of competence, so that the coarse approximation is possible.

An example of calculation : wage assignment according to age of the first production competence.

Inside the competence class C_{P1}, an 18-year-old individual has $\overline{W_{P1,1}}$.

$$\sum_{l=0}^{44}(\overline{W_{P11}} + l * b_1) = 45 * w_{P1} \quad (3.129)$$

Since a 18-year-old individual in class 1 has the minimum wage level, we can replace $\overline{W_{P11}}$ by 10 520 and the average wage level of the first production competence $\overline{W_{P1}} = 10835$. We get the identical increase $b_1 = 14.35$ where l=1. If we continue this calculation to the 63-year-old individual, his wage is 11 151. The ratio between the last and the first individual in the first production competence : $\overline{W_{P1,45}}/\overline{W_{P1,1}}$ = 11 151 / 10 520 = 1.06.

For other competences, the calculations are somewhat different because we do not know the first wage (of an 18-year-old individual in these competence). We assume that the range between a 18-year-old and a 62-year-old individuals increases with the complexity of competence, in accord to the stylised fact that the gain function is steeper, the higher the qualification (for instance see [Beffy et al., 2006]). If for the first competence, its range is only 1.06, we want a gap of two times for the last competence. It means for each higher competence, the range increases by 2 / 30 = 0.066.

For the second competence : $\overline{W_{P2,45}}/\overline{W_{P2,1}} = 1.06 + 0.066 = 1.126$.

For the third competence : $\overline{W_{P3,45}}/\overline{W_{P3,1}} = 1.126 + 0.066 = 1.192$.

We continue until the last production competence.

We give an example of calculations for the second competence : we use the same equation 3.129. However the difference is that we do not know the value of a 18-year-old individual, but we have the value of the range.

$\overline{W_{P2,45}}/\overline{W_{P2,1}} = 1.192$

From the equation 3.129, $\overline{W_{P2,45}} = \overline{W_{P2,18}} + 44 * \overline{W_{P2,18}}$ and the average wage of the second competence is 11 713 euros. We can deduce the value of $\overline{W_{P2,18}} = 10\ 686$ euros and $b_2 = 46,665$.

In the end, we get a double-dimension matrix of wage distribution according to competence number and age. From this matrix, we can know the wage level of an individual owning competence l and a certain age.

Then we build a second matrix of unemployment benefits based on the first matrix. The replacement rate corresponds to 70% of wage. We get then a double-dimension matrix of unemployment benefit distribution according to competence number and age by multiplying the corresponding element in the first matrix with the replacement rate.

For the sake of simplicity, we assume that there is not any unemployment which lasts more than 2 years in initialization. All unemployed are paid by the unemployment fund. The government does not have to pay a minimum allowance and the tax rate which has the only aim to fund it is equal to 0. There is no difference between gross income and net income.

From the value of wage and unemployment benefit, we can calculate other variables of the initialization in the following order :

- Capital sector wage bill, consumption sector wage bill, total wage bill (Equation 3.98).
- Capital sector unemployment benefit (equation 3.101), consumption sector unemployment benefit (equation 3.113), total unemployment benefit (equation 3.100).
- Contribution rate (equation 3.99)
- Capital firm deposit (equation 3.97)
- Capital production (equation 3.93), coefficients of production of capital firm (equation 3.94)
- Capital cost and capital unit cost (equation 3.95), capital price (equation 3.96), profit of capital firm (equation 3.102) , dividend of capital firm (equation 3.103) and debt of capital firm (equation 3.104)
- Output of consumption firm (equation 3.105), production coefficients of consumption firms (equation 3.79)
- Production unit cost (equation 3.107) , price of consumption product (equation 3.108), total sales of consumption sector.
- Innovation budget (equation 3.109), innovation effort (equation 3.110).
- Deposit of consumption sector (equation 3.111), its profit (equation 3.114), its dividend (equation 3.115) and its debt (equation 3.116).

- Net income of individuals (equation 3.118), their consumption budget (equation 3.119 and 3.120), their net worth (equation 3.121), their deposit (equation 3.122).
- Profit of the bank (equation 3.123), its dividend (equation 3.124) and its net worth (equation 3.125).
- Debt of unemployment fund (equation 3.126), its deposit (equation 3.127).

4 Competences, innovation, and employment in SIMECO 2

In this chapter, in section 1, we analyze results of the baseline simulation. In section 2 we attempt to validate the model output by some stylized facts. In section 3 run several experiments to study the importance of some parameters on our results.

The model has been implemented in Java, in a computer with Window 10 and processor Intel core i7. Running one simulation takes between 45 minutes and 1 hour. The value of the parameters in the baseline simulation is presented in the appendix C. The baseline simulation lasts 100 periods. Each period is considered as one year as in the first model. The results are averaged over 50 runs, except for diffusion rate graphics, and some other figures, and it is then mentioned.

4.1 Model dynamics

The baseline simulation starts from initial conditions as described in the initialization section. Then agents start to interact with each other. The dynamics start. This section describes the properties and determinants of this dynamics. As the main objectives of this model is to study the relation between innovation, growth and employment, we will show the properties of the dynamics in three blocs : innovation dynamics, growth (including demand and investment), and employment (including wage structure and competence evolution) dynamics. The model has not been calibrated over the real data except for the innovation rate and the initial wage distribution, but we have tried to replicate some figures and stylized facts.

4.1.1 Innovation dynamics

We define the total innovation rate as the number of firms which succeeded at least one innovation project (quality or sector) on the total number of firms for each period. Figure 4.1 shows that the innovation rate is stable in the long run around 15% , and close to the result obtained by the CIS survey (17%). In the initialization, free parameters have been set so as to obtain an average innovation probability per year close to this latter figure

taken from the CIS data for France over the period 2002-2004, as in SIMECO 1.

Figure 4.3 shows the average evolution of the number of total sectors in the economy. In the initialization, there are 6 sectors. The number increases to around 26 after 100 periods, meaning that on average a new sector appears every 5 years. The declining individual probability to innovate as the number of sectors increases, built in 3.18 to formalise the innovation limits of the fixed innovation competences vector is compensated by the increase in the number of firms, at least for over the 100 years covered.

The stability of the quality innovation rate is not a trivial result (figure 4.2). For each sector, as the absolute quality level keeps increasing, it becomes more difficult for firms to create a higher quality. However, new sectors are created frequently and their initial quality level is low. The quality innovation rate in new sectors is higher than in old sectors. It allows to maintain stable the quality innovation rate.

Figure 4.4 shows the stability of the aggregate R&D investment rate in the long term at 10% of total sales, which is an assumption provided the firms have enough funds. However, the investment rate increases to 15% from t=40 to t=65 before decreasing to its long term level. It will be described in the next subsection of growth dynamics where we have three phases of growth in our model. The period between t=40 and t=64 corresponds to the second phase where we have some recession and change of competition structure. As firms sales decrease during this period, the ratio between R&D expenditure and sales increases because firms should maintain some level of R&D budget to pay wage and unemployment contribution of their researchers.

4.1.2 Growth dynamics in baseline simulation

Aggregate evolutions : growth and crisis

We start by looking at the aggregate evolutions. Results show a long term growth based on three types of innovation : process innovation (learning by doing in innovation and production tasks, and labor-reducing effect of new generation of capital), quality innovation and sector innovation, as well as as demand and supply of competences. Population is constant. First figure 4.6 displays a long run growth of real GDP at the average rate of 0.8%/year, with substantial fluctuations. The total real sales index (figure 4.5) increases from 100 to 160 over 100 periods, the consumption sector real sales index (figure 4.9) from 100 to 180, the capital sector real sales index (figure 4.10) stays stable but it should be reminded that each unit of capital is becomes more efficient as time goes. The real capital stock index then increases from 100 to 160 (figure 4.12 since the aggregate physical investment rate is stable at 15% (figure 4.13). The aggregate utilization rate of production capacity rises and then becomes stable at 60% (4.11). Finally the financial setting is very stable[1].The aggregate ratio between debt and total sales is low and stable (figure 4.14). The

1. This could be otherwise, but it is preferable to have chosen such a stable environment to study the complex interactions between the innovation, demand and human resource constraints for a first version of the model. This does not mean that at the firm level, financial constraints do not matter.

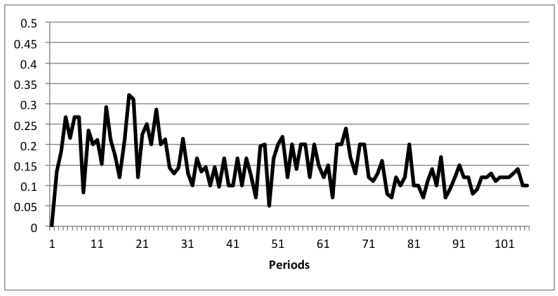

FIGURE 4.1 – Total innovation rate

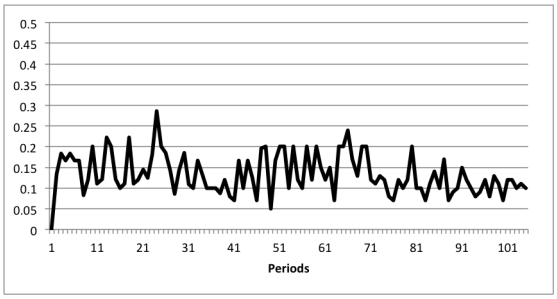

FIGURE 4.2 – Aggregate quality innovation rate

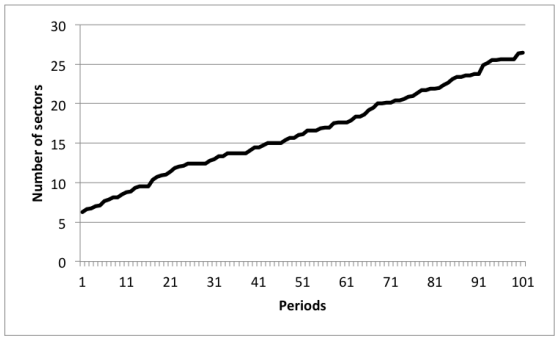

FIGURE 4.3 – Number of new sectors

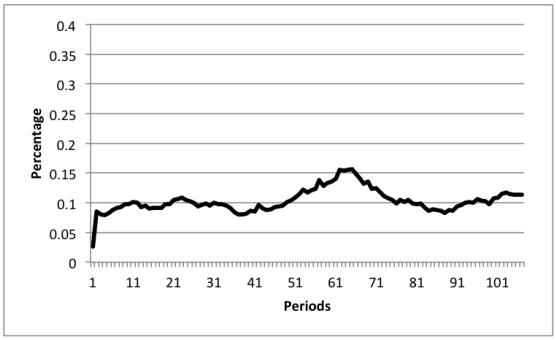

FIGURE 4.4 – Aggregate R&D investment rate

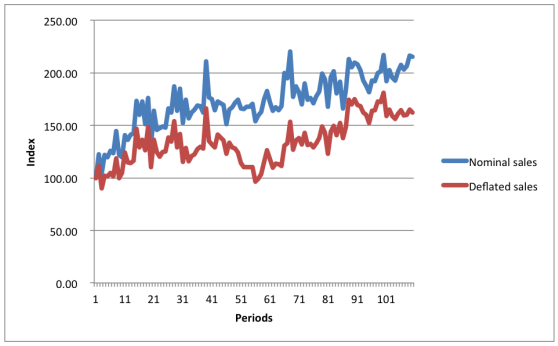

FIGURE 4.5 – Total sales index (nominal and real)

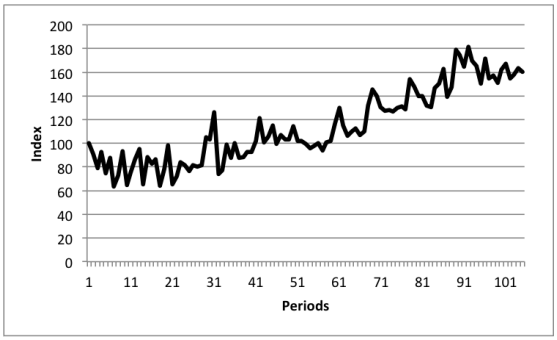

FIGURE 4.6 – Real GDP

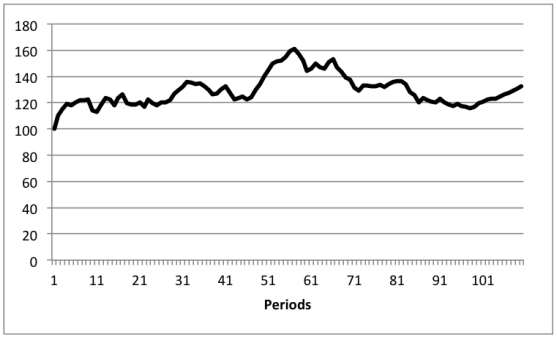

FIGURE 4.7 – Consumer price index

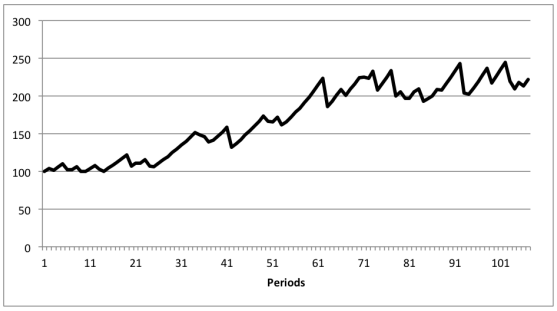

FIGURE 4.8 – Capital price index

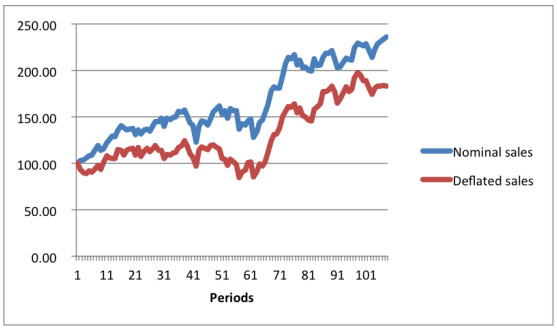

FIGURE 4.9 – Consumption sector sales index

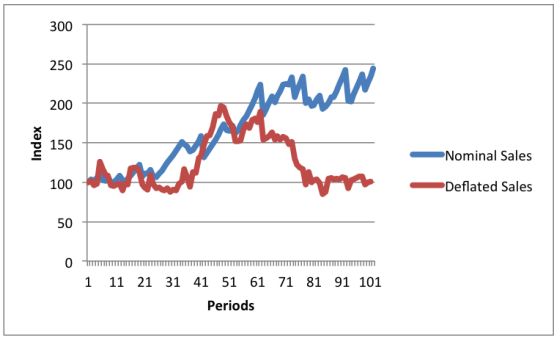

FIGURE 4.10 – Capital sector sales index

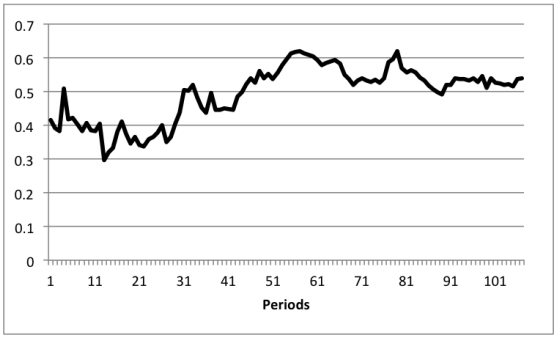

FIGURE 4.11 – Aggregate utilization rate of production capacity

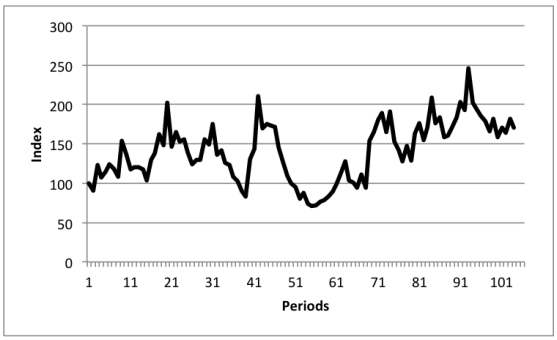

FIGURE 4.12 – Real capital stock index

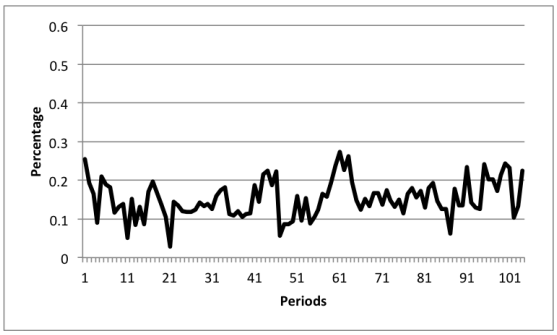

FIGURE 4.13 – Aggregate physical capital investment rate

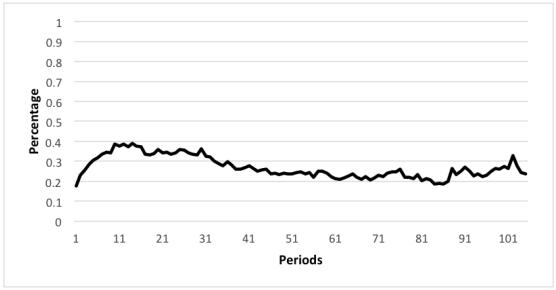

FIGURE 4.14 – Aggregate ratio between debt and total sales

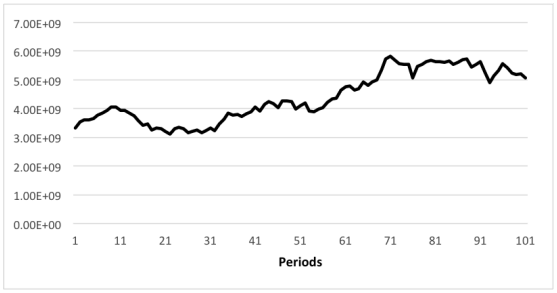

FIGURE 4.15 – Capital shares stock of the investment fund

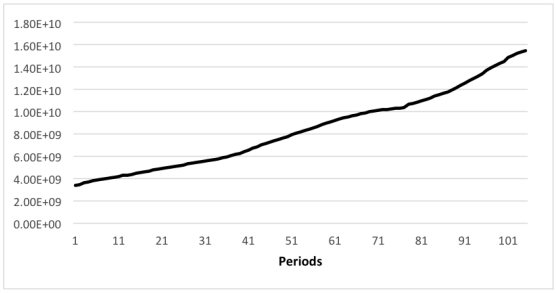

FIGURE 4.16 – Capital shares stock of households

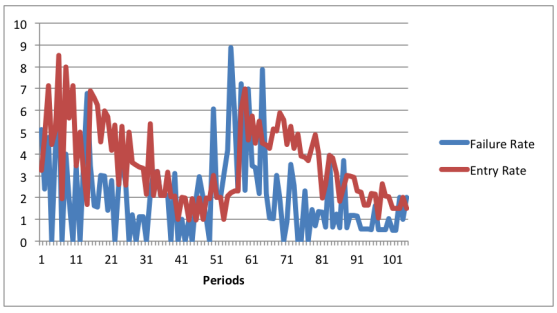

FIGURE 4.17 – Number of failures and creations of firm per period

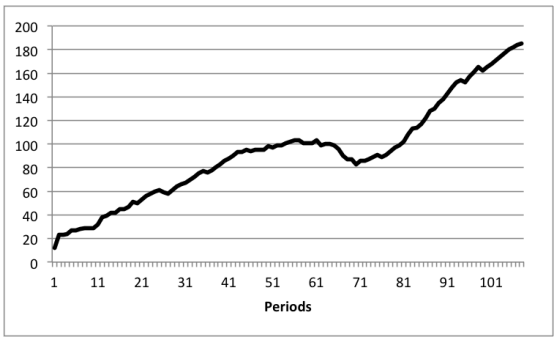

FIGURE 4.18 – Total number of firms

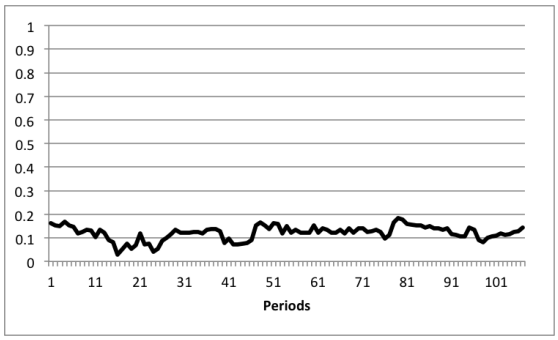

FIGURE 4.19 – Unemployment rate

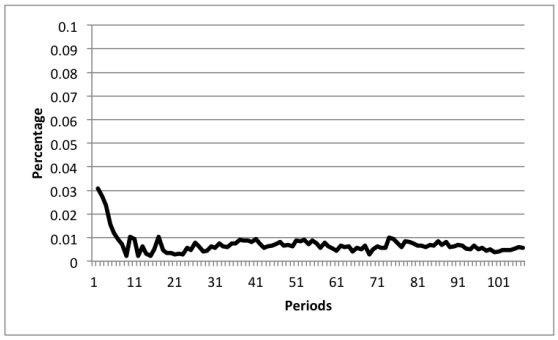

FIGURE 4.20 – Unemployment rate of researchers

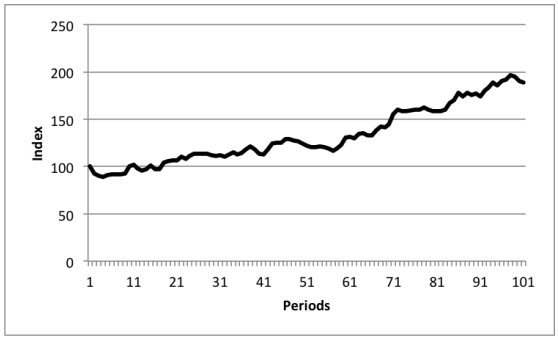

FIGURE 4.21 – Average real wage index

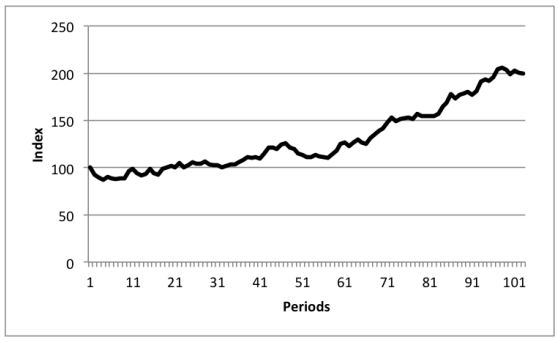

FIGURE 4.22 – Real minimum wage index

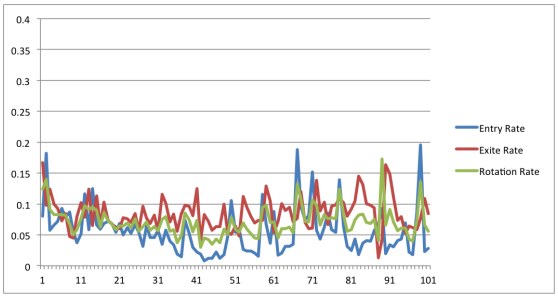

FIGURE 4.23 – Entry, exit and rotation rates in the labor market

capital shares stock of the households and of the investment fund rise, but the investment fund has a more perturbed pattern since it has to deal with failures (figures 4.15 and 4.16. The economy is the baseline then grows slowly. This is a choice we have made before setting the set of exogenous parameters for reasons of realism and reasons of sustainability in the model. First low real growth rates per head for an advanced country like France in the XXIth century are more likely than the reverse, and the rate in the model during the 40 last year is close to the long run growth rate in France, the even without choosing a side in the controversy between pessimists like Gordon and optimists like Brynjolfsson ([Gordon, 2012], [Brynjolfsson and McAfee, 2012]) . Second, as we will see, a fast growth meets the human resources constraint specially on complex competences, hence we had to choose growth low enough for the baseline to avoid the important problems that we will study in experiments, when the parameters are set to obtain a potential faster rate of growth. Entry and exit of firms take place (figure 4.17) in each period, and the total number of firms increases from 12 to 180, favored by the opportunities in new sectors (figure 4.18).

The global unemployment stays stable around 10%, with some fluctuations (figure 4.19). So does the researchers' unemployment rate, which is very low at around 1% (figure 4.20).

The consumers' price index (CPI thereafter) shows only a very mild inflation inflation over the 100 years of only 20%. It starts by a slow increase, which becomes strong during a period of 10 years (around 48-58), and then a slow deflation takes place almost until the end (figure 4.7). The source of the increase in CPI during the first half of the simulations is to be found in the increase of quality in the first sectors combined with little competition, as will be detailed further. In the second half of the baseline simulation, the number of firms increases at a higher rate, and more competition even induces some deflation. The minimum wage is fully indexed on the CPI, but is downward rigid, and therefore increases (see figure4.22). The average real wage is set on a base partially indexed on the minimum wage, and also on individual competences, and finally influenced by the excess demands, so that it rises except during the period 48-58 (figure 4.21. It corresponds to an average of 0.7% per year, close to empirical data in France. A study of [Natixis, 2017] finds that real average wage increased during the period 1998-2018 from 100 to 120 in the U.S and France, from 100 to 112 in Germany and from 100 to 106 in Italy. In the steady growth growth after t=60, the real average wage increases 1.3% per year.

The long run growth does not exclude a serious recession during 10 years, as the figures we presented reveal. We then have 3 phases. First a period of growth, second the recession, third a quasi steady state growth. As mentioned, inflation sets in, but the real wages do not follow and decline. Firms lay off and unemployment rises. Unemployed undergo a fall of their incomes, and they must keep some precautionary saving, and as a result the average propensity to consume falls (figure 4.32), as seems to be the case in France ([Berger and Daubaire, 2003]) and references in this paper)[2] Real consumption then de-

2. see below for a more detailed account of the APC.

clines, and a Keynesian recession takes place. In the model, there is little endogenous government anti-cyclical intervention . The economy could get trapped in a low steady growth.

However there is an endogenous escape from the crisis in the model. A Schumpeterian creative destruction process takes place. Firms fail much more during the crisis, as shows the figure 4.17, and new firms enter in the new sectors. This is possible because they offer new products which are at start of a lower quality and consequently less costly. Consumers can substitute some new products to old as shows figure 4.24. They also enter old sectors, being numerous and now large enough to compete the large incumbent firms with better quality/price ratios, while it was not the case in the first 45 periods. The fall in the Herfindahl index shows clearly this pattern (figure 4.28 . The physical capital sales in real terms, which were already high because of the development of new firms, remains high during the crisis, and sustains the economy (figure 4.10). The new firms can hire easily the laid off workers of the failed or declining firms, and as new products are proposed continuously to households, the economy sets off for the quasi-steady growth of the last phase of the baseline simulation. Income distribution plays an important role as in SIMECO 1. High incomes have a residual budget for the new products and are the first buyers. Then, as the new investment becomes more efficient, this induces a decrease in cost. Market competition between firms which progressively enter the sector leads to a decrease in price. Then lower income households start buying the product. It is important to note that SIMECO 2 does not integrate a learning by doing depending on the quantity produced by the firm, as in SIMECO 1, with dynamic increasing returns. Learning by doing is individual and incorporated in the workers under the form of higher competences and efficiency, which is exactly compensated by a higher individual wage. It is also lost if the worker retires or is fired. The mass consumption cycle in SIMECO 1 or in [Matsuyama, 2002] is based on dynamic increasing returns based on firm level learning by doing and market competition is replaced by less powerful mechanisms of process innovation and market competition.

The pattern of the crisis looks quite different from the patterns in the existing Schumpeterian endogenous growth models [Aghion and Howitt, 1992]. New firms do not simply replace old firms. They may do so, but they mainly supply new products and enable the growth of real consumption, and therefore the reactivation of the income employment growth loop. This is novel, when compared to the endogenous growth model of [Aoki and Yoshikawa, 2002] , which emphasizes that growth ultimately depends on demand. Process innovation is not sufficient according to Aoki and us. The present model incorporates the importance of product innovation, but integrates it with the Schumpeterian creative destruction process.

We feel that this integration of market competition based on innovation and endogenous growth with an emphasis in demand is a natural step. It takes a micro based macro model with heterogenous agents to formalise it. In order to understand better the microeconomic mechanisms involved, we now look at the diffusion rates which are behind the aggregate results.

Diffusion curves and competition

The most interesting results to study the dynamics of a model of product innovation are given by the diffusion rates of the sectors in Figure 4.24 and others. The dynamics is complex because firms compete also in quality on each sector, and households have hierarchic preferences and can substitute not only qualities but also products. The figures correspond to a specific run but analogous evolutions are found in the other runs. For a better view, we have disaggregated the figure into 3. Figure 4.25 shows the diffusion rate of 6 initial sectors over the simulation, figure 4.26 the diffusion rate of new sectors discovered in the first 50 periods and figure 4.27 the diffusion of new sectors in the last 50 periods. Underlying the long run growth process that we have described, we see that the new products diffuse with noisy logistic shapes. However initial sectors loose consumers during the crisis to recover after. We distinguish 3 phases in our results.

- *Phase 1 :*

As is usual with Agent-based models, initialization based on artificial data, have consequences for the market structure. There are 12 initial firms (plus the capital firm) in which all all initial workers are distributed. Firms are symmetric in each sector, and are then identical in quality and size at start, with two firms by sector. We assume also, to avoid a more complexity in the initializations, that all the households have a budget high enough to buy 5 of the 6 products, which are of low quality at start. Then head-on competition for this quasi-saturates market leads to the bankruptcy of one in several of these sectors. In figure 4.28, the Herfindahl index in the 6 initial sectors increases from 0.5 to 1 during the first 10 periods (except one). Almost each initial sector is then covered by a monopoly but with potential entry. New firms are created in these sectors but they cannot compete with incumbents for two reasons : (i) we assume that new firms have a on average a lower quality than incumbents[3], (ii) they have difficulties to hire and increase rapidly their production because employees in incumbent firms do not quit a firm in the model, unless they are fired or retire (see figure 4.43 below). Monopoly firms get all the market share, are profitable, and invest. In the innovation competence market, new entrants cannot innovate usually because researchers are distributed in initial firms. They must wait until they are fired or retire. Then new entrants in these sectors go bankrupt quickly. With these advantages, monopoly firms can innovate frequently and increase sharply their quality level[4]. However, the monopoly situation may be broken. First, when innovating, a new quality deteriorates the quality/price ratio at adoption, and households can substitute another good in the baseline even if they have a preference for old goods. Second the investment fund can precisely create new firms in the new sectors and these firms will not face as much

3. When there is only one firm in the sector, we assume that the entry firm has a quality 80% lower.

4. In this model, as in SIMECO 1, firms always try to innovate in quality and cannot return to their previous quality level or stop innovating because of threat by entry. We obtain by this behavioral assumption the same result than the fundamental result of game theory on threatened monopoly : [Gilbert and Newbery, 1982] show that because competition reduces profits, the monopolist's incentive to remain a monopolist is greater than the entrant's incentive to become a duopolist.

competition as the market is not saturated. Third, firms in new sectors do grow because each individual can only buys one unit of each product. After buying the 6 first products, many individuals have enough residual consumption budget to buy new products (figure 4.26). Some initial firms loose some market share before the crisis in figure 4.25 [5].

- *Phase 2 :*

The crisis around years 48 to 58 first decreases the sales and diffusion of the 6 initial sectors which drops quickly from 100% to a range of 90% to 30%. However other firms which have developed in the new sectors soon enter these old sectors with a better quality/price ratio. The concentration as measured by the Herfindahl drops from 1 to the range 0.6 to 0.1 (figure 4.28) and remains at this level until the end of the simulation.

- *Phase 3 :*

As incomes rise again, and since the old sectors have become competitive, the demand for the old sector products rises, and their diffusion rate re-starts to increase consistently to high diffusion rates in the long term, since they are preferred. However, the diffusion often does not reach 100%. Such an incomplete diffusion comes from the competition of other products, under the budget constraint. In the real world, it happens for a number durable goods, such as microcomputers, as figure 3.6 shows. Another wave of sector creation takes place , as shows figure 4.27. The firms innovating in a new sector first enjoy a monopoly position which gets eroded by entry (figure 4.29. For the most recent sector innovation, the concentration is unstable with few firms, as shows figure 4.30, and a possible difficulty to enlarge the market for the most recent products which have lower and lower priority [6]. Phase 3 represents a quasi-steady growth which is no longer perturbed by the initialisations as was the case in phase 1, under reserves concerning a possible new crisis and the effects of the decrease in the individual rates of innovation with the number of sectors.

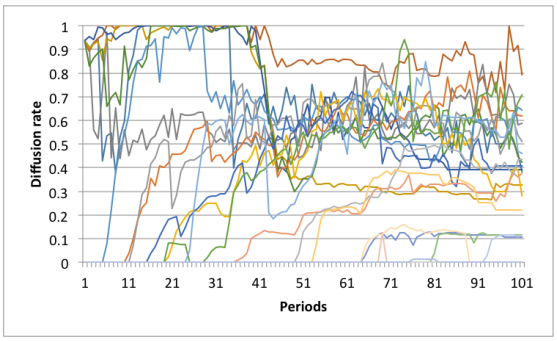

FIGURE 4.24 – Diffusion rate of all sectors

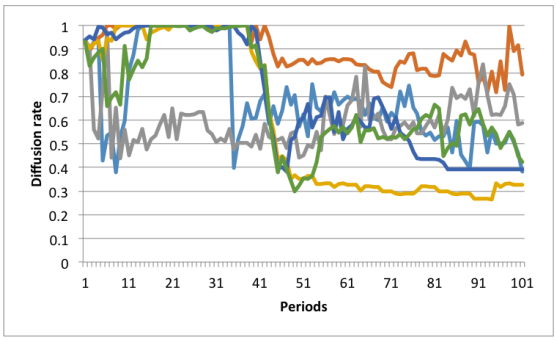

FIGURE 4.25 – Diffusion rate of six initial sectors

The diffusion stories : SIMECO 2 baseline and Matsuyama compared

5. Each run has different final diffusion rates for the initial sectors. In some many reach over 90%
6. Some other runs are much more favorable, and show a persistent rise at the end of the run.

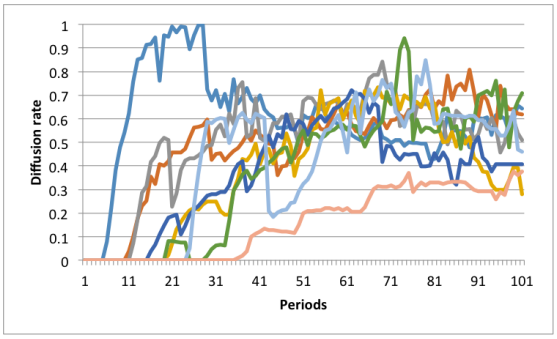

FIGURE 4.26 – Diffusion rate of new sectors discovered in the first 50 periods

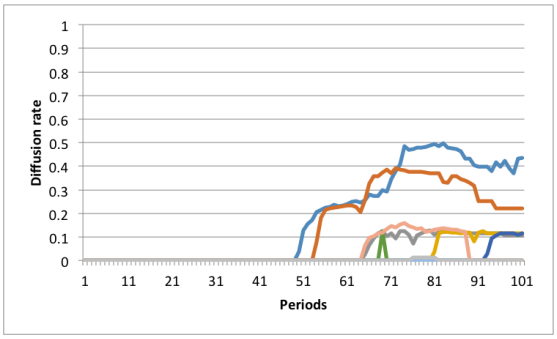

FIGURE 4.27 – Diffusion rate of new sectors discovered in the next 50 periods

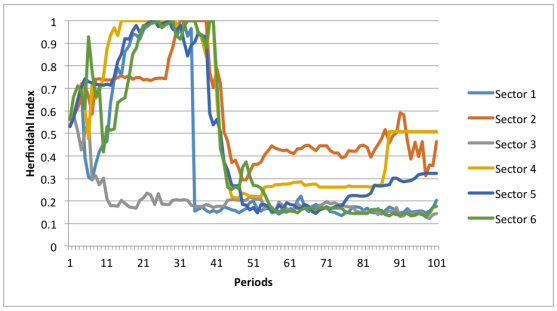

FIGURE 4.28 – Herfindahl index of the first 6 sectors

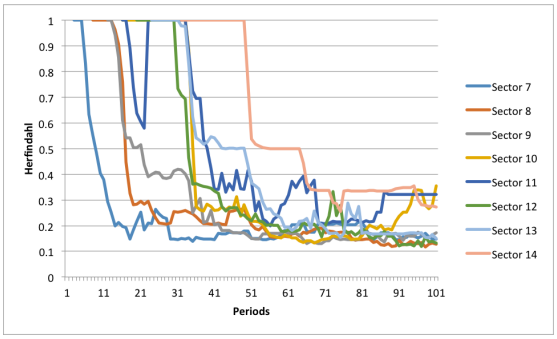

FIGURE 4.29 – Herfindahl index of new sectors discovered in the first 50 periods

To summarize, the diffusion curves shows, with much noise, the successive logistic (or S shaped) diffusion rates of the new sectors, that [Matsuyama, 2002] nicely calls a flying-geese pattern (also in [Aoki and Yoshikawa, 2002]). This noise is on two elements. One is the logistic shape, which is expected to show a monotonous increase. The second is on the hierarchy of the penetration rates, which is expected to be constant, with no crossing of the diffusion curves. Noise appears in the real world, as testifies the figure reproduced by Aoki & Yoshikawa, taken from Bill Gates. There are major reasons for noise in the model, which are part of the novel story that we present. In the two models mentioned, there is no noise. Aoki assumes the logistic pattern. Then it should be reminded why Matsuyama finds a pattern without noise. He assumes a quasi-lexicographic utility function : each product has zero utility if the preceding product has not been consumed by the household. There is learning by doing in each product which makes the price decrease with quantity (dynamic increasing returns). Then when the price for the high priority good goes down, the demand for the lower priority good goes up, yielding a Hicks-Allen demand complementarity from the high priority good to the low priority good. Matsuyama's model is intended to explain the development of mass consumption, with however a finite set of goods and a stationary

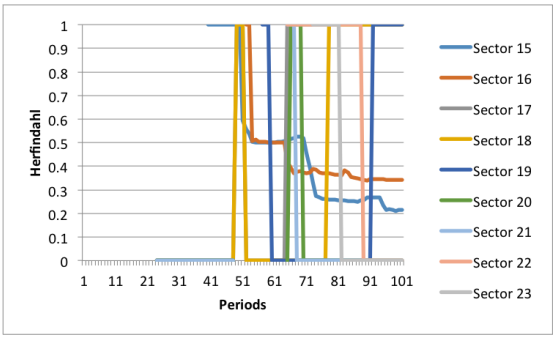

FIGURE 4.30 – Herfindahl index of new sectors discovered in the next 50 periods

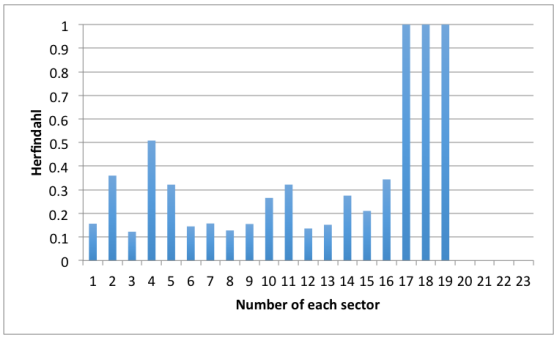

FIGURE 4.31 – Herfindahl index of each sector in the last period

state in the long run.

We obtain an increase in nominal incomes in the long run, anchored on higher competences given by initial education to new cohorts, since the competences accumulated by working and by training are lost when the workers retire. another factor of increase is the irreversible positive effect of the minimum wage. Prices decrease through a different story than in Matsuyama and SIMECO 1. The mechanisms is the increase of efficiency of labor, allowed by more efficient capital, translated into price decrease by competition for a given quality[7]. SIMECO 2 includes the same mechanism that transforms the price decrease in a high priority good into a increase in demand in a lower priority good, through saturation and the increase in purchase power. However, some high priority goods have not been bought by the household, and if the net utility of the low priority good is not higher than the net utility provided by the neglected high priority good, the complementarity can be downward. The latter complementarity should be less frequent than the former since the utility function is hierarchic.

The necessary condition is naturally that new products are invented so that the laid off workers by the process innovation in existing sectors are hired in the new sectors. It is also a novel condition that the human constraint does not bind too much to allow an increased production (see below the discussion around figure 4.43). The wages paid will buy the new goods. The real incomes and GDP can then increase on the long run.

An essential reason for the noise in the diffusion curves is that the household utility function in the baseline simulation has only weights on goods, instead of being lexicographic as in Matsuyama. Then any household can decide to buy a new good instead of an old good. Furthermore each product is supplied in several and new qualities. Therefore, even if the price of the basic quality of a product decreases, more costly but better quality varieties of new goods may be preferred. The relative rhythms of innovation of the different sectors and the competition within the sectors affect the households'choices, and yield an endogenous

7. The effect of the higher efficiency of capital will be made clear by the experiment on process innovation intensity, by varying the factor.

market structure, as in SIMECO 1. The implementation of full markets for qualities and products, based on rational individual choices, allows to obtain endogenous growth and crisis, which depend on the precise behavioral assumptions. Finally experiments with other utility functions will allow to deepen the analysis on the roles of preferences.

To summarize, one of the results of the model is to retrieve crucial Masuyama's main result, without putting the constraints so tight he has put, hence with some nuances. This crucial result is the necessity of the demand for new products, and more precisely a feedback system in which demand does not get saturated because product innovation proposes new goods, and real incomes increase as a result of productivity and competence increases so that they demand more goods. Finally, as noted, in opposition to Matsuyama, not all (mature) products diffuse to all households. The reason may come from demand through competition between goods, and not only qualities within sector, but also from human resources constraints, as will be studied further down.

Result 1 : The model offers an interacting system which sustains long run growth : in this framework, real incomes increase as a result of the rise of productivity based on the rise in initial education, as well as on the rise of capital efficiency , and product innovation is necessary to enable households to increase their real consumption and satisfy an increasing number of social needs that emerge. The decrease (increase) of the price of a high priority product favors (disfavors) the diffusion of the lower priority products more than the reverse.

Experiments will show that the case of increase in the price of the high priority products is important in the model, and not irrelevant in the real world, leading to a rise in the share of the constrained part of the consumption budget.

Result 2 : The demand for each new product follows a diffusion pattern which has a logistic shape. However not all products saturate the market.

Result 3 : As new qualities appear by innovation or firms creation, the substitution between qualities (mainly from low quality to more costly high quality) captures part of the increase in incomes with no positive effect on growth in real terms.

This can one part of the explanation of the fact that, despite a substantial rate of innovation in the France and in the model at 17% (for firms having an innovation activity), the growth rate is low, in France and in the model.

Result 4 : Exit of a keynesian crisis is obtained by the emergence of new sectors and often by young firms (if many other firms have failed), which provide better quality/price ratios. The creation of these new firms is conditioned by the availability of fund from the investment fund. They obtain their first consumers in the high income households, and then foster a new demand for capital. The economy sets out of recession by this mechanism which combines keynesian and Schumpeterian features in a novel manner, based on new products and inequality in incomes.

4.1.3 Unemployment dynamics

Labor turnover rate is situated at 8% in average. We have the same results for entry rate and exit rate. For exit rate, we take into account not only employees who have been fired by firms but also retirements (figure 4.23). The average equality of entry and exit means that unemployment rate remains stable at 10% on average. In old sectors, as demand is saturated, demand for labor decreases since workers accumulate competences and become more efficient. It frees up labor force to new sectors. Both process innovation and the creation of new sectors are required to obtain a balanced growth. If there is only process innovation, demand saturation leads to increase of unemployment rate and in turn it has a keynesian effect on demand and production. New sectors are introduced to create new demand. Unemployed will be used by new sectors and it maintains unemployment rate low. This fact has been observed in the history since the first industrial revolution. First productivity increases in agriculture which can provide enough food to the whole population. Then the creation and expansion of new industrial sectors require labor force which are provided by former farmers. And new sectors in services appear later.

In the crisis second phase of the simulation, demand for monopolists' products drops quickly but the dismissals have a lag of one year. New entrants take advantage of dismissal of many employees by monopolists to increase their production capacity. It keeps low the level of unemployment rate during this transition phase from monopolists to new entrants. We should note also that new entrants in new sectors need for each unit of product a higher quantity of all production competences because they do not benefit of the impact of the new generation of capital as much as the old products (it implies large investments which take time). Additionally, in old sectors, higher qualities lead to an increase in complex tasks demand and a decrease of simple tasks demand. The introduction of new sectors with low initial quality level allows to absorb high unemployment rate in simple tasks. The stability of the unemployment rate is then explained also by a complementarity between sector innovations and the demand for simple competences. New services are an example of such innovations that demand simpler competences than increasingly sophisticated manufactured goods.

4.2 Validation

4.2.1 The Stock Flow Consistency

Checking the logical and accounting coherence of a model is a necessary step of the overall validation process of an ABM-SFC model. As showed in [Caiani et al., 2016], we use two complementary methods to avoid misspecifications, based on the accounting matrices traditionally used in the SFC literature.

1. The first method is to use the Transaction Flow Matrix ([Godley and Lavoie, 2006]). Copeland's quadruple entry principle requires that every row and column of the matrices

sum up to zero in every single moment of the simulation.

2. We use the aggregate balance sheet and check that the sum of the net worth of all the agents is exactly equal to the values of real assets in every simulation round.

Figures A.1 and A.2 in the appendix A provide an example of the two checking procedures applied to the initial period of our simulations. In the next subsection, we proceed to the empirical validation of the baseline results. We compare the properties of our artificial data with a set of empirical stylized facts collected from other contributions in the ABM field and from other empirical studies.

4.2.2 Stylized facts

1. The stability of the aggregate average propensity to consume

Flow savings cannot be a simple constant proportion of current income at the micro economic level. Statistics show that the correlation in the short term is not very good at the micro level ([Arrondel et al., 2008]). Households want to smooth their consumption. Keynes thus explains this behavior by precautionary savings. But it is contradictory to assume that the propensity to consume or save is constant since the household can reduce its flow and even dissave to smooth its consumption. The Keynesian consumption function cannot be transposed from the macro to the micro level, unlike [Caiani et al., 2016], [Ciarli et al., 2010]. Micro modelling on rational bases is needed to explain that smoothing consumption implies precautionary saving : saving or unsaving, assuming a liquidity constraint - limitation or absence of possibility to borrow for consumption ([Deaton Angus, 1991]) or simply protection against the risk of a decrease in future consumption when it is necessary to repay ([Carroll, 1997]). Beyond precautionay and accumulation (or bequest) saving, specification of consumption as the purchase of one unit of a product at most implies that the high incomes households may have an involuntary saving if the new sectors appear at too low a rate. The need of the creation of new products,as has been exposed, is a key condition for the growth of consumption. Finally, products are not so many, especially, in the beginning periods, so that each product has a significant price compared to the consumption budget. A household then often needs to accumulate saving or benefit from a substantial rise in income to buy one more product, and meanwhile has also an involuntary saving. This discrete step feature of consumption at the micro level is however mitigated at the aggregate level by the large number of individuals in the model (25,000) and their distribution on the income scale.

The parallelism between consumption and real income over time is obtained on macro data, implying that the average propensity to consume is stable with the increase in aggregate purchasing power, subject to the stability of interest rates and systemic risk on income. For France, the rate fluctuates slowly with a decline in the 1990s, without much significant explanation ([Berger and Daubaire, 2003]) and is fairly stable (according to Banque de France's macro-economic projections September 2018) over 2007-2018.

In the figure 4.32, APC is stable at around 0.91 in the first phase, at 0.8 in the second

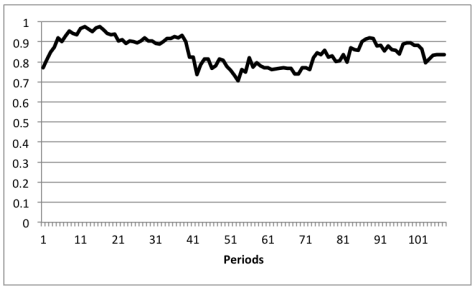

FIGURE 4.32 – Aggregate average propensity to consume (APC)

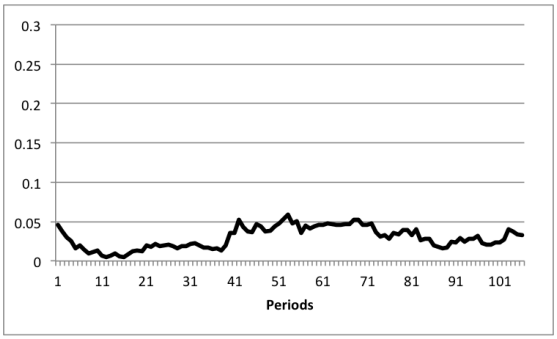

FIGURE 4.33 – Precautionary savings ratio

phase and returns to its long term level in the third phase. In the second phase, there is a recession in which the real average wage index decreases. Then this has several effects. First the accumulation saving rate depends for each individual on his rank on the income scale, and at the aggregate level, depends on the composition effect of the individuals income moves. Its evolution is therefore undetermined. Second precautionary saving increases (figure 4.33).The net effect in the crisis appears as to be an increase in the aggregate saving ratio and a decrease in APC, as seems to have been the case in France when unemployment has risen ([Berger and Daubaire, 2003]). In the steady growth, these wages increase constantly, and their liquidity ratio returns to their long term desired level. Our APC result is close to those of [Kuznets, 1946]. His paper presents a long-term study on the relationship between disposable income and household consumption in the United States between 1869 and 1938, which shows that the APC is stable in the long term between 0.8 and 0.9 but it varies in the short term.

In the model, the stability of the APC is also explained by the introduction of new sectors. In existing sectors, even if quality increases, and then cost at introduction, the replacing effect of new generation of capital lead to decrease of the average price in long term. In the beginning, individuals consume a few products among 6 initial sectors. In long term, the expense in these sectors will have a lower proportion in the total expense. Individuals use their residual budget to consume new products. Without the creation of new sectors, a third form of saving could emerge, namely an involuntary saving from rationed individuals. The ratio between real expenditure and disposable income will decrease because individuals cannot use their residual budget to buy something. The increase in quality often prevents this rationing, yet some very high incomes households may have some disposable income for consumption not used.

2. Increasing wage inequality

Empirical data shows an increasing wage inequality in many countries in the world. A study from Economic Policy Institute in the US ([Gould, 2016]) notes a higher increase of wage in this highest percentiles. In figure 4.34, annualized percent change of the 90th and

95th is always higher than in other percentiles since 2000. On the right, figure presents cumulative log change in real hourly earnings at the 90th, 50th and 10th wage percentiles between 1974 and 2008. This figure is used by Acemoglu and Autor, 2011 from May/ORG CPS data. For each year, the 10th, median and 90th percentiles of log weekly wages are calculated for all workers.

Hourly wages by wage percentile, 2000–2015 (2015 dollars)

	Wage by percentile									
	10th	20th	30th	40th	50th	60th	70th	80th	90th	95th
2000	$8.68	$10.69	$12.49	$14.44	$16.84	$19.92	$23.63	$28.70	$37.49	$47.80
2007	$8.90	$10.80	$12.61	$14.79	$17.27	$20.49	$24.32	$30.00	$40.19	$52.08
2014	$8.63	$10.10	$12.10	$14.48	$16.92	$19.95	$24.10	$30.03	$40.89	$53.20
2015	$8.92	$10.22	$12.35	$14.80	$17.21	$20.18	$24.82	$30.89	$42.57	$56.60
Annualized percent change										
2000–2015	0.2%	-0.3%	-0.1%	0.2%	0.1%	0.1%	0.3%	0.5%	0.9%	1.1%
2000–2007	0.4%	0.1%	0.1%	0.3%	0.4%	0.4%	0.4%	0.6%	1.0%	1.2%
2007–2015	0.0%	-0.7%	-0.3%	0.0%	0.0%	-0.2%	0.3%	0.4%	0.7%	1.0%
2014–2015	3.3%	1.2%	2.0%	2.2%	1.7%	1.2%	3.0%	2.9%	4.1%	6.4%

FIGURE 4.34 – Hourly wages by wage percentile, 2000-2015, from EPI

Acemoglu and Autor, 2011, Autor et al., 2006, Lemieux, 2008 explain this fact by job polarization. During the early 1980s, earnings inequality in the US labor market rose relatively uniformly throughout the wage distribution. However, inequality growth since 1990 has been concentrated in the top end of the distribution , while inequality in the low end of the distribution declined. Acemoglu and Autor, 2011 explain this phenomenon by evaluating the role of changing labor force composition and changing labor market prices. Their analysis reveals that shifts in labor force composition have primarily operated on the earnings distribution. Lemieux, 2008 propose other explanations such as the institutional change[8], technological change (based on the distinction between skilled and routine tasks), and off-shoring.

In the figure 4.38, the distribution of the average wage per unit of (production) competence becomes more inequal. The average wage increases more in the highest competences

8. However Lemieux, 2008 found that it only accounts for about a third of the observed changes in wage inequality.

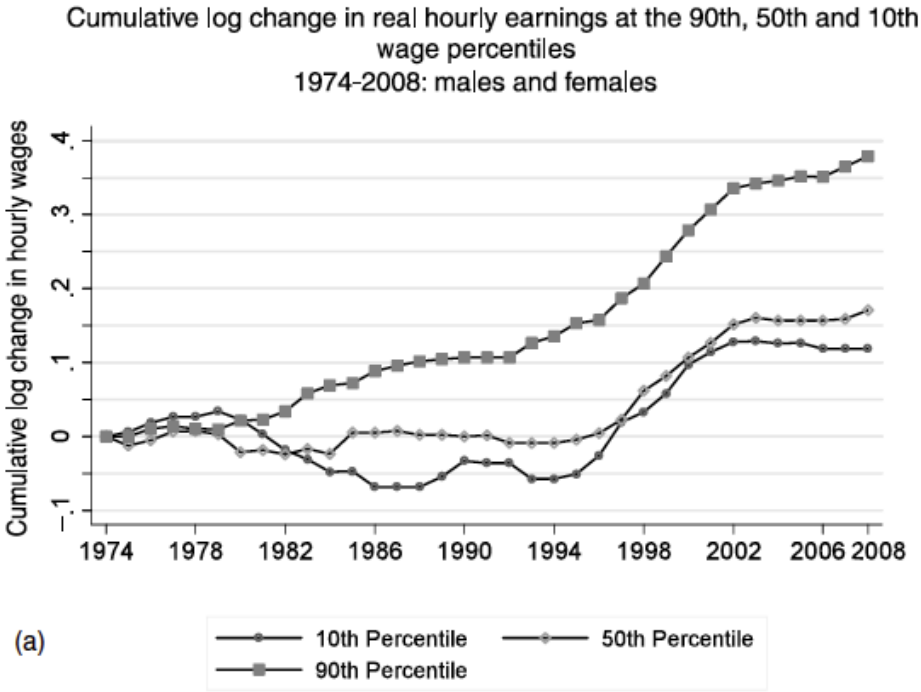

FIGURE 4.35 – Index of Gini income

because of tension in these competences' demand. To remind, two effects impact the total demand for production competences : quality innovation and sector innovation. A higher quantity requires a higher demand for complex tasks and lower demand for simple tasks. At the same time, the creation of new sectors absorbs unemployed in simple tasks. At the aggregate level, demand for complex tasks increases faster than those of simple tasks. Quality-innovation effect overrides sector-innovation effect. In the figure 4.39, high competences show a higher wage heterogeneity between firms (also observed by [Acemoglu, 1997]) because growing firms want to attract these workers.

In SIMECO 2, the increase in the wage inequality induces an evolution of the Lorenz curve and the Gini coefficent on incomes (figures 4.36 and 4.37). The Gini coefficient fits the facts in terms of level and in terms of evolution. First it is close to the empirical Gini in France which varies between 0.315 and 0.335 (from data on the website of World Bank). Second it increases, and this also has happened since the last 15 years, according to Banque de France (from data on the website of Banque de France).

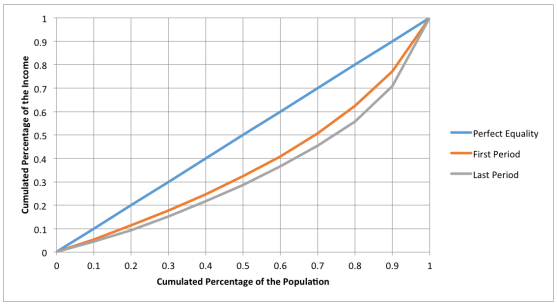

FIGURE 4.36 – Lorenz curve

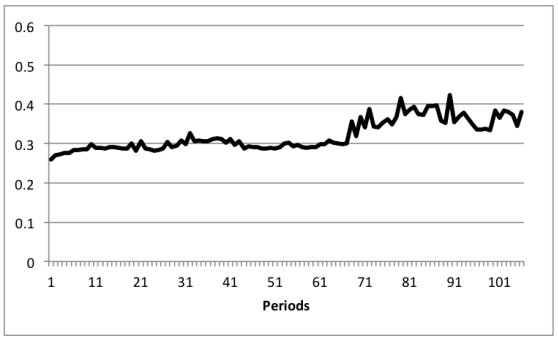

FIGURE 4.37 – Gini coefficient for income

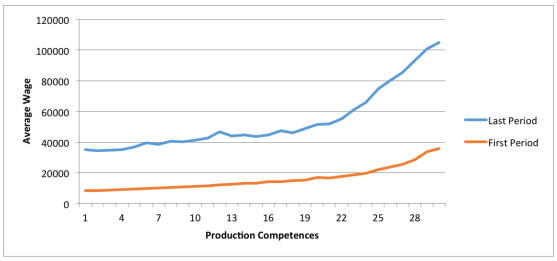

FIGURE 4.38 – Distribution of average wage per production competence

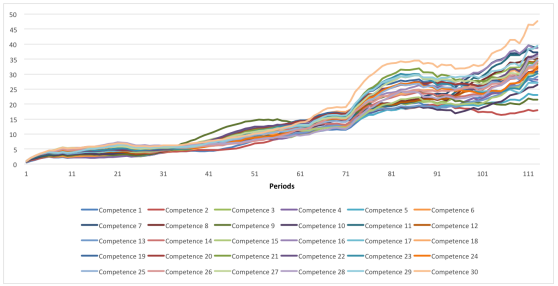

FIGURE 4.39 – Wage heterogeneity between firms

To understand better the existence of tightness on the labor market and the differentials between competences, we look at the excess demands. These are in terms of competence units, since firms post their demand in competence units as defined in equation (3.50). Figures 4.40 and 4.41 show task excess demand in each production competence in average of all periods of the simulations and in the 10 last periods. Excess demand increases with the complexity of tasks, and this has an impact on the evolution of the wage structure. The figure 4.43 presents the percentage of firms which cannot recruit in at least one competence. This is a crucial figure since firms have a Leontief production function, and if they cannot increase the hours or promote internally, this puts a limit on their production. This percentage stays high in the first two phases of the simulation then decreases and remains stable at 20% until the end. The difficulty to recruit in some competences in reflected in the Beveridge curve which is very flat (figure 4.45). These excess demand naturally imply a differential in the unemployment rates by competence class (figure 4.42). The unemployment is much higher for the most simple competences segments.

Monopolists in initial sectors, as they innovate frequently, have a high demand for complex tasks. Firms in new sectors innovate in quality too but at a weaker pace. Tension increases more quickly in the complex competences segments than in the segments of simple competences. In the steady growth of phase 3, the adjustment of competence supply follows the pace of those of competence demand, since the new sectors do not require as

complex task quantities as the older higher quality sectors. Another adjustment is the evolution of the initial education system towards more complex competences and higher initial endowments. A third adjustment is internal training Therefore, in the baseline, the complementarity between competences demand required by the Leontief production function only constrains the economy a little, and only during the first two phase. The important figure 4.44 shows the potential constraints on production and sales. The capacity of production allowed by capital equipment does not constrain, as the rate of utilisation showed already. The human resources constrains during the two fist phases, but no the third, and this also a condition for growth, besides demand. However parameters have been set to obtain this result, and experiments might show that the human resources can constrain more severely. To summarise :

Result 5 : The baseline scenario models a growing economy with increasing quality and an increasing number of sectors, which features a stable excess demand of labor and unemployment, but a higher rate of excess demand and a lower unemployment in the complex competences than in the simple competences. The inequality of wages increases with time, as well as the inequality in incomes.

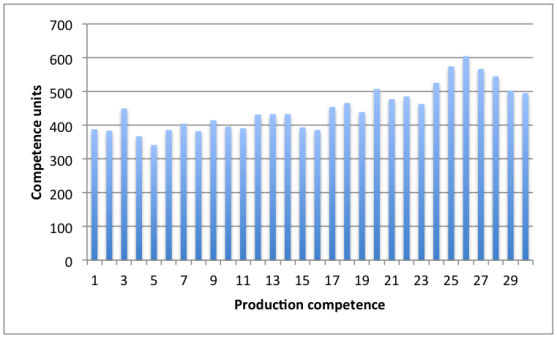

FIGURE 4.40 – Average task excess demand over the simulation per production competence

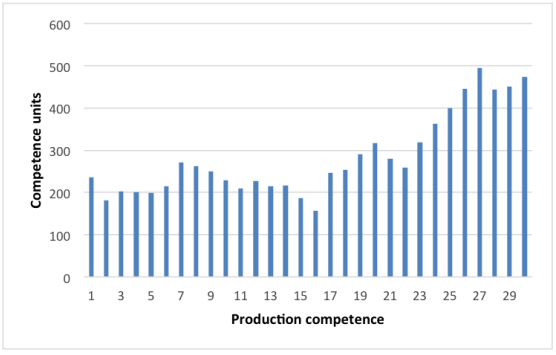

FIGURE 4.41 – Average task excess demand in the last 10 periods per production competence

3. Inequality of firms market share and mark up rates

Even if firms are almost perfectly homogeneous at the beginning of our simulations, heterogeneity emerges as a consequence of stochastic agents' interactions and adaptive behaviors, and as the result of the cumulative effects arising from agents' competition. The selection processes affect market structures.

First we obtain a highly skewed distribution of firms by sales size, in figure 4.49 as in all empirical studies and macro agent based models with endogenous firms. We have no theory predicting a precise mathematical form (Pareto, power law) so that we will try to fit such a function. In a given period a number of firms, namely here 65 on 161, have no sales. This occurence of zero sales is the result of the very competitive market rules that

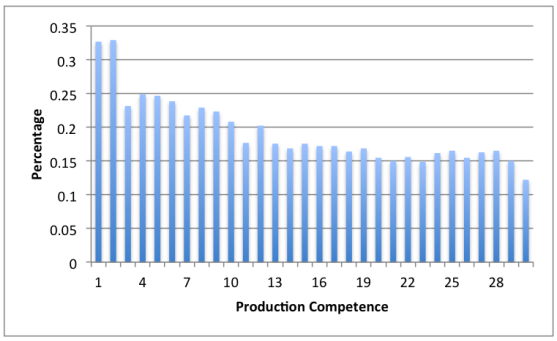

FIGURE 4.42 – Unemployment rate by competence class in the last period

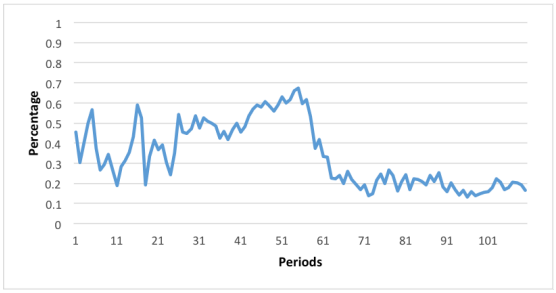

FIGURE 4.43 – Percentage of firms which cannot recruit at least in one competence

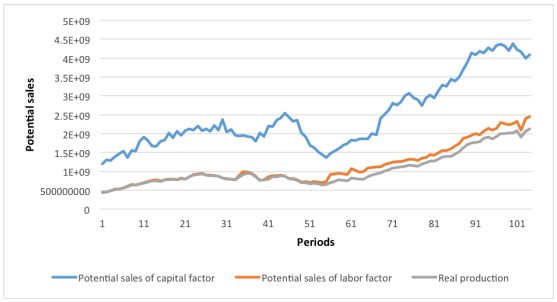

FIGURE 4.44 – Potential constraints on production by capital and human resources

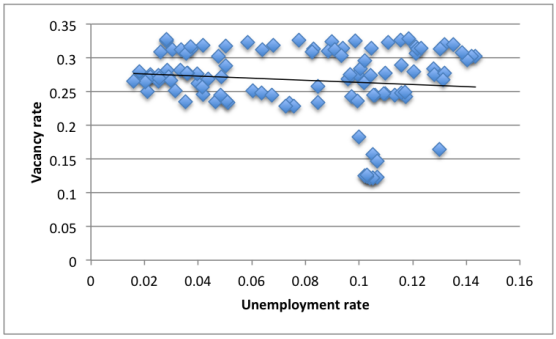

FIGURE 4.45 – Beveridge curve

we have set, as in SIMECO 1 : no attachment of consumers and no randomness in their preferences, no spatial markets.

Following [van der Hoog and Dawid, 2015], we plot the hierarchy of consumption firms' market share, for one run, and its evolution. Figure 4.46 shows the evolution of the market share of the largest firm (blue line), those of the 5% largest firms (red line) and of the 10% largest firms (green line). The firms having these shares can change in the course of time, and this is not a study on persistence of individual firms. The market share the largest firm decreases to stabilize to 5%. This reflects the presence of monopolies in initial sectors and has been extensively explained above. The 5% largest firms hold around 20% of the market, and the 10% largest firms 35%. This stability may a somewhat surprising result given the Schumpeterian turmoil that shows changes in concentration in phase 2, and the quite high level of apparent competition as the Herdindahl figures 4.28 and 4.29 have revealed. However the creation of new sectors generates temporary monopolies and rents, as the same Schumpeterian theory tells us, and this is nicely displayed in the same figure 4.29, figure 4.30, and the figure 4.31. They show that in the first periods of the new sectors, concentration is large, and then falls. The complete dynamics comprise the mix of

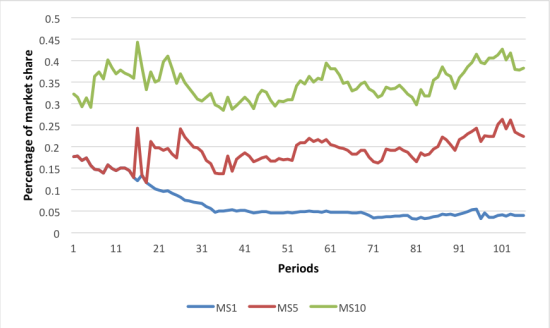

FIGURE 4.46 – Market shares of the largest and average firms

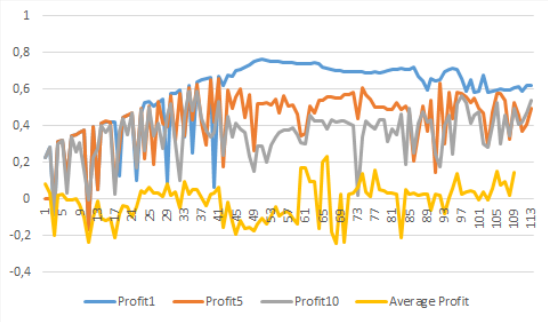

FIGURE 4.47 – Average operating margin of the largest an average firms

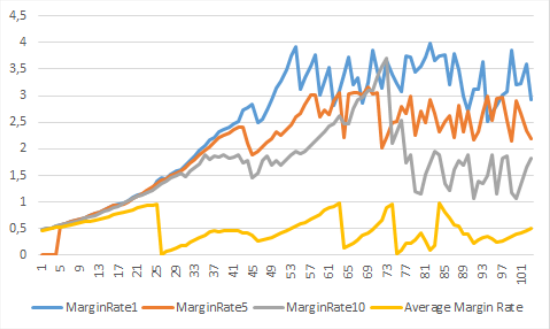

FIGURE 4.48 – Average mark-up of largest and average firms

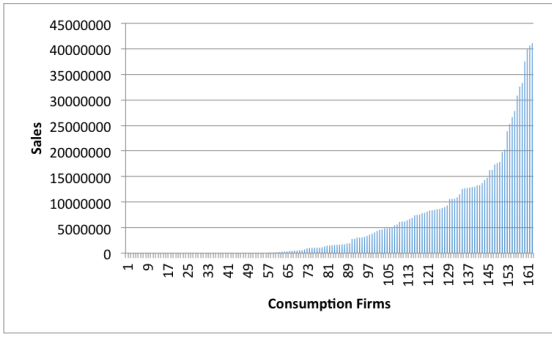

FIGURE 4.49 – Consumption Firms Size Distribution by Sales

the high concentration of new sectors and the low concentration of more mature sectors, and the aggregate result is hierarchic market shares, but not as much as in SIMECO 1, in which dynamic increasing returns played an essential role.

In figure 4.47, the average operating margin of all firms (net profit, after dividend payment) is around 6% in the steady growth. It is negative in the first 20 periods because 6 initial sectors are hold by monopolists. A high number of new entrants cannot compete and make usually losses. Then new sectors appear with high potential of demand. New firms in new sectors have significant sales and as there exists few competitors in these sectors, their operating margin is high between t=21 and t=41 and helps to compensate the negative operating margin in old sectors. The average operating margin of all sectors becomes positive but it is low, around 3% of total sales. During the second phase, it becomes negative because of drop in demand in many sectors. In the third phase, it is positive and higher than in the first phase because more firms can be profitable. The largest firm (blue line) has a much higher operating margin, above 60% of its total sales. The 5% and 10% of the largest firms (orange and grey lines) have the operating margins of respectively 57% and 54%.

The higher operating margin of the largest firms is explained by a higher mark-up (figure 4.48). In phase 3 steady growth, the average mark-up of all firms is situated around 50% of total sales, those of the largest firm 320%, of the 5% biggest firms 250% and of the 10% biggest firms 150%. The largest firms have higher quality and prices than other firms. First they benefit from a R&D - sales virtuous positive feedback, which allow them to innovate more both in quality and, when they are offensive, in new sectors. Second they are then less competed by other firms. In a sector, there exists many firms who have intermediate quality level and only a few high quality level. In the first case, the distance of two firms quality adjusted price is low and it decreases the mark-up of firms in this segment. In the second case, the distance is higher and it explains the difference in mark-up between firms due to quality difference. As high quality firms have higher mark-up and consequently higher operating margin, this is a second factor which allows them to have the means to invest in innovation in order to maintain their position. It explains an high degree of heterogeneity among firms. To summarize We find the same hierarchical market structure than in SIMECO 1 and the same correlation between size and the mark up, that seem to characterize the beginning of the XXIth century. This does not require dynamic increasing returns. The contribution of SIMECO 2 is that these results continue to hold in a SFC model, with product innovation which allows for more diversification than only quality innovation, and an endogenous income distribution.

Result 6 : The distribution of the market shares between firms and the distribution of mark up rates are highly skewed and positively correlated, as a result of endogenous market competition in qualities and sectors/products between multi-sectoral firms.

4.3 Experiments

we present four experiments. The first tries two utility functions as alternatives to the hierarchic utility function. The second varies the rate of the technical progress embodied in the capital good from zero to a rate much higher than in the baseline scenario, yielding different rates of substitution of capital to labor. The third test the effects of creating new sectors only as low tech or high tech, compared to the complexity level of the technology of the new sectors in the baseline scenario. The fourth considers that firms all have an aggressive or, alternatively all have a defensive strategy when considering the entry in new sectors, while firms were equally distributed (each period) between the two strategies in the baseline scenario.

4.3.1 The utility function : Lexicographic and equal preferences for all sectors

4.3.1.1 Presentation of the utility functions

Since the results are likely to be affected by the form of the preferences when new sectors appear and their are not substitutes to the others, we experiment with two opposed utility functions. The first is the case in which a household has no a priori preference for the products. He does not weight the net utilities, in opposition to the hierarchic utility function of the baseline scenario. He then uses the same procedure as for the hierarchic utility function, with step 1, 2 and 3, resented in section 3.2.2.8.2.

The second is a lexicographic utility function. As for the two other utility functions, hierarchic and unweighted, we assume that all households rank products in the same order of priority. Then the lexicographic utility function implies that that a household chooses to consume the products in this order. It then is more favorable to the low ordered products on the list which are really considered as not substitutable by higher ordered products. The function incorporates with more force the idea of hierarchised than the hierarchical function. However the household is likely to encounter the budget constraint, when selecting the nth product, and he cannot buy it. Then we adopt the rule that he will try as an alternative the next product in the order, and buy this (n+1)th product if it is less costly than the nth product. This procedure can be repeated 3 times if the (n+1)th product does not meet the budget constraint. This appears in terms of rationality as a better decision than saving, since saving for precautionary and accumulation motives have already been deducted from the income available for consumption. Our utility function is then different from Matsuyama's quasi-lexicograhic function which excludes such possibility and states that the household spends the income on leisure. This naturally excludes the jumps in the list of products which may render the flying geese pattern less prefect.

Then the complete sequence of choice under the lexicographic utility function in SI-MECO 2 comes as follows, compared to the hierarchic or unweighted functions. He makes the step 1 when a product comes in several qualities to select the quality which brings him the highest net utility. However he needs not to make this step for all products. He considers the first product in the lexicographic order, and uses step 1. The participation constraint must be respected for each quality examined. He then checks his budget constraint. If it fits, he demands the product to the supplying firm. If it is available, he buys it. If it is not, he chooses the second best if any, and checks again his budget constraint, until there he has examined 3 qualities or there is no quality to examine. In both cases, he then moves to consider the second product in the lexicographic order. This process is repeated either until he meets his budget constraint, or no product is left on the list.

The consumption set of a household may then contain some holes as in the other functions. It has the property of Hicks-Allen complementary with the asymmetry stated by Matsuyama, going from the low ordered (high priority) products to the high ordered (low priority) products. It has this strong form while the two other functions we study

have a weak form.

4.3.1.2 Comparison of results

In order to simplify the presentation and because of the existence of a large number of results in our model, we will make a comparison table between the results of the baseline scenario and experiment results. We use graphics when results cannot be described clearly by words or when it can help to clarify the intuition. Results of each experiment are the average of 50 simulations over 100 periods.

i) The lexicographic case

We start by presenting the diffusion rates to give a fits look at what happens, yet it concerns one run, and other runs may differ somewhat. The lexicographic function gives a priority to the low ordered sectors. For the new products we find individual logistic patterns and a noisy flying geese pattern as predicted by [Matsuyama, 2002], except that the diffusion does not go to 100%. However, in his model, he considers only the demand side and lets aside the supply side and the labor market. Implicitly he assumes that firms in a sector can always provide the quantity demanded by individuals. In our model, the supply side is endogenous because it depends on the rate of creation of new firms and firms' production constraints, in capital but more crucially in competences. The number of firms in each sector depends on decisions of the investment fund to create new firms. Even if firms are created, their production is conditioned by the availability of capital and labor factors. In the figures 4.50, 4.52 and 4.54, the long term diffusion rate is lower than in the baseline simulation for many sectors because of supply constraint.

Then we look at the average results in table 4.1. On average, the total number of firms is 120, lower than 180 firms in the baseline. In the last periods, only 1.8 new firms are created each period instead of 3 firms in the beginning of the simulation. In old sectors, even if the diffusion rate does not reach 100%, the investment fund does not want to create new firms here because the average operating margin is low.

In the baseline simulation, new sectors could substitute old sectors if they become less attractive in terms of quality/price ratio than the new sectors. The old sectors increase their quality fast, and become less competitive. In this lexicographic experiment, consumers want to consume old products which are expensive. Consequently the CPI keeps increasing constantly in the model from 100 to 210 instead of stagnating in the baseline simulation. Real consumption soon stagnates, even of the high income households can buy new products. It has an impact on the demand for capital firm. Investment rate in physical capital decreases from 15% to 10% of total sales. Firms capital stock declines too. With the crisis induced by the rise in the CPI, sales decrease and the unemployment rate keeps increasing from 15% to 40%. There is an excess supply in all production competences. The APC decreases from 0.87 to 0.70. Individuals reduce their consumption budget to restore their liquidity stock. There is a major Keynesian depression and the economy does not recover. The creative destruction process that transforms the low ordered sectors in the

Variables	Baseline Simulation	Lexicography	No weighting
Innovation dynamics			
Aggregate innovation rate	Stable at 15%	Same	10%
Aggregate quality innovation rate			
New sectors	20 new sectors over the simulation	25 new sectors	18 new sectors
Aggregate R&D investment rate	Stable at 10% of total sales	Increasing trend from 8% to 22% in long term	Stable at 10% in the first phase, constant increase to 22% in the second phase, constant decrease and stability at 10% (same level as in the first phase)
Growth dynamics			
Real total sales	Its index increases from 100 to 160, especially in the third phase where consumer price index (CPI) decreases.	It remains stable at 100. Both nominal sales and CPI increase at the same pace. After t=70, nominal sales decreases while CPI keeps increase. Index drops from 100 at t=70 to 70 at t=100.	It remains stable at 100 in the first two phases and decreases constantly to 60 in the steady growth.
Consumer price index	It increases from 100 to 160 in the first 50 periods before dropping and remaining stable at 120 until the end.	It increases constantly from 100 to 210.	It increases strongly from 100 to 220 in two first phases and remains at this level until the end.

Variables	Baseline Simulation	Lexicography	No weighting
Capital price index	It increases from 100 to 200 in the first two phases and remains stable at 200 in the third phase (steady growth).	It increases constantly from 100 to 240.	It increases constantly from 100 to 250.
Consumption sector sales	It remains stable at 100 before increasing strongly from 100 to 200 in the third phase.	It remains stable at 100 in the first two phases but drops in the third phase to 70.	It decreases constantly from 100 to 60.
Capital sector sales	Its index stays at 100 in the first and third phases while it increases and stays at 150 in the second phase.	Same in the first two phases but it drops more quickly in the third phase to 80.	It increases strongly from 100 to 200 in the first phase but decreases and remains stable at 50 in the two last phases.
Diffusion rate		See graphics	See graphics
Real capital stock	Index increases from 100 to 200.	It drops constantly from 100 to 40.	It increases in the first phase, constantly decreases to 40 in the second phase and remains stable at 40 in the last phase.
Aggregate physical capital investment rate	It remains stable at 15% of total sales.	Stable at 15% in the first two phases and at 10% in the steady growth.	Stable at 15%.
Total number of firms	It increases from 12 to 180 firms over the simulation.	120 firms at the end of simulation.	110 firms

Variables	Baseline Simulation	Lexicography	No weighting
Creation of new firms	In average 3.5 firms per period.	3 firms per period in the first phase but only 1.8 firm after.	2.2 firms per period
Firms' bankruptcy	In average 1.5 firm per period.	1.5 firm per period.	1.5 firm per period.
Employment dynamics			
Unemployment rate	Stable at 10%	Stable at 15% in the first two phases but constant increase in the steady growth to 40% at t=100.	Stable at 25%.
Unemployment rate of researchers	Less than 1%.	1.2% in average	1% in average.
Real average wage	Index increases from 100 to 200.	It is stable at 100 over the simulation.	It is stable at 100.
Real minimum wage	Index increases from 100 to 200.	It decreases to 90 and stable at this level until the end.	It is stable at 90.
Rotation rate in labor market	8% in average	6% in average	9%
Entry rate in labor market	8% in average	4% in average	5%
Exit rate in labor market	8% in average	8% in average	10%

Variables	Baseline Simulation	Lexicography	No weighting
Other variables			
Aggregate average propensity to consume	0.85 in average	Stable at 0.87 in the first phase, at 0.8 in the second phase and decreasing trend in the third phase until 0.7.	Same as lexicographic case.
Task excess demand	High excess demand in complex tasks. High wage heterogeneity between competences and between firms, especially in complex tasks.	Supply excess in all competences because of high unemployment rate.	Supply excess in all competences but smaller than in lexicographic case.
Percentage of no-recruiting firms	Increase from 30% to 70% in the first two phases and stability at 20% in the steady growth.	Constant decrease from 50% to 10%.	Same as lexicographic case.

TABLE 4.1 – Comparison of results between baseline, lexicography and no weighting simulations

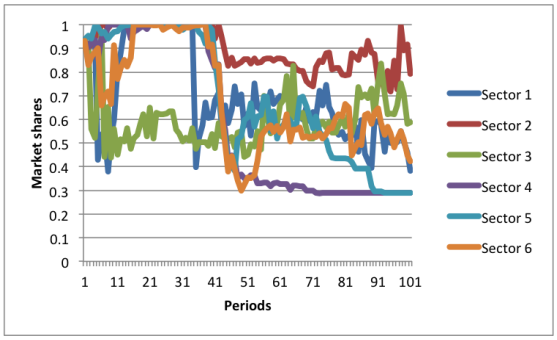

FIGURE 4.50 – Diffusion rate of six initial sector - Lexicographic case

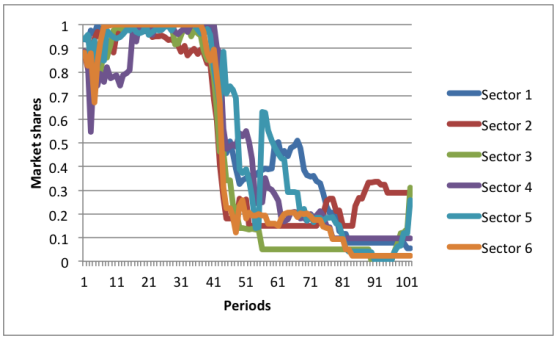

FIGURE 4.51 – Diffusion rate of six initial sector - No weighting case

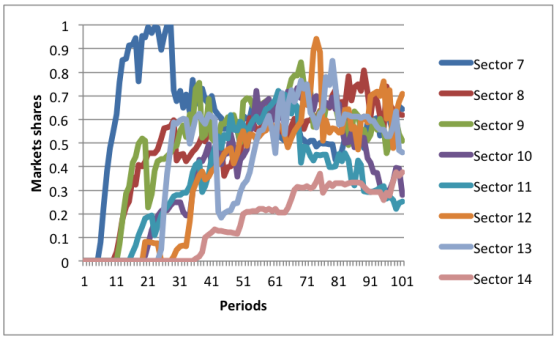

FIGURE 4.52 – Diffusion rate of new sectors discovered in the 50 first periods - Lexicographic case

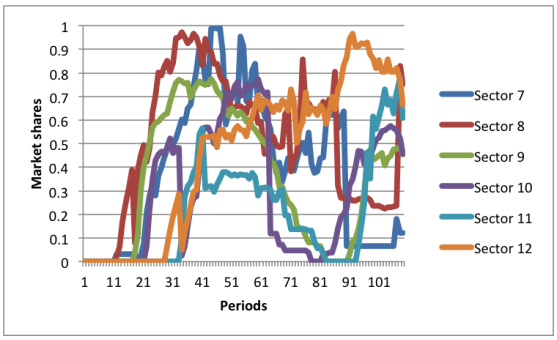

FIGURE 4.53 – Diffusion rate of new sectors discovered in the 50 first periods - No weighting case

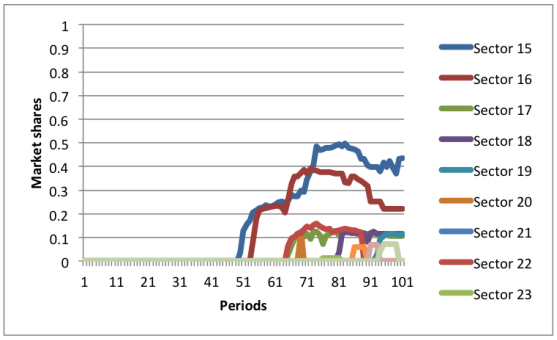

FIGURE 4.54 – Diffusion rate of new sectors discovered in the 50 last periods - Lexicographic case

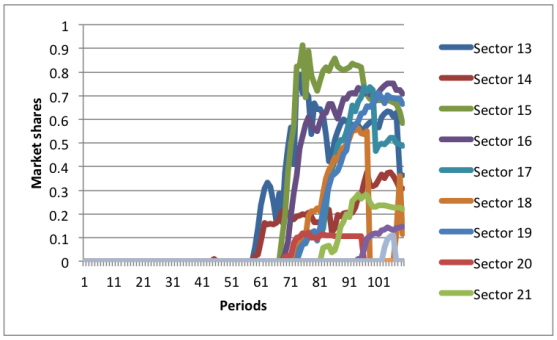

FIGURE 4.55 – Diffusion rate of new sectors discovered in the 50 last periods - No weighting case

baseline scenario does not take place, since households' need of these products does not put the pressure to make these products less costly. This mechanism can be illustrated by the present rise in the constrained expenditures in some high priority sectors as health and housing. The prices rise for reasons of improved quality (scientific progress in treatments, safety...) as well as other reasons (cost of energy, wages...), while low quality varieties disappear. This leads to a rise in the *constrained budget*. Then it reduces the non constrained budget. This affects negatively the demand for lower priority existing and new products[9]. In the model, it leads to a crisis from which the economy does not emerge, in opposition to the baseline scenario (result 4). The Schumpeterian destruction does not take place so that the creation does not occur either. It is aggravated by the of the investment fund for the existing sectors. The solution cannot occur endogenously in the model. It takes a more open attitude of the investment fund towards new firms creation, a reorganisation of initial sectors to lower the cost and give purchasing power to the households, or a subsidy to these sectors or their poorest buyers (such as subsidies to transport and energy), which must however be financed by taxes.

Result 7 : The lexicographic ordering of products involves, when the quality and price of low ordered products (corresponding to high priority needs) rises, an increase in constrained consumption, which prevents the development of new sectors, and generates stagnation and high unemployment.

ii) Equal preferences case

In the baseline simulation, there is a decrease of 2% in the weight of net utility for each new sector in the equation (3.85). In this experiment, $\beta_w = 0$.

We start by looking to the diffusion rate in one run, in figure 4.51. The demand of the six initial sectors drops quickly at the beginning of the second phase and does not return to a high level as in the baseline simulation. These sectors are consistently substituted by new sectors because of deterioration of their net utility in the first phase. For sectors which are discovered during the first 50 periods, they have more heterogeneous diffusion rates than in the baseline simulation (figure 4.53). This is because they are more willingly substituted by sectors which appear later. In the one run displayed (figure 4.55), the diffusion rate of new sectors discovered in the last 50 periods is higher than those of the baseline simulation.

To summarise, rather than a logistic pattern, we find a pattern for the diffusion of products which looks close to a hump shaped product life cycle. It confirms that it takes some hierarchy in preferences (lexicographic or weighted order) to obtain the logistic shape.

We now look at the results averages on 50 runs in table 4.1. The CPI increases constantly from 100 to 220 as in lexicographic case but each index does not have the same composition. Old sectors have high cost because of their frequent quality innovation. New sectors have

9. The net utility of the low ordered products does not increase much, and new products are beyond the budget constraint of most households. This scenario corresponds to some important aspects of the *gilets jaunes* crisis in France.

also a high cost but because this is because they do not take much advantage of task-replacing effect of new generations of capital. The high CPI in the no weights case is explained by the cost of new sectors while in the lexicographic case, it was explained by those of the old sectors.

The unemployment rate is high at 25% but stable. It does not have an increasing trend as in lexicographic case. The scenario is not biased against the consumption of the new products, and these use a higher proportion of employees per unit of product, since their quality is lower. The unemployment rate does not explode in long term as in the lexicographic case. However, as the CPI is higher than in the baseline simulation, many real variables decrease or do not increase with the same crisis mechanism as in lexicographic case (real capital stock, real sales, real average wage..). The surprise is that no Schumpeterian exit of the crisis takes place, as happens in the hierarchic case. In the model, the investment has a rule that favors the creation of firms in existing sectors, and this seems to be an obstacle to the recovery. The same rule applies in the baseline scenario, but in that case, the old sectors participate in the recovery since households put a preference on their purchase. It seems that for a recovery of growth it takes that all sectors participate to raise employment and demand, old and new, and that this explains the incapacity of the economy to recover.

4.3.2 Process innovation intensity

When firms order a new generation of capital, it will tend to replace labor in all production competences. The firms production coefficients A_{Pl} in the production function will increase (equations 3.38 and 3.39).

In the baseline simulation, we calibrate the value of g_t to get the process innovation effect near to 3% per year in average at the aggregate level. g_t represents the exogenous rise of the productivity of a unit of capital, due to the advancement of science. In this experiment, we test two cases : (i) no process innovation, in which a new generation of capital does not have impact on labor demand, keeping the quality of the consumption product constant ; (ii) strong process innovation where the average value is close to 10%.

This variable has a high impact on results. There are two sources of process innovation model : learning by doing and process innovation of new capital goods. The individual learning by doing process saves labor but is does not decrease the costs. Moreover the increase in competence is lost when workers retire except for the increase in initial education. The only source for price decrease comes from new generations of capital. Individuals have less residual budget to consume new products. If process innovation is too strong, job destruction in old sectors will exceed job creation in new sectors and the unemployment rate increases.

The following table 4.2 shows results in each case. They are the average of 50 simulations over 100 periods. The diffusion rate curves are for one simulation.

i) Case of no process innovation

Variables	Baseline Simulation	No process innovation	Strong process innovation
Innovation dynamics			
Aggregate innovation rate	Stable at 15%	8% in average	12% in average
Aggregate quality innovation rate			
New sectors	16 new sectors over the simulation	14 new sectors	20 new sectors
Aggregate R&D investment rate	Stable at 10% of total sales	Stable at 15%.	It increases constantly from 8% to 30%.
Growth dynamics			
Real total sales	Its index increases from 100 to 160, especially in the third phase where consumer price index (CPI) decreases.	It is stable at 100 in the first phase before dropping quickly to 10 in the second and third phases.	It constantly increases from 100 to 280 in the first two phases. The third phase has very strong fluctuation at around 500 because of strong dynamics of creations and bankruptcies.
Consumer price index	It increases from 100 to 160 in the first 50 periods before dropping and remaining stable at 120 until the end.	It constantly increases from 100 to 450.	It constantly decreases from 100 to 40 with a little increase in the second phase.
Capital price index	It increases from 100 to 200 in the first two phases and remains stable at 200 in the third phase (steady growth).	It is stable at 120 in the first phase, constantly increases to 200 in the second phase and to 250 in the third phase.	It is stable at 110 in the first phase, constantly increases to 160 in the second and remains at this level in the third.

Variables	Baseline Simulation	No process innovation	Strong process innovation
Consumption sector sales	It remains stable at 100 before increasing strongly from 100 to 200 in the third phase.	It is stable at 100 in the first phase before dropping quickly to 10 in the second and third phases.	It constantly increases from 100 to 150 in the third phase and remains stable at this level until the end.
Capital sector sales	Its index stays at 100 in the first and third phases while it increases and stays at 150 in the second phase.	It is stable at 180 in the first phase but drops quickly to 10 in the second and third phases.	It increases from 100 to 150 in the first phase, strongly increases to 400 in the second and to 800 in the third. The last two phases are subject to very strong variation between periods.
Diffusion rate		See graphics	See graphics
Real capital stock	Index increases from 100 to 200.	It is stable at 110 in the first phase and drops quickly to 10 in the second and third phases.	It keeps increasing from 100 to 300 in the first two phases and remains in average at this level in the third phase (with strong variations).
Aggregate physical capital investment rate	It remains stable at 15% of total sales.	It is stable at 15% in the first and third phases. It downs to 5% in the second phase.	It keeps increasing from 15% to 90% in the end.
Total number of firms	It increases from 12 to 180 firms over the simulation.	It increases continuously to 90 firms in the first phase then drops to 10 at t=100.	It increases constantly to 110 firms in the first phase and remains at this level until the end.

Variables	Baseline Simulation	No process innovation	Strong process innovation
Creation of new firms	In average 3.5 firms per period.	3 firms per period in the first phase and 1 firm the rest of simulation.	3 firms per period in the first two phases and constant increase from 3 to 8 firms per period in the third phase.
Firms' bankruptcy	In average 1.5 firm per period.	In average 1.5 firm in the first phase and 3 firms per period the rest of simulation.	It stays at 1 firm per period in the first two phases and remains at 8 firms per period in the third phase.
Employment dynamics			
Unemployment rate	Stable at 10%	It is stable at 20% in the first phase before increasing constantly to 85% in the end.	It increases constantly from 20% to 55% at constant pace.
Unemployment rate of researchers	Less than 1%.	1% in average	1% in average
Real average wage	Index increases from 100 to 200.	It is stable at 110 in the first two phases before constantly decreasing to 65 in the last phase.	It increases from 100 to 400.
Real minimum wage	Index increases from 100 to 200.	It increases slightly to 110 in the first phase, decreases and remains at 90 in the second phase and finally constantly decreases to 60 in the last phase.	It increases from 100 to 380.

Rotation rate in labor market	8% in average	Stable at 8% in the first phase before increasing to 35% in the end.	
Variables	Baseline Simulation	No process innovation	Strong process innovation
Entry rate in labor market	8% in average	Stable at 7% in the first phase before increasing to 25% in the end.	5% in the first two phases and constant increase to 9% in the third phase.
Exit rate in labor market	8% in average	Stable at 10% in the first phase before increasing constantly to 40% in the end.	9% in the first two phases and sharp increase to 16% in the third phase.
Other variables			
Aggregate average propensity to consume	0.85 in average	It is stable at 0.9 in the first phase before dropping strongly to 0.1.	It remains stable in the first phase at 92% before dropping constantly to 35%.
Task excess demand	High excess demand in complex tasks. High wage heterogeneity between competences and between firms, especially in complex tasks.	High excess demand especially in complex tasks.	High excess supply because of high unemployment rate.
Percentage of no-recruiting firms	Increase from 30% to 70% in the first two phases and stability at 20% in the steady growth.	It is stable at 40% in the first phase, then increases constantly to 85% before downing and remaining at 55%.	It decreases constantly from 40% to 5% during the first phase and remains at this low level until the end.

TABLE 4.2 – Table of comparison between baseline, no process innovation and strong process innovation.

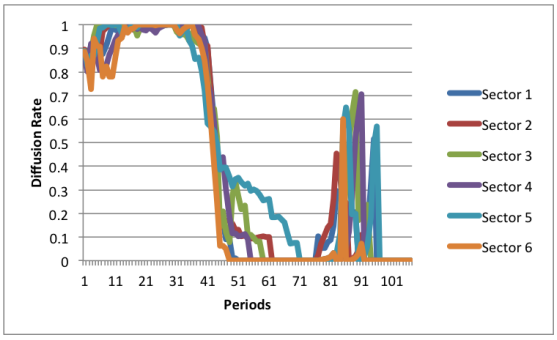

FIGURE 4.56 – Diffusion rate of six initial sector - No substitution

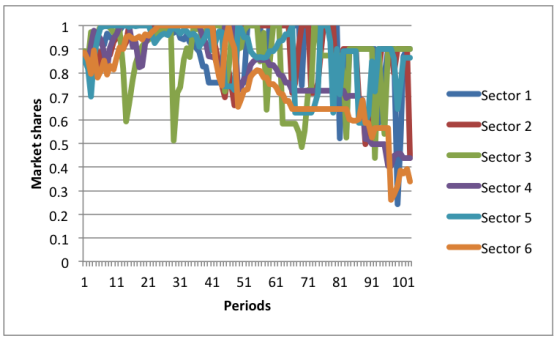

FIGURE 4.57 – Diffusion rate of six initial sector - Strong substitution

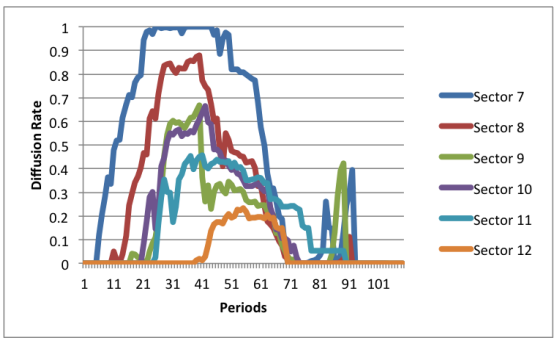

FIGURE 4.58 – Diffusion rate of new sectors discovered in the 50 first periods - No substitution

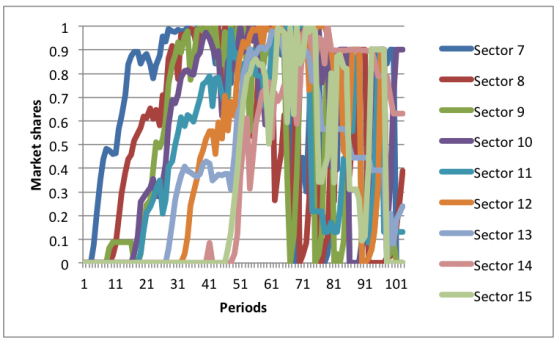

FIGURE 4.59 – Diffusion rate of new sectors discovered in the 50 first periods - Strong substitution

When we remove the process innovation of new generation of capital, the CPI increases strongly in the model from 100 to 450. This is explained by a continuous increase of quality in all sectors. High CPI lower the real wage which decreases constantly from 110 to 65. It has negative impact on demand and employment rate.

In the baseline simulation, the substitution effect of new generations of capital helps to release workers to new sectors. But in this experiment, employees continue to work massively in old sectors. Before the first industrial revolution, if productivity gain was very low, even zero in agricultural sector, the economy would not provide labor force to new industrial sectors. We can use the same argument for the transition between industrial sectors and services. In our model, the number of non recruiting firms increases strongly from 40% to 85%. Firms are in dire need of workers in particularly in complex production competences. This blocks the production of a great part of the economy because the production function is Leontief and all sectors use the same production competences. When the constraint reaches its highest level, it creates a deep recession in the economy. Sales in consumption sector drop quickly from 100 to 10. As an illustration, in the figures of

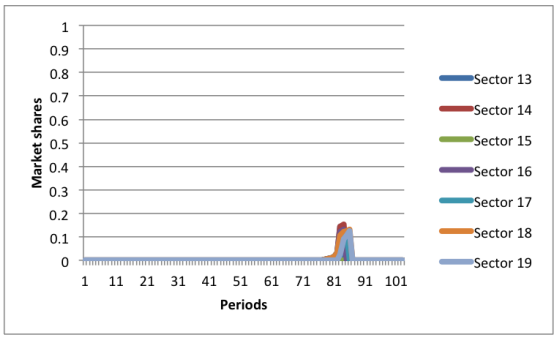

FIGURE 4.60 – Diffusion rate of new sectors discovered in the 50 last periods - No substitution

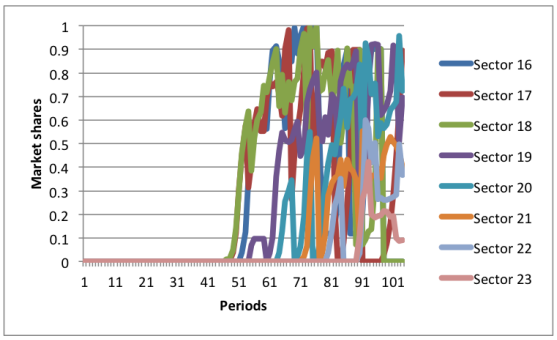

FIGURE 4.61 – Diffusion rate of new sectors discovered in the 50 last periods - Strong substitution

the diffusion rates (figures 4.56, 4.58, 4.60), they drop quickly since the beginning of the second phase. Even if it increases a little during 20 periods between t=70 and t=90, it does not last and the economy collapses. Decrease in consumption sector leads to those of capital sector. The aggregate investment rate in physical capital declines from 15% of total sales to only 5% in long term. The total number of firms decreases from 90 firms to 10 because there are many bankruptcies. The unemployment rate explodes to reach 85% in the end of the simulation. The real average wage decreases.

To summarise, when there is not process innovation effect of the new generations of capital, the economy will be in a deep recession for two reasons : (1) strong inflation due to continuous quality innovation which decreases the real wage, (2) firms cannot hire in many sectors because there is not productivity gain in old sectors and it blocks the production of a great part of the economy.

ii) Case of strong process innovation

New generations of capital substitute strongly labor. It helps to reduce price quickly and favors the consumption of new products. However, strong job destruction due to process innovation has a negative effect on the economy because the unemployment rate increases if job creation does not follow the same pace.

In the comparison table 4.2, the CPI constantly decreases from 100 to 40. The labor-reducing effect of capital overrides cost-increasing quality innovation effect. Nominal and real sales increase constantly and the diffusion rate reaches 100% in many sectors. Even if sales keep increasing, the unemployment rate increases constantly from 20% to 55%. One could hope that the job destruction effect of new generations of capital would be compensated by the job creation effect due to increase of demand in existing sectors (if they have not been saturated yet) and new sectors. If the first effect is near 10% per year, demand should increase at the same pace to maintain stable the unemployment rate. However initial sectors are saturated at start in real terms, by assumption. We need new

sectors which are created endogenously in the model. Firms cannot decide exactly when new sectors will appear because the innovation process is random. As the increase in demand is weaker than the pace of job destruction, the unemployment rate keeps increasing, and a depression feedback takes place.

In the the illustration for one run of figures 4.57, 4.59, and 4.61, even if the diffusion rate reaches 100% in many sectors, there are strong variations from one period to another. Strong process innovation leads to strong variation of firms price. When a firm orders and receives a high quantity of a new generation of capital, its price drops quicker than other firms which did not order. Since price may vary strongly, the competition is very strong. Demand changes rapidly between firms which have difficulties to follow. The anticipation of their capital needs can also be false because they do not anticipate the new price of their competitors. It explains a high dynamics of creations and bankruptcies after some time. On average 8 bankrupt firms per period instead of 1 firm in the first phase of the simulation. When many firms go bankrupt, it has a high impact on total capital stock and total production capacity which is compensated by the creation of a high number of firms. It leads to strong variation in these two variables.

To summarise, when the process innovation is strong, increase in demand may not follow the same pace. Job destruction is stronger than job creation and it leads to increase of the unemployment rate. This has interesting results for income distribution. It yields a very dualist society in which the employed have a very high purchasing power twice the level in the baseline scenario, but unemployed are 55% of the population and live on unemployment benefits or minimum allowances. The high wages and incomes allow for the intense creation of new sectors and avoid a Keynesian recession.

Result 8 : No process innovation leads to an excess demand of labor, and this human resource constraint blocks the development of the economy, even inducing a fatal Keynesian depression. A strong process innovation rate generates a high technological unemployment but also high real wages and incomes. The society is dualist , and income distribution is very unequal. The recession is avoided by the combination of high real wages and minimum allowances. For long run growth, a process innovation neither too high nor too low is then a necessary condition.

4.3.3 Degree of complexity of new sectors

In this experiment, we test the effects of the initial characteristics of new sectors. A new sector may be low tech or high tech. Each new sector starts with the same initial quality level but the corresponding demand for each class of production competence is different according to its degree of complexity. At the initial quality level, a high tech sector is considered as a sector using many complex tasks and few simple tasks. It usually has a higher price in the beginning. At the same time, a low tech sector uses many simple tasks and few complex tasks. In the first case, the production coefficients A_{Pl} in the production

function of simple tasks ($l_P \leq 15$) are high and those of complex tasks ($l_P > 15$) are low at initial level of quantity. We inverse for the second case.

The aim of this experiment is to test the complementarity of labor demand of new sectors with those of existing sectors. In existing sectors, as quality increases constantly, demand for complex tasks increases while those for simple tasks decreases. If a new sector is low tech, it can help to absorb unemployment in simple competence classes and maintains the unemployment rate low. If it is high tech, both old and new sectors have strong demand for complex tasks but the unemployment rate remains high in the simple competence classes. In the baseline simulation, we have an initial vector of production coefficients $[A_{P1}, A_{Pl2}..., A_{Pl}, ...]$ for the first sector. For each new sector, we draw randomly each A_{Pl} which may increase or decrease at most 3% of the corresponding value in the initial vector. In the low tech case, we reduce the value of A_{Pl} of simple tasks (a fixed percentage randomly chosen between 1% and 10% for all simple tasks) and increase the values of complex tasks coefficients. For high tech sectors, we inverse the algorithm.

i) Low tech sectors

The figures of diffusion rate in figures 4.62, 4.64 and 4.66 have the same form as in the baseline simulation. We then look at table 4.3, we see that when new sectors are low tech, they require a high quantity of simple tasks in the beginning. Their labor demand is complementary with those of existing sectors, and the economy avoids a depression. However there is an excess demand for simple competences and this limits the expansion of the economy.

This main result is complemented by the other results in table 4.3. They are stable in real term (a stationary state instead of a steady growth growth in the baseline simulation) : real total sales, consumption sector sales, capital sector sales, unemployment rate, real capital stock, average wage. Contrary to the baseline simulation, the CPI increases constantly from 100 to 180. Nominal variables increase in general at the same pace as the CPI. The real wage then does not increase after the first phase, so that demand does not increase, as opposed to the case of the baseline scenario.

ii) High tech sectors

In the figures of diffusion rate (4.63, 4.65, 4.67), demand of many new sectors remains low, compared to those of low tech sectors case and of the baseline simulation. We propose two explanations. First high tech products are more expensive in the beginning. Individuals have less residual budget to consume products in the new sectors. Second as new sectors require a high number of complex tasks, they are in competition with existing sectors. Higher tension in complex competences blocks seriously the economy because of the complementarities between the different competences in the production process (Leontief). The proportion of firms which cannot recruit remains high at 40% while it decreases to 20% in the baseline simulation and to 15% in the low tech case. Competence supply adjustments (in education, promotions and training) cannot follow competence demand change. As firms cannot produce what is demanded, they reduce the number of employees with simple competences who are complementary to those competences in excess demand. The

Variables	Baseline Simulation	Low tech sectors	High tech sectors
Innovation dynamics			
Aggregate innovation rate	Stable at 15%	17% in average	8%
Aggregate quality innovation rate			
New sectors	16 new sectors over the simulation	22 new sectors	20 new sectors
Aggregate R&D investment rate	Stable at 10% of total sales	11%	12%
Growth dynamics			
Real total sales	Its index increases from 100 to 160, especially in the third phase where consumer price index (CPI) decreases.	It is stable at 110 over the simulation.	It increases from 100 to 140 in the first phase, drops to 100 in the second phase and remains at this level until the end.
Consumer price index	It increases from 100 to 160 in the first 50 periods before dropping and remaining stable at 120 until the end.	It increases constantly from 100 to 180.	It is stable at 110 in the first phase, constantly increases to 140 in the second phase and remains at this level until the end.
Capital price index	It increases from 100 to 200 in the first two phases and remains stable at 200 in the third phase (steady growth).	Same	Same

Variables	Baseline Simulation	Low tech sectors	High tech sectors
Consumption sector sales	It remains stable at 100 before increasing strongly from 100 to 200 in the third phase.	It stays at 100 over the simulation.	It increases from 100 to 140 in the first phase, then drops and stays at 100 in the last two phases.
Capital sector sales	Its index stays at 100 in the first and third phases while it increases and stays at 150 in the second phase.	It is stable at 200 in the first phase and at 110 in the last two phases.	It is stable at 80 in the first phase and at 40 in the last two phases.
Diffusion rate		See graphics	See graphics
Real capital stock	Index increases from 100 to 200.	It is stable at 130 in the first phase and at 80 in the last two phases.	It increases from 100 to 120 in the first phase then drops and stays at 50 in the last two phases.
Aggregate physical capital investment rate	It remains stable at 15% of total sales.	Same	It is stable at 10%.
Total number of firms	It increases from 12 to 180 firms over the simulation.	It increases from 12 to 160.	It increases from 12 to 80 in the first phase and remains at this level until the end.
Creation of new firms	In average 3.5 firms per period.	2.5 firms per period, with a higher number of 4 firms per periods in the third phase.	3 firms per period in the first phase and 2 firms in the two last phases.
Firms' bankruptcy	In average 1.5 firm per period.	Same	1 firm per period in the first phase and 2 firms in the two last phases.

Variables	Baseline Simulation	Low tech sectors	High tech sectors
Employment dynamics			
Unemployment rate	Stable at 10%	Stable at 16%	It is stable at 15% in the first phase, at 35% in the second phase and at 45% in the third phase.
Unemployment rate of researchers	Less than 1%.	1% in average	1% in average
Real average wage	Index increases from 100 to 200.	It increases from 100 to 120 in the first phase and remains at this level until the end.	It increases from 100 to 140 in the first phase and remains at this level until the end.
Real minimum wage	Index increases from 100 to 200.	It increases from 100 to 120 in the first phase and remains at this level until the end.	It constantly increases from 100 to 140.
Rotation rate in labor market	8% in average	8%	7%
Entry rate in labor market	8% in average	6%	4%
Exit rate in labor market	8% in average	9%	10%
Other variables			
Aggregate average propensity to consume	0.88 in average	Stable at 0.85	It is stable at 0.92 in the first phase, constantly decreases to 0.72 in the second phase, then drops quickly and remains stable 0.6 in the third phase.

Variables	Baseline Simulation	Low tech sectors	High tech sectors
Task excess demand	High excess demand in complex tasks. High wage heterogeneity between competences and between firms, especially in complex tasks.	High excess demand in simple tasks because of new low tech sectors.	High excess demand in complex tasks because of strong competition of new high tech sectors.
Percentage of no-recruiting firms	Increase from 30% to 70% in the first two phases and stability at 20% in the steady growth.	It is stable at 45% in the first phase, at 60% in the second, and finally drops quickly and remains stable at 15% in the third.	It is stable at 40%.

TABLE 4.3 – Table of comparison between baseline, high tech and low tech sectors.

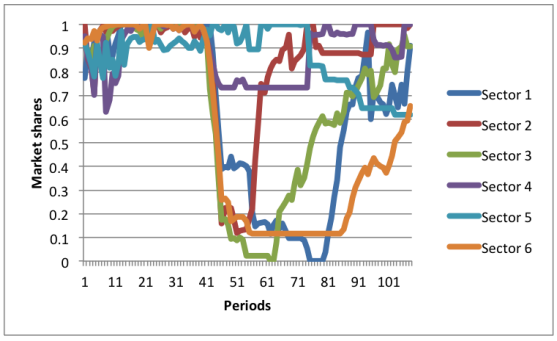

FIGURE 4.62 – Diffusion rate of six initial sector - Low tech sectors case

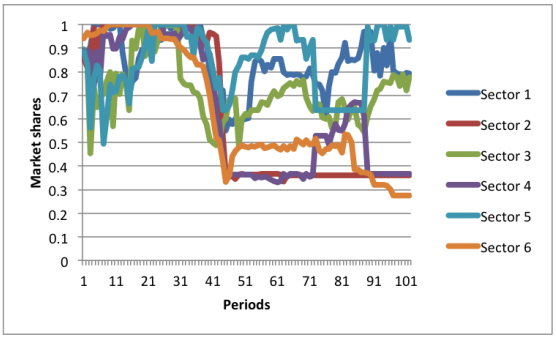

FIGURE 4.63 – Diffusion rate of six initial sector - High tech sectors case

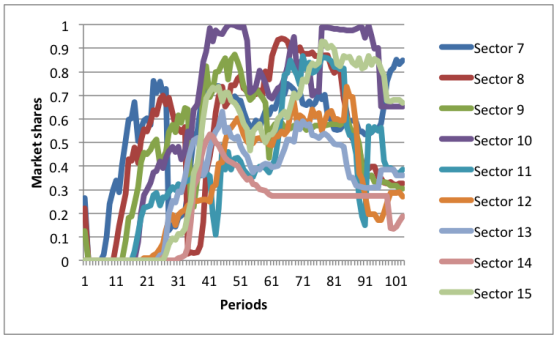

FIGURE 4.64 – Diffusion rate of new sectors discovered in the 50 first periods - Low tech sectors case

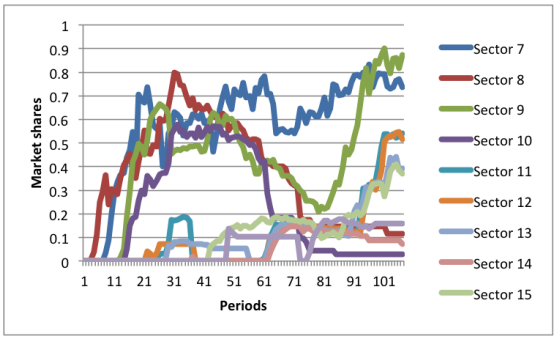

FIGURE 4.65 – Diffusion rate of new sectors discovered in the 50 first periods - High tech sectors case

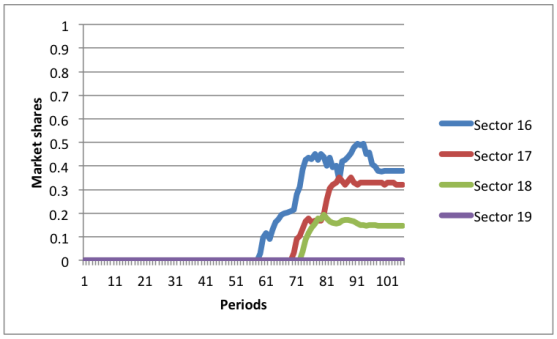

FIGURE 4.66 – Diffusion rate of new sectors discovered in the 50 last periods - Low tech sectors case

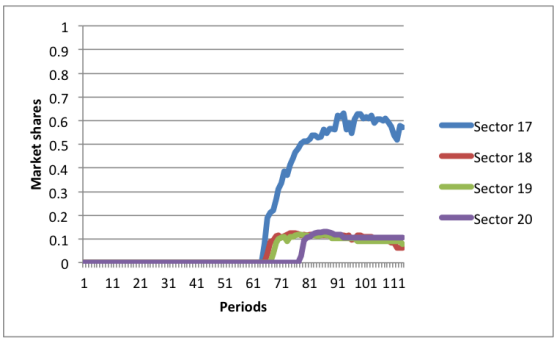

FIGURE 4.67 – Diffusion rate of new sectors discovered in the 50 last periods - High tech sectors case

unemployment rate then, in a paradoxical manner, increases constantly from 15% to 45% in the third phase. The human constraint on complex competences traps the economy in a Keynesian recession. In the long term, macroeconomic results are then poor : stagnation of total sales, of consumption sector sales, increase of unemployment rate. To summarise :

Result 9 : An economy in which new sectors are all high tech, requiring complex competences, faces an excess demand for these competences, which blocks growth, and by complementarity, generates unemployment in the simple competences and a Keynesian depression with high unemployment. An economy with all new sectors low tech, also generates excess demand, but on simple competences, and induces simply a stagnation, with a level of unemployment only somewhat higher than in the baseline scenario. The baseline scenario, with firms with more balanced requirements at entry, generates a long run growth, as studied.

4.3.4 Agressive and defensive strategies in sector innovation

In this experiment, we test two regimes of sector innovation. In the agressive regime, when the operating margin is higher than a certain threshold (12% in the computation), all firms who make at least this margin try to enter a sector new to them, in order to diversify their product portfolio. In the defensive regime, they all try to enter a new sector when the operating margin decreases under a critical threshold, to avoid failure. this is in contrast to the baseline simulation, in which each firm with a 50% probability each period is in a regime or the other. In the present experiment, all firms adopt the agressive or defensive regime until the end of the simulation.

The experiment of sector innovation regime has an impact on the total number of new sectors created over the simulation. The dynamics of sector innovation have great impact on the results. As showed in the figure 4.47, the average operating margin rate was 6% in the baseline scenario. A great number of firms has in all experiments have a low operating margin and they are under the threshold. A higher number of firms then tries sector innovation in the defensive regime.

i) Agressive regime

In the aggressive regime, only 11 new sectors are created instead of 16 in the baseline simulation (table 4.4). Only 2 firms are created per period instead of 3.5 firms in the baseline. Only 90 firms are present at the end of the simulation instead of 180 in the baseline scenario. As There are less firms and less sectors competition for consumers is tougher and it decreases the average operating margin rate of the sectors. The investment fund does not have many opportunities to create new firms.

The unemployment rate is high at 40% for two reasons : (1) low creation of new firms, (2) total demand does not increase in the model, since creating new products is a condition of growth to avoid demand saturation. Real total sales and real consumption sector sales are stable at 100 over the simulation. However, and this shows the importance of income distribution in the model, the figures 4.68, 4.70 and 4.72 show that for many products,

Variables	Baseline Simulation	Aggressive Regime	Defensive Regime
Innovation dynamics			
Aggregate innovation rate	Stable at 15%	Stable at 8%	Stable at 8%
Aggregate quality innovation rate			
New sectors	16 new sectors over the simulation	11 new sectors	21 new sectors
Aggregate R&D investment rate	Stable at 10% of total sales	Stable at 12%	Stable at 11%
Growth dynamics			
Real total sales	Its index increases from 100 to 160, especially in the third phase where consumer price index (CPI) decreases.	It is stable at 100 over the simulation, with little recession at t=40 as in the baseline simulation.	It increases from 100 to 140 in the first phase, stays stable in the second phase and strongly increases to 200 in the third phase.
Consumer price index	It increases from 100 to 160 in the first 50 periods before dropping and remaining stable at 120 until the end.	It decreases in the first period from 100 to 80 before constantly increasing to 160 until the end.	It is stable at 110 over the simulation.
Capital price index	It increases from 100 to 200 in the first two phases and remains stable at 200 in the third phase (steady growth).	Same	It increases slightly from 100 to 130 in the first two phases and strongly from 130 to 250 in the third phase.

Variables	Baseline Simulation	Aggressive Regime	Defensive Regime
Consumption sector sales	It remains stable at 100 before increasing strongly from 100 to 200 in the third phase.	It is stable at 100 over the simulation, little recession in t=40 as in the baseline simulation.	It increases from 100 to 150 in the first phase, stagnate in the second phase and increase to 200 in the third phase.
Capital sector sales	Its index stays at 100 in the first and third phases while it increases and stays at 150 in the second phase.	It is stable at 70 over the simulation.	Stable at 50 over the simulation.
Diffusion rate		See graphics	See graphics
Real capital stock	Index increases from 100 to 200.	It is stable at 100 in the first phase, suddenly drops to 20 in the second phase and stabilizes at 70 until the end.	It remains stable at 100.
Aggregate physical capital investment rate	It remains stable at 15% of total sales.	Stable at 20% in the first phase and 10% in the two last phases.	Stable at 15%.
Total number of firms	It increases from 12 to 180 firms over the simulation.	90 firms at t=100	It increases constantly from 12 to 130 in the first two phases but stagnate at this level until the end.

Variables	Baseline Simulation	Aggressive Regime	Defensive Regime
Creation of new firms	In average 3.5 firms per period.	2 firms per period	Constant increase from 1 to 5 firms per period in the first two phases but stable at 2 firms per period in the third phase.
Firms' bankruptcy	In average 1.5 firm per period.	1 firm per period	1 firm per period in the first two phases and 2 firms per period in the third phase.
Employment dynamics			
Unemployment rate	Stable at 10%	Stable at 40%	Stable at 15%
Unemployment rate of researchers	Less than 1%.	2% in average	1% in average
Real average wage	Index increases from 100 to 200.	It increases in the first phase from 100 to 160, drop to 120 in the second phase and increases constantly to 150 at t=100.	It increases constantly from 100 to 220.
Real minimum wage	Index increases from 100 to 200.	It increases in the first phase from 100 to 160, drops to 120 in the second phase and remains stable until the end.	It increases constantly from 100 to 208.
Rotation rate in labor market	8% in average	8% in average	6% in average

Variables	Baseline Simulation	Aggressive Regime	Defensive Regime
Entry rate in labor market	8% in average	5% in average	4% in average
Exit rate in labor market	8% in average	10% in average	8% in average
Other variables			
Aggregate average propensity to consume	0.85 in average	Stable at 0.88 in the first phase and at 0.75 in the two last phases.	Stable at 0.9 in the first two phases and at 0.75 in the third phase.
Task excess demand	High excess demand in complex tasks. High wage heterogeneity between competences and between firms, especially in complex tasks.	High excess supply because of high unemployment rate.	Higher excess demand in simple tasks than in baseline because of demand of new sectors.
Percentage of no-recruiting firms	Increase from 30% to 70% in the first two phases and stability at 20% in the steady growth.	Stable at 35% in the first 50 periods and at 20% in the last 50 periods.	Stable at 40% of firms in the first two phases and at 18% in the third phase.

TABLE 4.4 – Table of comparison between baseline, aggressive and defensive regimes.

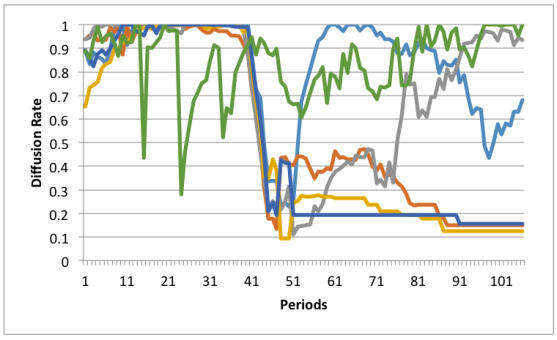

FIGURE 4.68 – Diffusion rate of six initial sector - Agressive regime

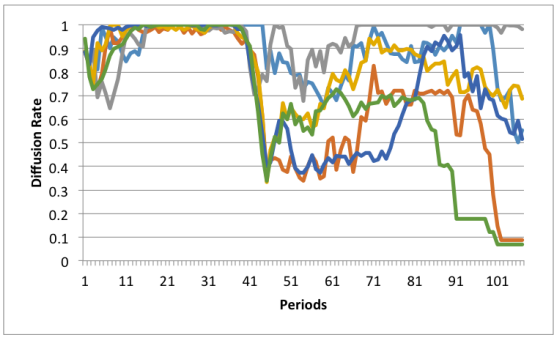

FIGURE 4.69 – Diffusion rate of six initial sector - Defensive regime

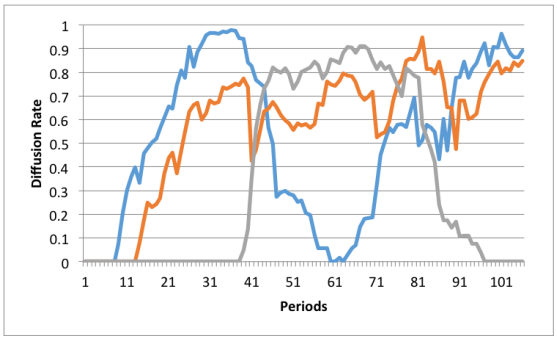

FIGURE 4.70 – Diffusion rate of new sectors discovered in the 50 first periods - Agressive regime

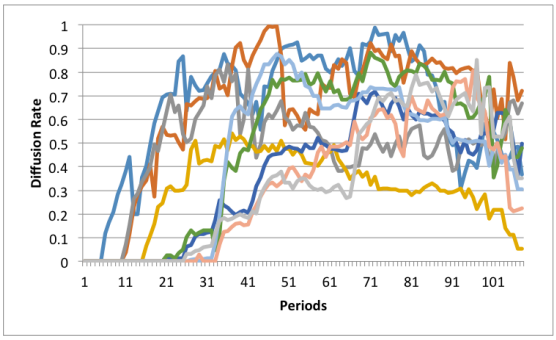

FIGURE 4.71 – Diffusion rate of new sectors discovered in the 50 first periods - Defensive regime

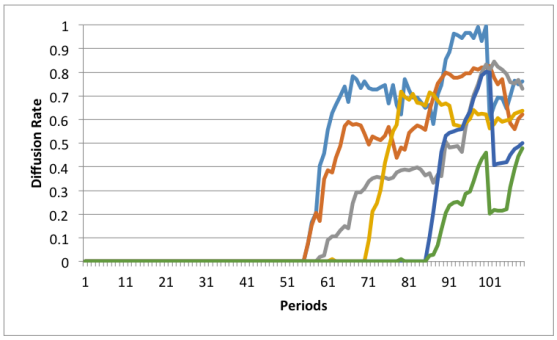

FIGURE 4.72 – Diffusion rate of new sectors discovered in the 50 last periods - Agressive regime

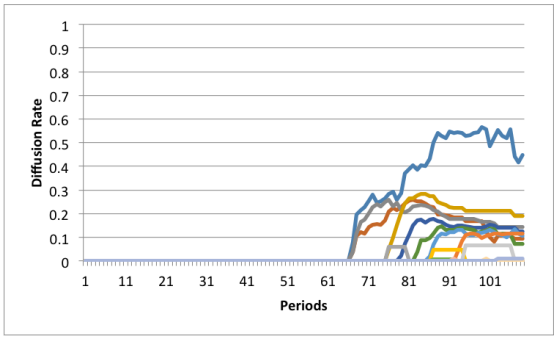

FIGURE 4.73 – Diffusion rate of new sectors discovered in the 50 last periods - Defensive regime

the diffusion rate is high. They cater to the employed workers who have a long run rise in wages similar to the baseline scenario. Yet there are less products and their demand is saturated. Moreover unemployed have low incomes, nad this does encourage the creation ofnew sectors.

ii) Defensive regime

There are more new sectors than in the baseline simulation, 21 versus 16 since more firms innovate in new sectors. However the aggregate innovation rate is lower, only 8% against 15% because each firm has to allocate its R&D effort to more innovation projects (it tries to innovate in quality as well). Real total sales and real consumption sector sales increase faster, from 100 to 200 instead of 160 in the baseline. The CPI is lower because we have more new sectors with lower average price.

However, the unemployment rate is stable but higher (15%) than in the baseline simulation because of a weaker dynamics of creation of new firms.The number of new firms per period increases constantly from 1 to 5 firms in the first two phases but decreases to only 2 firms in the steady growth, with more bankrupt firms. The total number of firms stagnates at 130 from the beginning of the third phase until the end of the simulations. The figures for one run, 4.69, 4.71 and 4.73 show a wide range of diffusion rates, with most new sectors finding a market.

To summarise, first this experiment would need to test for the minimum operating margin in the case of the aggressive regime, and the maximum operating margin for the defensive regime. Second, yet, as it is, it adds to our understanding of the important role of the number of sectors for growth in the model :

Result 10 : When the number of sectors remains low (as in the offensive regime), demand is saturated and growth remains low. When many sectors are created (as in the defensive regime), demand can grow, and the economy grows.

4.4 Conclusions on SIMECO 2

SIMECO 2 displays an endogenous growth model with new features. It adds essential elements to the rare models with product innovation in which demand of new products is a condition for growth since it gets saturated otherwise ([Matsuyama, 2002], [Aoki and Yoshikawa, 2002]). The main element is the competences constraint on production. It is modeled not just as a limited labor supply, but for the first time, as a vector of competences. Then as quality increases, and in one experiment as new sectors are high tech, production requires a higher proportion of complex competences and a lower proportion of simple competences. This induces an excess demand in complex competences, and strangles growth. Moreover, as the production process requires technological complementarities between the different competences, unemployment may rise and Keynesian traps may appear.

Not only product innovation appears as a condition of growth in real terms. The limitation of the excess demand on competences, specially complex competences appears as a condition for steady growth. In the baseline scenario, rising quality induces some excess demand, but training and promotions, and in the long run, the adaptation of initial education allow for some adjustment, and a slow real growth rate.

The change in the structure of labor demand towards higher competences appears as a stylised fact that has been popularised as skill biased technical change (SBTC). The later change is now studied in more depth as the task biased technical change (TBTC), and the model is conceived in terms of tasks. As exposed, however, the task structure changes in the SIMECO 2 as a direct result of change in technology when a a new quality variety or a new product (when new sectors are low or high tech), and not indirectly through a change in the relative wages structure or the relative price of capital. This links in a clearer manner the constraint on competences supply to product innovation and demand.

SIMECO 2 then builds a system of interactions which emphasises essentially three factors : product innovation, demand and the competence constraint. However a fourth factor, the financial constraint, is also present both at the micro level since firms can be financially rationed on capital investment and on R&D investment, and at the macroeconomic level since the model is Stock Flow Consistent, and any real flow has its financial counterpart. It constitutes the fourth factor.

There are mutual interactions which take place in this system, as between product innovation and demand development, but also financial funding and the creation of new sectors versus funding old sectors. However in fine, with the reserves that must be made since the financial constraint has not yet been explored fully (by sensitivity analyses on the parameters), the competence constraint appears the most binding. This has been illustrated by the figure on the 4.44 which shows that capital equipment is less binding, and by several experiments. The experiment on high tech shows that the increase in demand for complex competences induces an excess demand and by complementarity a high unemployment in the simpler competences, and finally a Keynesian depression (result 9). The experiment on process innovation shows that if new generations of capital are not more efficient, an excess demand takes place particularly for complex tasks, and the economy collapses (result 8). This result of the model is a coherent formalisation of the increasing recognition that the growth rate of an advanced economy requires more competences. The acknowledgment remains timid in France, though, since unemployment is high in 2019 at 8.8%. It is difficult to admit that firms cannot hire in such a situation, that many of them have an excess demand, and that growth will not come back until a massive improvement in the supply of competences, notably the most complex, has been obtained, and that this will take many years, since, as the model features, initial education treat only entering cohorts and moreover, lags[10]. Either unemployed are blamed for not accepting the jobs, or employers are blamed for being too selective, or offering too low wages. In the model, however, unemployed decrease their reservation wage with time. Employers increase the offered

10. see the figures in the introduction

wage in response to excess demand, and they accept to promote and training workers even several steps in the hierarchy of competences. it does not prevent that in the optimistic baseline scenario, 20% of firms cannot hire, and in the experiments mentioned, higher figures, and the strangulation of the economy. Naturally a more detailed analysis of wages and reservation wages would need to be done, and the model is not calibrated, but the different mechanisms are in the model.

The interactions between the four factors which condition growth, when studied in the baseline scenario and the different experiments show that growth is fragile. When we set assumptions different from those made in the baseline scenario, it is difficult to obtain a steady growth. There are several reasons. An important one is that the experiments study extreme cases in order to make clear the effect of the factor studied. Another is the effect of the initialisation assumptions that favor a crisis after a number of years. Then the economy faces a problem different from the problem of pursuing growth. It has the problem of getting off this crisis. This is not obvious in a Keynesian recession with rigid nominal wages, and no endogenous anti-cyclical policy. Yet this crisis is an artificial experiment which enables us to analyse the mechanisms of the recovery or its impossibility. When the recovery takes place, as in the baseline scenario, it is through a creative destruction in which new firms in new sectors and demand interact to initiate a new growth process. But other situations may arise as well. Notably, when there is a strong process innovation in capital equipment, the excess demand generates a dualist economy in which employed workers have high wages and firms create new products for them (Result 8). There is growth while the unemployment rate represents half of the population. More generally the income distribution plays a great role in the model, since high income consumers allow a new sector to develop, and this income distribution has the advantage to be endogenous, a intellectually more satisfactory status for an ABM.

It does not appear as a rewarding exercise to compare the model results with the few growth SFC Agent Based Models we know about, essentially EURACE ([Dawid et al., 2016], [Dawid et al., 2018]) , [Caiani et al., 2018], and the K+S model by [Dosi et al., 2019] since they do not introduce new products. [Ciarli et al., 2019] does not consider individual workers/consumers, but social groups, does not deal with heterogeneous competences, has an infinite labor supply and cannot study the human resource constraint. The TEVECON model by [Saviotti and Pyka, 2013] is not an ABM and does not deal with the human resources constraint. These models bring interesting contributions to the analysis of growth but the frameworks are too different to compare the results. SIMECO 2 then brings as main contributions to the ABM literature, new products and the role of demand in growth, and the human resource constraint with heterogeneous competences. It seems to bring some other novel results such as a rising inequality between competences or skill classes (Result 5) as quality increases, a feature of advanced economies as the new more sophisticated products and services arise. It also displays the positive correlation between market share and mark up rates in a hierarchic endogenous market structure (Result 6), which characterises the global competition of early XXIth century. This latter result is the fruit of a precise

modeling of competition on the quality and product market with entry and exit (with a SFC validation). The model also brings several specific contributions to behavior modeling which will need more thorough analysis. First it provides mechanisms to model the link between product innovation and the change in the structure of the tasks (experiment on high tech and low tech). Second it introduces overtime, endogenous training, promotions, reclassification and downgrading as the only means of adjusting the labor force to demand, besides hiring, within a plant or product line dedicated to a given product and quality, during a period. Changing the mix of competences and capital if relative prices change, as in the neoclassical mode, is not an option. We then present an alternative to the standard approach in task modeling in which the (firm) production function with the substitution of tasks does not take into account the technological and organisational constraints on workers allocations and their asymmetric nature (automation or training cannot be reversed, and reclassification and downgrading are costly, by labor law). Third it introduces a savings function which includes an effect of the income rank (representing social imitation) to explain the stability of the aggregate saving rate over long periods of growth, and consumption increases in the creation of new products. Fourth we can also mention the differentiation of behavior (aggressive versus defensive) when deciding to invest in entry in new sectors. We keep for the general conclusion the contributions of SIMECO 1 which have been kept in SIMECO 2.

The present version of the model is the first, and the model will have to be analysed in more depth, corrected to take into account better specifications for some behaviors, such as wage, price, and the interest rate settings, and to introduce some extensions such as a more important level of government expenditures. Its calibration can then be improved, for a use in analysis and policy discussion, which however should be considered as thought experiments, and not quantitative policy advice. We leave other possible extensions to the general conclusion, to avoid repetition.

Conclusion

General results

In this dissertation, the concept of competence is central and helps to explain the dynamics of economic growth or slowdown. The competence building process is studied through two models but each one focuses on different features. In the first model, competences are at the firm level. The building process depends on firms learning by doing with dynamic increasing return and competence transfer within the alliances. In the second model, competences are held by individuals. They evolve because of individual learning by doing with accumulation of competences on the career. Additionally firms can training. It allows to individuals to acquire new competences and maintains the demand excess in complex task at the reasonable level.

Competence building allows to increase the productivity of labor factor and income over the long run. The first model is a diffusion model with one product in consumption sector. With rise in income, the product becomes more affordable to an increasing number of consumers of individuals and the wealthiest buy higher incoming quality. However, in the long term, the market becomes saturated. In the second model, new sectors are introduced. On the demand side, consumers with higher residual incomes after consuming the first product continue to buy new products. On the supply side, the takeoff of new sectors is favored by process innovation from the capital sector and higher level of education of new generations of individuals. The unemployment rate does not increase in the long run because job destruction by process innovation is compensated by job creation by higher diffusion of existing products up to saturation and by new sectors.

Competences are heterogeneous. Firms change their demand for different classes of competence according to the change in characteristics of existing varieties and demand of new sectors. We assume that when the quality level increases, firms must increase their demand for high competences at the expense of low competences. In SIMECO 1, the lack of high competences makes a firm less competitive, and leads to possible failure. In SIMECO 2 new sectors have the same demand for competence than the old sectors at entry, but in experiments, they can be high tech or low tech, and need more high or low competences. At the aggregate level, we observe excess demand in complex tasks which explain higher wage inequality over the simulation. This excess demand has a negative effect on the economy because it limits firms production. However in the baseline scenario, it is kept at a reasonable level because of the adjustments of competences supplies. The education system forms new generations of individuals and takes into account the excess demand on the labor market to orient the supply. Firms have many internal tools to meet their competence demand such as training, promotion and reclassification. In this dissertation, our explanation of the observed excess demand in complex tasks and the increasing wage inequality is different from the task-based approach in the literature. The model first considers, in a traditional way, that new equipment increases the productivity of (all) tasks rather than replacing them directly as in the literature since [Autor et al., 2003]. Second competences produce tasks, and they are not substitutable since competences are knowledge in practice, while in the mainstream task approach, skills relate informally to

education and are then substitutable although with a comparative advantage. Competences are in our two models accumulated, and a source of process innovation. Third competences structure then changes with the quality of product and possibly with product innovation, so that our view of TBTC is based on technology evolution directly rather than on the relative costs of the neoclassical literature.

In addition to these global results, each model has other specific results.

Results of the first model

In the first model, we prove the persistence of R&D alliances with a parsimonious setting in which there is only cognitive embeddedness. This is a contribution to the management literature which usually combines this motive with social (relational and structural) embeddednesses to explain the persistence of alliances to counteract the increase of uniformity through competences sharing. For us, trust and reputation cannot counteract the convergence to uniform competences. The lack of competence complementarity does not maintain the economic efficiency of alliances not only at the micro level but also at the aggregate level in the long run. We build a new theoretical framework where we distinguish two types of behaviors of partners in an alliance : they consider some competences as strategic and some as non strategic. This distinction is close to the concept of core competencies in the management literature where firms try to sustain their competitive advantage. They do not transfer the content of their strategic competences. This has the effect that each partner builds a specialisation profile, and that diversity of competences among firms is maintained in the long run.

An another contribution is the modelling of the competition on the consumption product market. In the management literature, the emergence of R&D network depends on firms interaction in the competence building and innovation process. The production department and the competition between firms are let aside. Our model is a co-opetition one where firms cooperate in research but are competitors on the market for the product. It is a precise, and a Schumpeterian way, to obtain the consequences of the distinction between strategic and non strategic competences. Through experiments We find that the mix of integration versus specialization modes of tasks allocation in alliances is necessary to maintain obtain the persistence of our alliances in long term, and also a continuous increase of the diffusion of the product among the population.If partners treat all their competences as either strategic or non strategic, the alliances vanish, and also diffusion is not complete.

The emerged R&D network presents properties of a small world one sees in the literature. However, contrary to the the management literature, this network is obtained by the formal modeling of competition on the product market and the dynamics of entry and exist of firms. The market structure is endogenous and feeds back on R&D, innovation rate, and diffusion of the product. The distribution of market shares and marks up is endogenous. They are highly skewed and positively correlated, a major stylised fact of industrial orga-

nisation observed in the beginning of the XXIth century, little modelled, yet also of major economic and social importance.

Results of the second model

In the second model, we build an endogenous growth model based on quality product innovations, especially the introduction of new sectors to desature demand. Real income increases as a result of the rise of productivity based on the rise of initial education and capital efficiency. Higher incomes allows to consume higher quality and new goods. In the baseline scenario, the demand for each new product follows a diffusion pattern which has often a (noisy) logistic shape, but does not necessarily go to saturation, since the order on products is not strict as in Matsuyama. New sectors appear in the course of time. Excess demand is shown to be limited to reasonable level in the baseline scenario, in spite of quality innovations, by the mechanisms of overtime, training, promotions which increase the supply of competences most demanded. The distribution of the market shares between firms and the distribution of mark up rates are highly skewed and positively correlated, as a result of endogenous market competition in qualities and sectors, as in SIMECO 1 .

The baseline simulation shows the existence of keynesian crisis in the model. Exit of this crisis is obtained by the emergence of new sectors and by young firms which provide good quality/price ratios. The economy sets out of recession by the mechanism which combines Keynesian and Schumpeterian features in a novel manner, based on new products, demand rise and some inequality in incomes, the high income household bringing demand to the new sectors as in Matsuyama.

In the second model, we have realized different experiments to check the sensibility of our results with some assumptions. Above all, it allows to understand better the role of effects of induced effects demands of competences as a constraint on the growth process..

The first consists of changing the utility function. The lexicographic ordering of products involves an increase in constrained consumption, if the quality and price of low ordered products rises, and this prevents the development of new sectors and generates stagnation and high unemployment. This is a major difference with [Matsuyama, 2002]'s smooth flying geese pattern, and could be a possibility in the real world if the low ordered products see their cost rise (energy, housing) rather than decrease.

The second experiment checks the intensity of process innovation on growth and employment. Process innovation plays an important role in explaining the long term growth. On the demand side, it allows to reduce the price of existing products which become more affordable to a larger number of individuals. On the supply side, it frees the labor factor which will be used in new sectors. It is particularly important since the size of the population remains constant in the model. The history of the first industrial revolution shows the importance of gains in productivity in agriculture to the takeoff of industrial sectors. However, for long run growth, a process innovation neither too high nor too low is a necessary condition. To obtain the stability of the unemployment rate, job destruction by process innovation should be compensated by job creation due to increase in demand.

If process innovation is too strong, it can lead to high unemployment rate and then a keynesian crisis. If it is too weak, the price of existing products does not decrease and new sectors cannot take off.

In the third experiment, we show that the characteristics of new sectors play a great role. In existing sectors, the rise in quality leads to a higher demand for complex competences. If new sectors are high tech, it leads to a strong competition between firms in these competence classes. Excess demand blocks growth and has a negative effect on employment. On the contrary, when all new sectors are low tech, they generate excess demand on simple competences, and can generate a simple stagnation. These second and third experiments confirm that competences insufficient supply, especially in the complex competences, can be a severe obstacle to growth, even if innovation and financial funds are present. These results should be looked as the most novel.

The last experiment shows the role of the rate of innovation in sectors. When the number of new sectors creations is low, demand is saturated and growth remains low.

Extensions

In the future, many extensions and new experiments will be considered.

1/Extensions on alliances and network for SIMECO 1

a) In the first model, firms do not take into account the position in the network as strategies. In reality, firms usually try to increase their centrality in order to get more competence transfer from other firms and consequently increase their innovation result. It may change the form of the emerged network because firms do not have the same motive for creating alliances.

b) In the alliances may not be anymore dyadic. We can extent to alliances with many partners.

2/ Extensions for SIMECO 2

c/ New competences to innovate would be very necessary in the very long run, since the rate of creation of new sectors is by our assumption decreasing in the number of existing sectors, as an implementation of the idea that the set of competences types puts bound to innovation. Alternatively this assumption could be changed.

d) In the production department, new production competences may appear with new sectors. It will change our results on competition because a new condition for existing firms to enter new markets would be the acquisition of new competences. Additionally innovating firms may take advantage of their monopoly power for a longer period of time because new entries have a low stock level in new competences while presently in the model, they can transfer their employees to produce new products.

e/ Several competences could be needed to do one task. This would correspond to the recent empirical studies on competences that we mentioned. New tasks could also appear. This would lead to major extensions of the model, particularly needed to tackle the question of the impact of the numerical tools as replacing or helping the workers, a subject so broad to treat in depth that we have left it for future work.

The behavioral functions of some agents need to be considered in more details.

f) The financial features need to be studied in more depth, and could be developed in response. For the bank, the interest rate may be determined in the credit market where the interactions between bank and firms take place. Several banks may be created and be in competition to attract deposit from individuals. It may lead to new results on business cycle and crisis and we may obtain new mechanisms to exit Keynesian crisis in the model.

g) For the capital sector, the competition may be modelled as in the consumption sector. Several capital firms may be created, have a research department, and the efficiency of the capital good could be made endogenous.

h) The investment behavior of individuals and of the investment fund could be extended and we can introduce more experiments. Presently the investment fund, when deciding to create new firms, gives priority to old sectors. If many sectors have an average operating margin rate higher than some level, it creates firms in the first sectors. We may realize an experiment where it ranks the average operating rate of all sectors and starts by the most profitable ones. As each sectors does not have the same characteristics and do not require the same number of employees (effect of previous process innovations), some results may change because demand and employment will change.

i) The price of a capital share remains constant at 1 euro in the model. We may introduce a simple financial market where the interaction between capital share supply and demand will determine its price. The investment fund will have a new objective of maximizing the value of its capital stock.

j) The government may become more active. It can use a progressive income tax system. Fiscal policy experiments may clarify the role of income distribution on demand, innovation and growth. In the literature, there exists a debate on whether an equal or unequal income distribution fosters the economy. For instance, the existence of individuals with high income level favors the emergence of new products. New products being expensive at the beginning because of the lack of process innovation, the high-income individuals have important residual budget and they will consume them. Their initial demand should be large enough to allow firms in these sectors to survive. Over time when process innovation becomes stronger, their price decreases and they become more affordable to the rest of the population. We move from a small consumption to a mass consumption. However, if the income distribution is too unequal, the gap between high and intermediary-income level individuals is large, and the transition from a niche market to mass market cannot take place. An example of the importance of income inequality is the case of the dualist society that we find when process innovation is strong (result 8).

k) We can add new policies to adjust more quickly or more slowly the competence supply and it has effect on growth and employment. Actually, in France, the training system does not depend only on firms but also on Pole emploi who can train unemployed to acquire new competence and to favor their return to work. Continuous training can be extended to situations others than the one we have considered : training only when a job is vacant, and impossible to fill through the labor market. In France, each employee has

a personal training account and can use this amount to follow training courses to acquire new competences. We may give also added interest to firms for training. It allows a more flexible adjustment to the evolution of competence demand.

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Annexes

A Aggregate balance sheet and transaction flow matrix in initial setup

	Individuals	Consumption Firms	Capital Firm	Bank	Unemployment Funds	Government	Central bank	Investment Funds	Total
Physical Capital		812852988.37							812852988.37
Immaterial Capital		517800079.46							517800079.46
Loans		-468359243.34	-77414570.32	545773813.66					0.00
Debt to government					0.00	0.00			0.00
Capital Share, Firms		-1368341865.00	-309658281.00					1678000146.00	0.00
Capital Share, Bank				-500000000.00				500000000.00	0.00
Capital Share, IF	2178000146.00							-2178000146.00	0.00
Deposit	96804513.85	407518763.00	72861000.00	-577184276.85	0.00	0.00		0.00	0.00
Bills						0.00	0.00		0.00
Reserves				0.00			0.00		0.00
Net Worth	-2274804659.85	98529277.51	314211851.32	531410463.19	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1330653067.83

FIGURE A.1 – Initial aggregate balance sheet

	Households	Consumption Firms		Capital Firm		Bank		UF	IF	Central Bank	Government	Total
		CA	KA	CA	KA	CA	KA					
Consumption	-377867599.98	377867599.98										0.00
Investment			-81285299.00	81285299.00								0.00
Wage	480379763.00	-364305000.00	-43213763.00	-72861000.00								0.00
Unemployment Contribution		-22768945.00	-8566245.00	-4553570.00				35888760.00				0.00
UF Debt								0.00			0.00	0.00
Unemployment Benefit	35888760.00							-35888760.00				0.00
Income Tax	0.00										0.00	0.00
Profit, Consumption Firms		18569454.52	-9284727.52						-9284727.00			0.00
Profit, Capital Firm				-2323167.00	0.00				2323167.00			0.00
Profit, Bank						-10909704.00	0.00		10909704.00			0.00
Dividends	3948144.00								-3948144.00			0.00
Interest on loans		-9367185.00		-1548291.00		10915476.00						0.00
Interest on deposit	968.00	4075.00		729.00		-5772.00		0.00	0.00		0.00	0.00
Changes in loans		0.00	0.00		0.00		0.00					0.00
Investment, IF			142350034.47						-142350034.47			0.00
Investment, Individuals	-142350034.47								142350034.47			0.00
Changes in deposits	0.00	0.00		0.00			0.00	0.00	0.00		0.00	0.00
Change in bills										0.00	0.00	0.00
Change in reserves							0.00			0.00		0.00
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00

FIGURE A.2 – Initial transactions-flow matrix

B List of symbols

Symbol	Description
A_{01}	Initial coefficient of production for simple tasks
A_{02}	Initial coefficient of production for complex tasks
A_{0l}	Initial task demand coefficient of production task l
A_{Kl}	Task demand coefficient of capital task l
A_{Pl}	Task demand coefficient of production task l
a	Parameter of the Pareto distribution
a_l	Efficiency ratio between two consecutive competence classes
B	Bills
b_l	Difference of stock level between two consecutive age classes
B_I	Innovation budget
B_I^E	Expected innovation budget
B_I^R	Real innovation budget
B_I^{min}	Minimum innovation budget
B_s^{min}	Minimum innovation project
B_{IP}	Sector innovation budget
B_{II}	Imitation innovation budget
B_s	Innovation budget of project s
b_I	Part of sales for innovation
b^{IP}	Part of budget for product innovation
b^{II}	Part of budget for imitation innovation
C	Consumption
C_i^E	Expected consumption budget of individual i
C_i^R	Real consumption of individual i
CF_l	Training cost to acquire a new competence l
D	Total debt
D_C	Debt of consumption sector
D_f	Debt of firm f
D_K	Debt of capital sector
D_U	Debt of Unemployment fund
E^S	Supply of capital shares
E^D	Demand of capital shares
E^R	Real supply of capital shares
E_B	Capital shares stock of banking sector
E_C	Capital shares stock of consumption sector
E_f	Capital shares stock of firm f
E_H	Capital shares stock of individuals
E_K	Capital shares stock of capital sector

Symbol	Description
ED_{flt}	Demand excess in competence l of firm f at t
F_B	Profit of banking sector
F_C	Profit of consumption sector
F_K	Profit of capital sector
FD_B	Dividend of banking sector
FD_C	Dividend of consumption sector
FD_f	Dividend of firm f
FD_H	Dividend of individuals
FD_{IF}	Dividend of investment fund
FD_K	Dividend of capital sector
FU_B	Residual profit of banking sector
FU_C	Residual profit of consumption sector
FU_K	Residual profit of capital sector
f	Firm
g	Technical progress of capital good in t
H	cash
IC_f	Self-financing capacity
I_C	Capital investment of consumption sector
I_f	Capital investment of firm f
I_f^E	Expected capital investment of firm f
I_f^R	Real capital investment of firm f
i	individual
k	quality
$\overline{k_s}$	Average quality of a sector s
K_C	Tangible capital stock of consumption sector
K_I	Intangible capital stock of consumption sector
K_f	Capital stock of firm f
K_0	Capital demand in stationary state
l	Task
L_{lf}^S	Labor supply by firm f in task l
L_{lf}^D	Labor demand by firm f in task l
L	Total number of competence classes in the economy
L_I	Number of innovation competences
L_{Ilf}	Number of workers in firm f owning the innovation competence l
L_K	Number of competences in capital sector
L_{Kf}	Number of workers in capital firm owning the innovation competence l
L_P	Number of production competences
L_{Plf}	Number of workers in firm f owning the production competence l

Symbol	Description
M	Total deposit
M_C	Consumption sector deposit
M_G	Government deposit
M_H	Individuals deposit
M_{IF}	Investment fund deposit
M_K	Capital Sector deposit
M_U	Unemployment fund deposit
M_{it}^A	Deposits level of individual i after receiving his wage
M_{it}^B	Deposits level of individual i before receiving his wage
n	Increase of capital firm mark-up per period
N_{TOT}	Total number of workers
N_C	Number of workers in consumption sector
N_K	Number of workers in capital sector
N_{LC}	Degree of local competition
N_U	Number of unemployed
N_{18}	Number of new individuals
NI_H	Net income of individuals
NW_B	Net wealth of banking sector
NW_C	Net wealth of consumption sector
NW_G	Net wealth of government
NW_H	Net wealth of households
NW_{IF}	Net wealth of investment fund
NW_K	Net wealth of capital sector
NW_U	Net wealth of unemployment fund
p_C	Consumption product price
p^E	Capital Share Price
p_f	Price of firm f
p_K	Capital price
Pr^{IP}	Sector innovation probability
Pr^{II}	Imitation innovation probability
Pr_s	Quality innovation probability in the sector s
R_{it}	Income of individual i
R_{it}^A	Income after tax of individual i
r_l	Interest on loan
r_m	Interest on deposit
Ra_i	Ranking of individual i on the revenue scale
RSA	Active solidarity income

Symbol	Description
s	Sector
s_a	Accumulation savings rate
S_{Ci}	Investment in equities of individual i
S_f	Number of sectors of firm f
S_t	Number of sectors at t
$Smic_t$	Minimum wage level at t
$Smic_t^C$	Competence minimum wage level at t
t	Period
T_G	Tax paid to the government
T_I	Total innovation effort
T_{Il}	Total of efficient units supply in the innovation task l
T^{II}	Imitation innovation effort
T^{IP}	Sector innovation effort
T_{Is}	Quality innovation effort in sector s
T_{Kl}	Total of efficient units supply in the capital task l
T_{Pl}	Total of efficient units supply in the production task l
U	Unemployment fund
ur	Unemployment rate
uc_C	Unit cost of consumption product
uc_f	Unit cost of firm f
uc_K	Unit cost of capital
U_i	Net utility of individual i
UB_C	Unemployment benefit paid by consumption sector
UB_F	Unemployment benefit paid by firms
UB_H	Unemployment benefit to individuals
UB_i	Unemployment benefit received by individual i
UB_K	Unemployment benefit paid by capital sector
UB_P	Unemployment benefit of production department
UB_R	Unemployment benefit of research department
v_{ijs}	Net utility of individual i when consuming one unit of variety j in sector s
V_{Iil}	Productivity of individual i in the innovation task l
V_{Il}	Productivity of the innovation task l
V_{Kl}	Productivity of task l to produce capital good
V_{Pil}	Productivity of individual i in the production task l
V_{Pl}	Productivity of the production task l
$\overline{W_{I1}}$	Average wage of innovation competence l
$\overline{W_{Pl}}$	Average wage of production competence l

Symbol	Description
w_{Il}	Wage of the innovation task l by efficient unit
w_{lft}	Task wage of firm f in task l at period t
w_{Pl}	Wage of the production task l by efficient unit
w_{Kl}	Wage of the task l by efficient unit of capital firm
W_{ilt}	Total wage of individual i in task l at period t
W_{il}^{R}	Reservation wage of individual i in task l
w_{ift}^{C}	Competence wage of individual i in firm f at period t
w_{ift}^{CR}	Reservation competence wage of individual i in firm i at period t
WB	Total wage bill
WB_C	Wage bill of consumption sector
WB_H	Wage bill of household sector
WB_K	Wage bill of capital sector
WB_P	Wage bill of production department
WB_R	Wage bill of research department
x_{Il}	Unit efficiency of the innovation task l
x_{Pl}	Unit efficiency of the production task l
x_{Kl}	Unit efficiency of the capital task l
X_{Iil}	Stock level of the innovation competence l of individual i
X_{Pil}	Stock level of the production competence l of individual i
$Y_{C,t}$	Production of consumption firm at t
Y_t^D	Demand at t
Y_t^e	Demand expressed by individuals at t
Y_t^E	Expected production at t
$Y_{K,t}$	Production of capital firm at t
Y^L	Labor-constraint production
Y_t^S	Supply at t
Y^{PC}	Capital-constraint production
Z_l^D	Demand for each competence class l
α_{Kf}	Substitution effect of new generation of capital
β	Loan duration
β_w	Rate of decrease of the weight in utility function
Δy_l	Rate of change in percentage of the structure of the incoming cohort in l
ϵ_s	Weight coefficient of the sector s
ζ_A	Adjustment rate of production capacity

Symbol	Description
η_U	Contribution rate set by unemployment fund
η_W	Proportion of unemployment benefit to wage
Θ_s	Technical complexity degree of new product
κ	Lifetime of capital good
λ_s	Period adjustment rate
μ_C	Mark-up of consumption firm
μ_f	Mark-up of firm f
μ_K	Mark-up of capital firm
$\overline{\mu_K}$	Maximum mark-up of capital firm
ν	Adjustment rate of the education system with labor demand
ξ	Sensitivity parameter of wage with productivity
π_f	Operating margin rate of firm f
π_B	Operating margin rate of bank
Π_B	Profit of banking sector
Π_C	Profit of consumption sector
Π_f	Profit of firm f
$\overline{\pi_f}$	Profitability threshold
Π_{IF}	Profit of investment fund
Π_K	Profit of capital sector
Π_U	Profit of unemployment fund
ρ_B	Dividend rate of bank
ρ_C	Dividend rate of consumption firm
ρ_{IF}	Dividend rate of investment fund
ρ_K	Dividend rate of capital firm
σ_K	Productivity of an unit of capital
τ_{Il}	Quantity of the innovation task l
τ_{Pl}	Quantity of the production task l
τ_{Kl}	Quantity of the capital task l
τ_{Il}^S	Supply of the innovation task l
τ_{Pl}^S	Supply of the production task l

Symbol	Description
Υ	Value of capital stock
Φ_B	Number of banks
Φ_C	Number of consumption firms
Φ_{Cs}	Number of consumption firms in sector s
Φ_H	Number of individuals
Φ_K	Number of capital firms
φ_f	Self-financing rate of firm f
ψ_s	Parameter of the quality innovation probability function in a sector s
ψ^{IP}	Parameter of the sector innovation probability function
ψ^{II}	Parameter of the imitation innovation probability function
Ω_{ft}	Sales of firm f at t
Ω_i	Desired ratio of liquid assets to disposable income

C Parameters in the baseline simulation

Symbol	Description	Baseline
b_I	Part of sales for innovation	0.2
b^{IP}	Part of budget for product innovation	0.2
b^{II}	Part of budget for imitation innovation	0.1
g	Technical progress of capital good in t	0.02
L	Total number of competence classes in the economy	40
L_I	Number of innovation competences	10
L_K	Number of competences in capital sector	30
L_P	Number of production competences	30
r_l	Interest on loan	0.03
r_m	Interest on deposit	0.005
β	Loan duration	10
β_w	Rate of decrease of the weight in utility function	0.02
ζ_A	Adjustment rate of production capacity	0.5
η_W	Proportion of unemployment benefit to wage	0.7
κ	Lifetime of capital good	10
λ_s	Period adjustment rate	0.5
$\overline{\mu_K}$	Maximum mark-up of capital firm	2
ν	Adjustment rate of the education system with labor demand	0.2
ξ	Sensitivity parameter of wage with smic change	0.6
$\overline{\pi_f}$	Profitability threshold	0.12
ρ_B	Dividend rate of bank	0.5
ρ_C	Dividend rate of consumption firm	0.35
ρ_{IF}	Dividend rate of investment fund	0.7
ρ_K	Dividend rate of capital firm	0.35
Φ_B	Number of banks	1
Φ_H	Number of individuals	25 790
Φ_K	Number of capital firms	1
ψ_s	Parameter of the quality innovation probability function in a sector s	0.000196
ψ^{IP}	Parameter of the sector innovation probability function	0.0000133
ψ^{II}	Parameter of the imitation innovation probability function	0.0000785
Ω_i	Desired ratio of liquid assets to disposable income	1.2

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Résumé : Le concept de compétences et leur hétérogénéité doivent être considérés comme importants en théorie économique et en empirique car les compétences sont une chance pour la croissance mais aussi un problème pour la croissance. Nous étudions le processus de construction des compétences dans deux modèles basés d'agents, mais chacun se concentre sur des caractéristiques différentes de ce processus. Dans le premier modèle, les compétences augmentent avec l'apprentissage et le transfert de compétences dans le cadre d'une alliance. Nous construisons un modèle de co-coopétition où les entreprises sont partenaires en R&D pour l'innovation de qualité mais restent concurrentes sur un marché à secteur unique. Les partenaires ne partagent pas toutes leurs compétences et se spécialisent en partie. Cela permet la persistance d'alliances et d'un réseau à long terme. Le deuxième modèle est un modèle stock-flux cohérent, avec les principaux types d'agents. Elle introduit l'innovation de secteur qui joue un rôle crucial pour la possibilité d'une croissance à long terme en surmontant la saturation de la demande. La demande des entreprises pour des compétences complexes augmente avec la qualité des produits existants et les caractéristiques des nouveaux produits. L'offre de compétences est modélisée au niveau individuel. Nous montrons l'effet de blocage de la contrainte de compétence, en particulier dans les compétences complexes, sur la croissance et l'emploi, avec de possibles dépressions keynésiennes de longue durée.

Title and Abstract : The concept of competences and their heterogeneity should be considered as important in economic theory and empirics because the competences are a chance for growth but also a problem for growth. We study the competence building process in two agent-based models but each focuses on different features of this process. In the first model, competences increase with firms learning by doing and competence transfer in an alliance. We build a co-opetition model where firms are partners in RD for quality innovation but remain competitors in a one-sector market. Partners do not share all their competences and partly specialise. This allows for the persistence of alliances and a network in the long run. The second model is stock-flow consistent, with the main types of agents. It introduces sector innovation which plays a crucial role for the possibility of long run growth in overcoming the saturation of demand. Firms demand for complex competences rises with quality of existing products and the characteristics of new products. Competences supply is modelled at the individual level. We show the binding effect of the competence constraint, especially in complex competences, on growth and employment, with possible long lasting Keynesian depressions.

Keywords : Competences, tasks, process innovation, product innovation, quality innovation, sector innovation, learning by doing, endogenous growth, AB model, AB-SFC, human resource constraint, employment, unemployment, demand saturation, financial constraint,

alliances, co-opetition, network, Schumpeterian competition.

Résumé de la thèse

May 27, 2019

1 Introduction

Les compétences sont une chance pour la croissance et l'emploi. Elles peuvent être aussi une source de décroissance et chômage, si la structure de l'offre ne s'adapte à celle de la demande, qui tend à privilégier les compétences complexes. Tel est le fil de ce travail.

Depuis plus de 40 ans, la croissance ralentit en France, de 4.6%/an en moyenne dans les années 60 à 1.86%/an depuis le début des années 2000 jusqu'à aujourd'hui. En même temps, le taux de chômage reste élevé en France. Durant ces 30 dernières années, il ne descend jamais en dessous de 7%. La relation entre croissance et emploi ne s'explique pas simplement par le fait que le ralentissement de la croissance entraîne un taux de chômage élevé. A contrario le facteur de travail peut jouer un rôle important pour expliquer la croissance de l'économie. Dans cette perspective, les compétences ont un rôle ambivalent: elles peuvent apporter de nouvelles opportunités de croissance et elles peuvent non seulement la freiner, mais la casser en cas d'insuffisance d'offre. Dans cette thèse, on utilise une définition précise des compétences à des fins de modélisation. Il s'agit "d'une capacité à effectuer une quantité d'une tâche nécessaire à la production avec un niveau d'efficacité déterminé par le niveau dans la compétence et le temps de travail au cours d'une période". Cette définition est proche de celle de la Commission nationale des certifications professionnelles : 'une compétence se traduit par une capacité à combiner un ensemble de savoirs, savoirs-faire et savoir-être en vue de réaliser une tâche ou une activité. Elle a toujours une finalité professionnelle'. A travers deux modèles à base d'agents, on étudiera le processus de construction des compétences dans un premier modèle à travers l'apprentissage (au sens de learning by doing) et les alliances, mais aussi en étendant l'analyse dans un second modèle aux relations entre compétences et innovation, demande, croissance agrégée et enfin structure de l'emploi et chômage.

Le concept de compétences est présent dans la littérature en science économique, sous le vocable de capital humain, ou au pluriel, de qualifications (en anglais skills) et sous le terme même de compétences en sciences du management. Deux concepts de compétence sont utilisés dans cette thèse: compétence individuelle et compétence de l'entreprise. Les compétences individuelles sont abordées dans

la littérature sur le changement technique biaisé sur les compétences complexes (traduit du terme en anglais "skill-biased technical change"). Cette littérature montre la relation entre le progrès technique et la demande de différentes catégories de compétence. L'apparition de nouvelles technologies et biens d'équipement (micro-ordinateur, automatisation, machines...) a des conséquences sur la structure de l'emploi et des salaires. En revanche, les compétences de la firme sont souvent abordées en science de management, notamment dans la littérature sur les compétences "noyau" (core en anglais). Elles permettent de connaître les sources de croissance de l'entreprise. En identifiant, développant et protégeant des compétences considérées comme les plus importantes, les firmes peuvent maintenir et développer leur avantage concurrentielle face à leurs concurrentes. Ce concept est important pour comprendre comment les compétences sont construites au niveau des firmes.

L'importance du concept de compétence s'explique au niveau agrégé par ses interactions avec l'innovation, la demande et l'emploi. Dans la littérature, il existe des modèles de croissance endogène fondés sur le capital humain et innovation. Par exemple, Aghion-Howitt (1992) montrent que la possession d'un nombre élevé de salariés qualifiés détermine l'intensité de l'innovation qui apportent ensuite des effets positifs sur la croissance. La productivité de l'activité de recherche s'accroît avec l'accumulation des compétences. Elle donne comme résultats de nouvelles technologies qui seront incorporées dans les biens intermédiaires de production et qui permettront d'augmenter la productivité de la production des biens finaux. Le mécanisme schumpétérien est modélisé car les nouveaux biens intermédiaires remplacent les anciens. Il s'agit des modèles de croissance endogène fondés sur l'innovation de procédé.

Une autre littérature, extrêmement réduite, mais inspiratrice pour ce travail, met l'accent sur les innovations de produit. Partant du travail pionnier de Pasinetti (1981), développée par Matsuyama (2002) et Aoki et Yoshikawa (2002), elle montre le rôle crucial de l'apparition de nouveaux secteurs sur la demande et donc la croissance. En effet, partant d'une économie composée d'un seul secteur ou d'un nombre très faible de secteurs, la croissance ne peut pas croître infiniment car la demande va saturer à long terme. Il existe un plafond pour la croissance d'un bien en quantité. S'il agit d'un bien durable comme la télévision, la machine à laver, le lave-vaisselle... les individus ou ménages consomment 0 ou 1 unité pendant la période. Même si leur revenu augmente, ils ne vont pas acheter une quantité plus importante. Quand le taux de diffusion atteindra 100%, le marché sera saturé. Pour les autres biens comme la nourriture,les vêtements, un bien culturel particulier,...la quantité consommée n'augmente pas infiniment avec les revenus à cause du principe d'utilité marginale décroissante. Un millionnaire ne consomme pas un millier de baguettes ou cent kilos de viande par jour. Quand le revenu des ménages augmente, ceux-ci préfèrent très souvent consommer de nouveaux biens qu'augmenter la quantité des biens existants. Ils peuvent certes passer à la qualité supérieure d'un même bien, mais le rapport qualité/prix peut se dégrader et inciter à passer à de nouveaux biens. Pour obtenir une croissance équilibrée à long terme, l'apparition de nouveaux secteurs est nécessaire car elle permet de

surmonter la saturation de la demande. Ces secteurs créent de nouveaux potentiels de croissance et commandent plus de capital. La relation entre innovation, demande et croissance est ainsi établie.

Toutefois cette littérature n'étudie pas une autre interaction entre innovation et croissance par l'intermédiaire du marché de travail. Or les conséquences sur l'emploi et le chômage peuvent changer les résultats macroéconomiques. A nos connaissances, il existe peu de travaux empiriques qui évaluent l'impact des innovations de produit sur l'emploi. Harrison et al. (2014) parviennent à distinguer les effets relatifs des innovations de procédé et de produit sur l'emploi. L'augmentation de la productivité réduit la demande du facteur travail pour produire une même quantité de bien. Le prix de ce bien diminuant, sa demande augmente car il devient abordable à un nombre plus important d'individus. Toutefois, à long terme, ce secteur peut faire face à la saturation. La hausse de pouvoir d'achat induite par la baisse des prix de certains biens élève aussi la demande des autres biens existants. Cette augmentation de la demande crée de nouveaux emplois. Harrisson et al. montrent que les effets positifs l'emportent. Mais ils vont au delà: l'introduction de nouveaux secteurs permet d'obtenir plus de créations d'emplois car de nouvelles opportunités de croissance de la demande apparaissent, dépassant nettement les effets de cannibalisation des anciens biens par les nouveaux.

Toutefois les modèles de croissance endogène supposent une absence de contrainte forte sur les compétences, et l'analyse de Harrison et al. va de même de l'innovation à l'emploi. L'offre de compétences est pourtant limitée. Elle peut être inférieure à la demande exigée par la croissance et un problème de changement de structure peut surgir au delà de la quantité de main d'oeuvre. L'étude du processus de construction des compétences est pourtant primordial car il permet de comprendre ensuite les différentes relations entre compétences et innovation, entre innovation et croissance/demande, entre demande et emplois. Les compétences sont un facteur de croissance mais elles peuvent aussi bloquer l'économie.

Actuellement, dans plusieurs pays, on observe un paradoxe sur le marché du travail. En France, même si le taux de chômage est élevé, un grand nombre de firmes ont des difficultés de recrutement. Pôle Emploi a publié sur son site une étude montrant que 44.4% des entreprises françaises sont dans ce cas, souvent pour deux motifs: elles manquent de candidats et les candidats manquent de compétences. Cette inadéquation sur le marché du travail s'explique par l'évolution asymétrique de l'offre et la demande des compétences. Dans cette thèse, la première dépend de l'ajustement de l'éducation pour répondre partiellement à la demande du marché du travail, et des politiques de formation continue des entreprises . La seconde dépend de l'évolution des caractéristiques des biens existants et de nouveaux biens. Si le déséquilibre entre l'offre et la demande est significatif, cela entraînera des effets néfastes non seulement sur les entreprises concernées, mais aussi toute l'économie, à travers la boucle Keynésienne qui va de l'emploi aux revenus et à la demande.

Dans cette thèse, on construira deux modèles à base d'agent, appelés SIMECO 1 et SIMECO 2. Il y a des points communs et des différences entre eux.

Points communs

Dans les deux modèles, la réalisation des tâches, multiples, requiert des compétences différenciées. Les processus d'innovation et de production sont distingués, comme en témoigne l'existence de deux départements dans l'entreprise : le département de R&D et le département de production. Le premier a pour objectif d'innover en matière de produit (une nouvelle qualité supérieure ou un nouveau secteur) et le second de produire. Cette distinction conduit à une première distinction de deux types de compétences : les compétences de production et d'innovation, mais il faut aussi un nombre important de tâches pour innover ou fabriquer un produit.

Dans les deux modèles, les entreprises doivent modifier la structure de leurs tâches de production vers des tâches plus complexes au détriment des tâches simples (et augmenter leur quantité d'équipement) lorsqu'elles innovent et produisent une qualité supérieure.

Dans les deux modèles, nous modélisons la concurrence sur le marché avec entrée et sortie, avec fixation des prix. Les modèles apparaissent comme un nouveau type de modèles *Keynes+schumpeter* avec des innovations de produit, poursuivant l'axe initié et développé par Eliasson (1977) avec le modèle MOSES, puis repris par Dosi (2010).

Différences

Le premier modèle, SIMECO 1, est un modèle de co-opétition, mais aussi un modèle de diffusion avec un seul bien de consommation. Il présente un bouclage macro-économique, ainsi qu'une distribution des revenus, car elle est essentielle en tant que déterminant des choix des consommateurs. Le modèle SIMECO 2 est né de la volonté de passer d'un modèle de diffusion à secteur unique avec saturation, à un modèle de croissance endogène. Il intègre plusieurs secteurs, et la création de secteurs, et constitue un modèle de croissance endogène avec agents hétérogènes. Il n'intègre pas les alliances pour des raisons de complexité calculatoires mais aussi pour limiter la complexité théorique.

Les compétences sont au niveau de l'entreprise chez SIMECO 1 mais sont détenues par des individus dans le SIMECO 2. Cette distinction a des conséquences sur le processus de construction des compétences. Dans le premier modèle, le stock de compétences augmente grâce à l'utilisation d'alliances, et avec l'apprentissage des entreprises. la productivité augmente grâce à des rendements dynamiques croissants pour chaque firme. Dans le second, l'apprentissage est individuel avec accumulation de compétences sur la carrière, et la formation continue faite par les entreprises. Il est donc perdu pour l'économie qaund l'individu part à la retraite. Par contre, il existe de nouvelles générations de capital qui augmentent la productivité du travail.

Contribution méthodologique

Dans cette thèse, nous utiliserons la méthode à base d'agents. Cette méthode permet de modéliser des prises de décision multiples, dynamiques et décentralisées de nombreux agents hétérogènes. Il existe plusieurs compétences, plusieurs types d'agents, de nombreux agents dans certains types, de nombreux marchés dans nos modèles, et les interactions ne sont pas linéaires. Dans le deuxième modèle, nous avons ajouté la cohérence des flux et stocks (traduit du terme

en anglais SFC Stock-Flow Consistency) (Godley et Lavoie, 2006) pour créer un modèle AB-SFC (Caiani et al., (2016), Dosi et al., (2019), Dawid et al., (2011)). Pour respecter les exigences de bouclage comptable de cette méthode, nous avons introduit de nouveaux types d'agents : le gouvernement, la caisse d'assurance chômage, la banque centrale, la banque (commerciale), le fonds d'investissement, une entreprise de bien d'équipement et les individus en tant que travailleurs/consommateurs. Afin de respecter les principes de la SFC, nous construisons des tableaux de flux de transactions et des bilans agrégés et nous nous assurons que chaque opération dans le compte d'un agent a une contrepartie ailleurs. La somme de toutes les lignes et colonnes doit être égale à 0 dans les matrices. Voici deux exemples de l'importance de la cohérence introduite par cette méthode. Le premier est le processus de création de monnaie. La plupart des modèles DSGE partent du principe que les banques sont totalement absentes et que les prêts sont directs. Leur rôle se réduit à celui d'intermédiaire, acceptant les dépôts des épargnants et les prêtant aux emprunteurs. En réalité, les banques peuvent créer des moyens de paiement supplémentaires en accordant des prêts à des agents non bancaires. Le processus de création de prêts correspond à une expansion du bilan de la banque. Le deuxième est le traitement des créations et faillites d'entreprises. Les individus doivent apporter de la richesse pour créer des entreprises et ce capital est détruit lorsque les entreprises font faillite. Par conséquent, nous pouvons être assuré de ne pas faire surgir de la richesse de nulle part. C'est essentiel pour modéliser le processus de croissance dans une économie avec des entrées et des sorties d'entreprises. Ce modèle est probablement un des premiers à tirer un important parti de cette exigence de la méthode SFC, parce que le fonds d'investissement crée des entreprises nouvelles, et que la concurrence est souvent frontale et meurtrière, en l'absence d'imperfections de l'information ou d'attachement des consommateurs à des firmes. Par ailleurs, dans le processus d'initialisation du modèle AB-SFC, nous créons un modèle stationnaire cohérent, afin de diminuer les incohérences d'initalisation qui peuvent perturber longtemps la dynamique du modèle, car les modèles macro-AB sont assez sensibles à la dépendance de sentier. A notre connaissance, cela n'a été fait que par Caiani et al. (2016) et Caiani et al., (2018).

2 Description du modèle 1

Les réseaux d'alliances en R&D jouent un rôle de plus en plus important dans l'économie, surtout dans les secteurs de haute technologie où la complexité et la sophistication accrue du produit demandent de plus en plus de compétences complexes. Les études empiriques (Hagedorn (2002)) montrent une augmentation continue du nombre d'alliances en R&D de 400 à 700 alliances par an entre 1985 et 2004. Les firmes créent des alliances pour plusieurs motifs: accéder à des compétences des partenaires, partager des ressources, partager des coûts de R&D... Parmi ces motifs, partager le savoir est un motif essentiel des alliances pour innover. Ce savoir est fait d'un ensemble de *compétences* : des

savoirs et savoir-faire définis ici au niveau des firmes. L'intérêt d'une alliance apparaît quand les firmes ont des compétences complémentaires de sorte que chacune apporte un savoir que l'autre n'a pas. Dans la littérature de management, on l'appelle "encastrement cognitif". L'autre motif essentiel de création des alliances en R&D est la mise en commun des dépenses de R&D puisque la probabilité d'innover augmente avec le niveau absolu de l'effort de R&D. Le nombre des chercheurs détermine cet effort, mais la complémentarité et le transfert des savoirs augmentent leurs compétences et donc leur efficacité.

Le modèle a un premier but méthodologique. Il pose les bases d'une modélisation d'un système productif en termes de compétences, tâches, alliances pour innover, l'innovation de qualité et la concurrence entre firmes. Cette modélisation d'un système ayant tous ces éléments simultanément est nouvelle en analyse économique. Elle montre qu'une concurrence en qualité - prix entre les firmes conduit à des faillites et des entrées de firmes sur une longue période avec une croissance en volume par diffusion du bien concerné, et en valeur. Toutefois, la saturation de la demande limite la croissance en volume. Le deuxième objectif théorique est de résoudre l'énigme de la persistance des alliances à long terme.

En effet, l'origine de l'énigme est à la fois micro-économique et aussi au niveau agrégé du marché. D'abord, au niveau micro-économique, chaque alliance devrait être rompue une fois que le savoir a été partagé, parce que les partenaires n'ont plus de compétences à transmettre alors qu'ils peuvent en recevoir d'autres partenaires en forgeant d'autres alliances. Or les données montrent que des alliances peuvent persister longtemps (Gulati (1995)). Au niveau agrégé du marché, si les firmes vivent longtemps – ce qui est souvent le cas – les alliances successives doivent conduire à ce que tout le savoir soit partagé entre les firmes, de sorte que les alliances devraient disparaître à long terme. Or on ne voit pas disparaître les réseaux de R&D –même si les alliances ont une durée limitée.

Plusieurs solutions ont été proposées dans la littérature. La première est l'introduction des concepts d'encastrement relationnel et d'encastrement structurel (Uzzi (1996)). Pour l'encastrement relationnel, les firmes dans une alliance développent de la confiance, ce qui permet de poursuivre ou de renouveler une alliance, le partenaire étant jugé fiable. Pour l'encastrement structurel, la réputation du partenaire pour sa fiabilité lui permet de nouer des alliances. Toutefois, notre critique est que la confiance et la réputation sont des conditions nécessaires pour rendre les alliances durables, pour les renouveler, et pour trouver de nouveaux partenaires. Mais elles ne sont pas suffisantes si tout le savoir a été partagé.

Notre solution réside dans la spécialisation partielle et le non transfert des compétences correspondantes. La R&D est décomposée en tâches toutes nécessaires pour l'innovation – mais qui pourraient être effectuées en commun par les partenaires. Chaque partenaire se refuse à transférer certaines compétences qu'il considère stratégiques (Hamel (1991), Mowery (1996)). Il effectue ces tâches lui-même, mais livre les résultats à l'alliance pour parvenir à l'innovation commune. L'hypothèse faite est que le plus compétent dans une tâche effectue cette tâche (division du travail optimale). Cette démarche maintient la complémentarité,

car chaque firme accroît ses compétences par la pratique. Ceci augmente la durée des alliances et assure la persistance d'un réseau d'alliances à long terme.

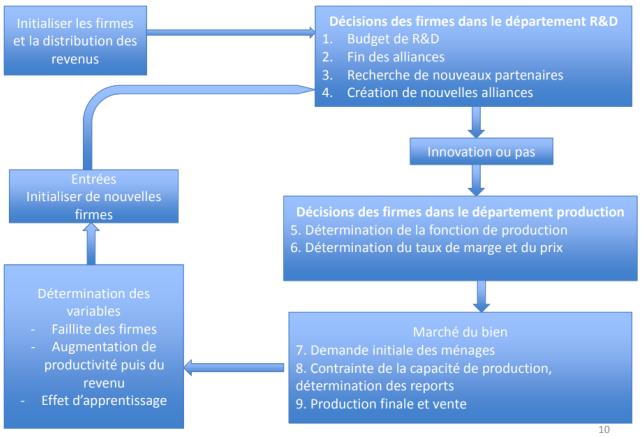

Figure 1: Simulation Cycle

Le graphique suivant décrit le cycle de la simulation. D'abord, on initialise les firmes et une fonction de distribution des revenus. Dans le département de R&D, les firmes fixent un budget de R&D. Si elles ont des alliances, elles décident de les continuer ou interrompre. On suppose que les firmes ne peuvent créer une seule alliance à la fois. Si elles sont seules, elles peuvent essayer de chercher des partenaires et créent de nouvelles alliances si leurs critères d'alliance sont respectées. Ensuite, elles essaient d'innover. Une fois que le niveau de qualité est déterminé, on obtient les caractéristiques de la fonction de production. Les firmes entrent dans le département de production. Elles fixent le taux de marge en fonction de la concurrence locale en qualité/prix, et donc le prix. Chaque firme propose une qualité et un prix différent sur le marché des biens. Dans ce modèle, on suppose qu'il existe un seul secteur. Toutes les firmes sont dans le même secteur mais elles ont des variétés différentes. On utilise l'algorithme de répartition de la demande pour déterminer la demande initiale des ménages. Les firmes peuvent avoir une contrainte de capacité de production et peuvent ne pas satisfaire toute leur demande. On détermine le report, la production finale et la vente de chaque firme. Si les firmes font des pertes, elles peuvent ne pas avoir de liquidité pour continuer et font faillite. A la fin de la période, le stock de compétences des entreprises augmente avec l'apprentissage, et donc la productivité, et cela se traduit par une augmentation de la rémunération des tâches, et donc des revenus. Pour mieux comparer les réseaux entre différentes expériences (variantes), on suppose un nombre de firmes constant au cours de la simulation. Chaque firme ayant fait faillite est remplacée par une nouvelle firme, qui entre dans le cycle.

Chaque simulation dure 500 périodes qui sont équivalentes à 500 ans, à

travers le calibrage du taux d'innovation sur le taux français. On a un nombre fixe de 100 firmes avec sortie endogène à cause des faillites. Les firmes sont hétérogènes: leurs compétences de production et d'innovation évoluent avec l'apprentissage qui dépend de la quantité de tâches réalisées. Chaque firme fait évoluer sa qualité par ses innovations successives, mais fait faillite si elle ne réussit pas à être concurrentielle en qualité/prix pour une fraction des consommateurs au moins. Les firmes ont une rationalité limitée: elles peuvent faire des erreurs d'anticipation et elles ne connaissent pas les décisions des autres firmes. On suppose dans ce modèle qu'il n'y a pas de stratégies de réseau au travers desquelles les firmes essaieraient de s'allier avec des firmes dans une certaine position dans le réseau. La stratégie est une recherche aléatoire de partenaires avec des critères de décision d'alliance, dans une optique de recherche coûteuse en temps. Les alliances sont des dyades (deux firmes seulement) exclusives.

Les firmes ont des structures similaires dans les deux départements: R&D et production. Chaque département a 50 compétences avec un niveau (qui évolue) dans chaque compétence. Les tâches sont hiérarchisées de la plus simple à la plus complexe selon la productivité d'une unité de compétence. Les firmes ont un niveau, soit un nombre d'unités, dans chaque compétence qui détermine l'efficacité dans la tâche correspondante. Chaque tâche dans une firme donnée apporte enfin une contribution en proportion de sa quantité (effectifs) et des deux facteurs ci-dessus, niveau dans la hiérarchie, et nombre d'unités de compétence disponibles. Une substitution imparfaite est supposée à l'aide d'une fonction Cobb-Douglas, de sorte que les firmes ne sont pas obligées de former une alliance.

Dans le département de R&D, le budget de R&D contraint la quantité des tâches (chaque unité de tâche a un coût). Il dépend de trois facteurs: (1) une proportion fixe du chiffre d'affaires de la période précédente, (2) un minimum de dépenses en proportion des actifs initiaux, (3) la concurrence locale en termes de qualité/prix (une concurrence forte stimule la R&D). Avec ce budget, on détermine la quantité réalisée de chaque tâche. Selon le type de compétence requis par la tâche, on distingue compétence stratégique versus compétence non stratégique. Une compétence est définie comme stratégique si la productivité par unité de compétence est supérieure à un certain seuil, c'est-à-dire ces compétences sont susceptibles d'apporter beaucoup de valeur ajoutée à l'entreprise. A ce titre, elle ne veut pas transférer son savoir de peur de perdre son avantage concurrentiel. Dans l'alliance, si une tâche inclut une compétence non stratégique, les deux partenaires vont choisir l'intégration. Ils rassemblent leur force pour la réaliser. Si la tâche demande une compétence stratégique, les partenaires choisissent la spécialisation. Seule la firme la plus performante dans la tâche la réalise pour le compte de l'alliance. Il n'y a donc pas de transfert de compétence dans ces tâches. La probabilité d'innovation est croissante et concave avec l'effort d'innovation et décroissante avec la qualité (plus la qualité est élevée, plus il est difficile d'innover). Un projet de R&D dure 3 ans maximum ou jusqu'à ce que l'innovation survienne. L'effort est cumulé pendant le projet.

Pour créer une alliance avec un partenaire, celui-ci doit remplir plusieurs critères: (1) complémentarité entre partenaires: l'indicateur est la somme des

différences entre leurs stocks de compétences. Un seuil minimal est requis; (2) similarité entre partenaires: les firmes doivent avoir une somme pondérée de compétences suffisamment similaire pour que chacun puisse espérer recevoir des transferts de compétence; (3) similarité des budgets de R&D: pour que les contributions soient équitables. Chaque firme peut examiner l'alliance avec un certain nombre de partenaires potentiels tirés au hasard et par conséquent sans encastrement réputationnel (3 essais) au cours de la période. Si l'innovation est obtenue, les partenaires ne renouvellent l'alliance que si les conditions de formation sont encore remplies. Sinon, ils cherchent ailleurs (pas d'encastrement relationnel). Si une innovation n'est pas obtenue en 3 ans, l'alliance est rompue.

A la fin de la période, les niveaux de compétence croissent avec les tâches correspondantes effectuées par chaque firme, et avec le transfert d'une partie de la différence de niveaux de compétences non-stratégiques (une autre partie reste tacite). La spécialisation partielle dans les compétences stratégiques favorise le renouvellement de certaines alliances, et la pérennité d'un réseau d'alliances en R&D .

Dans le département de production, chaque firme a sa propre technologie (ou fonction) de production basée sur les tâches de production. Cette technologie dépend de sa propre qualité. La technologie est à facteur complémentaires (Léontief). Par contre, il n'y a pas contrainte d'offre en quantité dans SIMECO 1. Il suffit de payer les tâches. Toutefois, les stocks de compétence déterminent l'efficacité dans la production à l'aide d'une unité de tâche. le coût de production peut être trop élevé du fait d'un niveau faible des compétences, et mener à la faillite. Le capital détermine une capacité maximale de production pendant la période, mais peut être accru par investissement, avec un coût. Les compétences de production bénéficient d'un apprentissage lié aux quantités produites.

Dans ce modèle, on fait deux hypothèses: (1) Si la qualité augmente, les tâches simples sont moins utilisées et les tâches complexes davantage (hypothèse validée par les études empiriques); (2) le coût d'une tâche est croissant convexe en complexité, de sorte que le coût d'une qualité supérieure à son entrée sur le marché est supérieur au coût de la qualité précédente de la même firme (hypothèse qui prévient la prise de tout le marché par un innovateur). Cette hypothèse est justifiée dans la théorie économique (Rosen, 1982) et par des études empiriques (Lemieux, 2006).

Les revenus français suivent une distribution de Weibull (Bandourian et al. 2002) estimée. Le bien dure une période (un an). Les ménages achètent une unité ou 0, s'ils jugent le rapport qualité- prix. Plus un ménage a un revenu élevé, plus il est disposé à payer cher pour la qualité (donc accepter un rapport qualité-prix plus faible). Les ménages aisés achètent donc des qualités nouvelles, les ménages à revenus faibles les qualités faibles. Mais l'échelle des qualités s'élève toujours plus haut, sans toutefois bloquer l'entrée de qualités faibles par de nouvlles firmes pouvu que leur rapport qualité/prix soit concurrentiel et attire des consommateurs.. La modélisation permet de déduire la demande par qualité de la distribution de Weibull, sans devoir individualiser les ménages, dans un cadre de type échelles de qualité (quality ladders). Le modèle offre sur ce sujet des résultats avec une grande économie de moyens.

L'innovation accroît le désir d'achat par la hausse de la qualité. Elle accroît d'abord le coût de production (en général), mais l'apprentissage réduit ce coût et augmente donc la productivité. Les prix des tâches sont indexés sur la hausse de la productivité moyenne hors innovation, et les revenus aussi par conséquent. La hausse des revenus engendre la diffusion du bien auprès des ménages. L'innovation stimule la hausse de la dépense des ménages aisés (sur les qualités élevées). Le modèle assure donc une croissance endogène en valeur, mais la croissance en volume est limitée par la saturation, du fait du bien unique et consommé de manière unitaire, et peut l'être par des rapports qualité prix trop faibles pour les bas revenus. Un mécanisme original est le rôle de stimulation de l'innovation sur la demande par la qualité et réciproquement par la demande via les revenus, donnant un rôle important à l'existence d'une distribution des salaires (ici les prix des tâches), même si sa forme est exogène.

Résultats du simeco 1

On obtient la résolution de la persistance des alliances en R&D avec uniquement l'encastrement cognitif, qui est l'objectif théorique de ce modèle. La distinction des compétences stratégiques versus non stratégiques implique des conséquences sur l'allocation des tâches dans l'alliance: spécialisation versus intégration. Cette distinction est justifiée par le concept de compétence "noyau" dans la littérature du management. C'est une contribution par rapport à la littérature qui utilise des encastrements sociaux, à savoir l'effet de réputation et la confiance, qui nous paraissent impuissants à justifier seuls l'absence de convergence des compétences à long terme, qui sont inutiles quand ils sont surajoutés à l'hypothèse de nouvelles compétences (Cowan et al.,2007).

Dans le premier modèle, le processus de construction des compétences dépend de l'apprentissage dans l'entreprise avec des rendements croissants dynamiques (propre à la firme) et le transfert des compétences entre les partenaires de l'alliance. La hausse du stock de compétence permet d'augmenter la productivité du facteur travail et le niveau de revenus à long terme. Le premier modèle est un modèle de diffusion avec un seul bien. Avec la hausse du revenu, ce bien devient accessible à un plus grand nombre d'individus, et les individus plus riches peuvent acheter des qualités supérieures. Toutefois à long terme, quand le taux de diffusion s'approche de 100%, le marché est saturé, on a besoin d'introduire de nouveaux secteurs. Ils seront modélisés dans le deuxième modèle.

Une autre contribution de ce papier est la modélisation de la co-opétition des firmes, ce qui n'est pas le cas dans la littérature en sciences de gestion qui s'intéresse plutôt à la coopération des entreprises, et presque par nature, ne modélise pas les marchés et les bouclages macroéconomiques. Or si elles sont concurrentes sur le marché des biens, cela va changer leur comportement ainsi que la forme du réseau qui émerge. Le réseau de R&D qui en ressort présente les propriétés d'un petit monde que l'on retrouve dans la littérature. Cependant, contrairement à la littérature de gestion, ce réseau est obtenu par la modélisation formelle de la concurrence sur le marché de produits et de la dynamique d'entrée et d'existence des entreprises. On obtient alors une structure du marché endogène. Elle impacte à son tour la R&D, le taux d'innovation et la diffusion du produit. La répartition des parts de marché et des marges

est endogène. Ces dernières sont très asymétriques et positivement corrélés, fait stylisé majeur de l'organisation industrielle observé au début du XXIe siècle, peu modélisé encore, mais d'une grande importance économique et sociale.

3 Description du Simeco 2

Le modèle Simeco 2 est un modèle de croissance endogène. Il s'appuie sur certains éléments du premier modèle et intègre plusieurs de ses blocs, à savoir l'organisation du département de R&D, les fonctions d'innovation et de production, la concurrence en qualité sur le marché des biens de consommation, ainsi que la formation des prix. On ajoute la possibilité que les firmes puissent innover en secteur, c'est-à-dire elles créent un nouveau produit qui n'existe pas sur le marché pour satisfaire à un nouveau besoin. Cela aide à surmonter la saturation de la demande. On introduit l'innovation de secteur sous une double forme: création d'un nouveau secteur, et innovation d'imitation (entrée d'une firme dans un secteur existant). Du coté du processus de production, on introduit l'innovation de procédé liée à l'apparition de nouvelles générations de capital. Du côté de la demande, les consommateurs avec un revenu résiduel plus important après avoir consommé le premier bien continuent à acheter les nouveaux biens. Du coté de l'offre, le décollage de nouveaux secteurs est favorisé par l'innovation de procédé dans le secteur de bien de capital et un niveau plus élevé de l'éducation de nouvelles générations d'individus

Deuxièmement, dans ce modèle, les individus ne sont pas représentés par une fonction de répartition du revenu, mais sont de véritables agents qui ont des caractéristiques différentes et sont capables de prendre des décisions. Le marché du travail est composé de plusieurs segments correspondant aux compétences. Les compétences sont individuelles dans ce modèle. Le processus de construction des compétences dépend de l'apprentissage des individus avec l'accumulation des compétences au cours de leur carrière. En plus, les entreprises y jouent un rôle important car elles forment les salariés pour acquérir de nouvelles compétences. Les firmes changent la demande pour différentes classes de compétence selon le changement des caractéristiques des variétés existantes et la demande de nouveaux secteurs. Comme dans SIMECO 1, quand la qualité augmente, elles augmentent la demande pour les compétences élevées au détriment des compétences simples. Quand l'innovation est de secteur, dans le scénario de base, la structure des compétences nécessaire est la même que pour le bien précédent au départ. Le bien n'est ni plus ni moins complexe. Cette neutralité sera abandonnée dans des variantes.

La figure du diagramme des flux décrit les interactions entre les agents. Ils interagissent sur 6 marchés différents. On décrira les caractéristiques des agents et les marchés.

3.1 Les agents

(1) Les individus

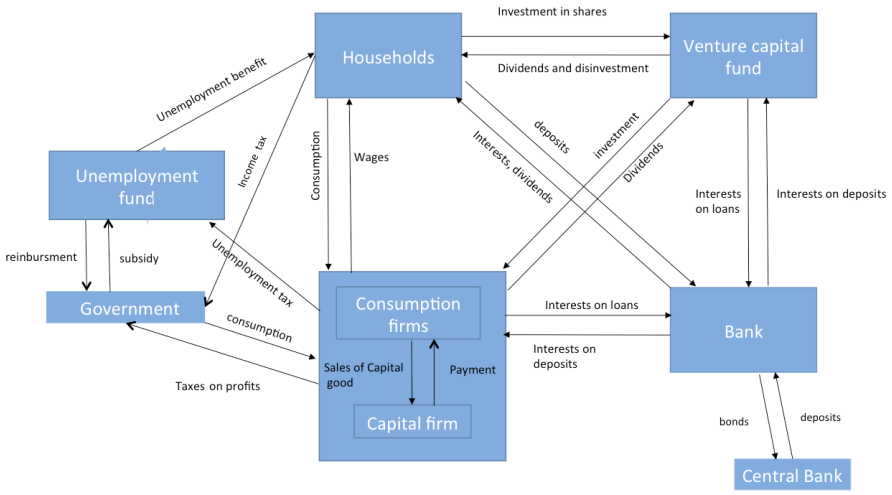

Figure 2: Le diagramme des flux dans le modèle

Chaque individu fournit plusieurs unités de travail. On suppose que chacun veut consommer au maximum une unité de chaque bien de consommation. Il a un vecteur de caractéristiques suivant:

(i) Âge: il a un âge qui varie entre 18 et 62 ans. On considère que toute la population est active pour simplifier le comportement de consommation et le transfert du revenu entre individus s'ils ne travaillent pas. Quand un individu part à la retraite, il sera remplacé par un autre individu de 18 ans.

(ii) Compétence: il possède soit des compétences d'innovation soit des compétences de production. Les compétences ne sont pas substituables pour réaliser une tâche donnée. Chaque individu possède un portefeuille de 3 compétences adjacentes au départ mais cela peut évoluer dans la suite avec les formations. Il a un niveau de stock dans chaque compétence.

(iii) Situation professionnelle: il peut être salarié ou chômeur.

(iv) Niveau de revenu: le revenu des individus provient de plusieurs sources: salaire pour les salariés et allocation de chômage pour les chômeurs (le RSA pour les chômeurs de longue durée), intérêts sur leur dépôt à la banque, dividendes payés par le fonds d'investissement.

v) Richesse: la richesse d'un individu dépend de son dépôt à la banque et de ses parts de capital dans le fonds d'investissement.

Les individus ont plusieurs motifs d'épargne: épargne d'accumulation et legs (qui dépend de la position de l'individu dans l'échelle de revenus et non pas de son revenu absolu, ce qui mènerait à long terme à une hausse du taux d'épargne agrégé qu'on n'observe pas), épargne de précaution (qui est représenté par un ratio désiré des liquidités sur le revenu disponible). On en déduit leur budget

de consommation.

Quand un individu atteint 62 ans, il meurt et est remplacé par un nouvel individu ayant 18 ans. La taille de la population reste constante. Pour respecter les règles SFC, on transfère le patrimoine entre ces deux générations de manière aléatoire sous la forme d'un héritage mais toujours au sein d'une classe de compétence afin de respecter une certaine homogamie. Les nouvelles générations d'individus se voient attribuer les compétences en fonction des excès de demande sur les segments du marché du travail correspondant aux différentes compétences. Comme les demandes des compétences les plus complexes augmentent, le niveau d'éducation augmente. Il s'agit d'un ajustement partiel par l'éducation de l'offre des compétences pour satisfaire la demande.

(2) Les firmes

Il existe plusieurs firmes de bien de consommation dans le modèle et pour simplifier, une seule firme de bien de capital. La firme de bien de capital utilise le facteur de travail pour fournir le bien de capital aux firmes de bien de consommation. A chaque période, si une firme investit, la nouvelle génération de capital remplace la plus ancienne et qui a une productivité plus élevée (augmentation exogène). Elle substitue une partie du travail, à demande constante. La firme bien de capital est créée en initialisation et est détenue par le fonds d'investissement qui achète ses parts au départ. Comme elle est un monopole, sa marge est réglementée.

Les firmes de bien de consommation utilisent à la fois le facteur travail et capital dans leur fonction de production. Elles ont 3 types d'innovation: innovation en qualité, innovation de secteur et innovation d'imitation. La première permet d'augmenter la qualité de leur variété existante, la seconde de découvrir un nouveau secteur qui n'existe pas encore sur le marché, et la troisième d'entrer dans un secteur nouveau pour la firme. Ces firmes peuvent donc être mono-produit ou multi-produits. Pour chaque bien, elles ont un seul niveau de qualité. A côté de l'investissement en R&D, elles investissent aussi en capital physique en commandant le bien de capital à la firme de bien de capital. La décision dépend de leur niveau de capacité de production. Pour simplifier, on suppose qu'il n'existe pas de coût d'utilisation du capital, mais un taux d'utilisation souhaité.

(3) Les banques

On distingue ici la Banque centrale et une seule banque commerciale pour simplifier.

La banque commerciale est créée en initialisation et détenue par le fonds d'investissement qui a acheté ses parts de capital. Elle utilise les dépôts d'autres agents pour accorder des prêts aux firmes pour avancer des salaires ou acheter le capital physique. Elle refuse ainsi de financer la R&D, plus risquée. Ceci est rationnel de sa part car on a introduit un marché du capital d'occasion et la banque est prioritaire sur le résultat de la vente en cas de faillite, et dispose donc d'un collatéral partiel. Elle paie les intérêts sur les dépôts aux autres agents et reçoit les intérêts sur les emprunts des entreprises. Comme il n'existe qu'une seule banque commerciale, on la considère comme une banque privée réglementée. Le taux d'intérêt est fixe dans le modèle. Si le ratio de liquidité de la banque descend en dessous d'un seuil critique, elle doit demander à la Banque

centrale qui achètera de nouvelles actions émises.

La banque centrale (BC) est une banque publique détenue par le gouvernement. Elle a le rôle de fournir la liquidité à l'économie et d'acheter les obligations du gouvernement si ce dernier n'a pas suffisamment de liquidité pour faire face à ses dépenses. A la fin de la période, si la BC fait des profits, elle les transfère au gouvernement.

Caisse d'allocation chômage

Elle collecte des taxes auprès des entreprises (un pourcentage de leur masse salariale) et paie des allocations aux chômeurs. Si la durée du chômage dépasse 2 ans, les chômeurs passent au régime RSA et sont payés par les impôts sur le revenu collectés par le gouvernement. Si la Caisse manque de crédit pour faire face à ses dépenses, le gouvernement lui transfère de l'argent pour payer les chômeurs. Le taux de contribution est fixé de manière à permettre à la Caisse de couvrir ses dépenses. Toutefois, pendant les périodes de crise, la hausse importante du nombre de chômeurs peut faire augmenter fortement le taux de contribution qui à son tour plombe l'économie. On fixe donc un seuil maximum du taux de cotisation.

Fonds d'investissement

Il finance la création de nouvelles entreprises et l'activité de recherche. Ses décisions sont basées sur certains critères fixés. Pour des raisons calculatoires (mais en fait réalistes), on suppose que seuls les 20% individus les plus riches peuvent acheter des parts du capital du fonds d'investissement. Ils détiennent le fonds qui à son tour détient les entreprises et la banque. A chaque période, les entreprises profitables paient les dividendes au fonds qui verse ensuite une part de ces dividendes aux individus selon le pourcentage de leurs parts. La faillite des firmes se traduit par une perte de capital (ce n'est pas un flux financier) du fonds et par conséquent des individus. Pour simplifier, on suppose que chaque part a une valeur de 1 euro dans tout le modèle.

Le gouvernement

Le gouvernement collecte les taxes sur le revenu des individus pour payer le RSA. Le taux d'imposition est fixé à chaque période pour pouvoir couvrir les dépenses. Comme avec la caisse de chômage, on fixe un seuil maximum pour éviter une crise plus profonde pendant les périodes de récession, ce qui ouvre la voie à un déficit couvert par la BC.

3.2 Les marchés

Il existe 6 marchés dans le modèle:

Le marché du travail

Du coté de l'offre, les individus offrent un nombre d'unités de travail efficaces. Leur nombre dépend du stock de compétences, de la classe hiérarchique de compétences, et du nombre réalisé d'heures de travail. On a supposé que la réalisation d'une tâche demande une seule compétence et que les compétences ne sont pas substituables. Le marché de travail est donc composé de plusieurs sous-marchés de compétences. Pour chaque période, les individus cherchent du travail dans la classe de compétence qui leur permet d'obtenir le salaire espéré

le plus élevé (parmi leurs autres compétences). Du coté de la demande, les firmes expriment des demandes pour chaque compétence. Les individus et les entreprises interagissent sur le marché du travail selon une règle de matching. Un chômeur accepte un poste si l'entreprise lui propose un salaire supérieur à son salaire de réserve.

Le marché du bien de capital

Du coté de la demande, les firmes de bien de consommation commandent le capital en fonction de leur capacité de production. Si le taux d'utilisation actuel dépasse un seuil plafond (80%), elles commandent auprès de la firme de bien de capital. Cette dernière utilise le facteur travail pour produire. Elle produit la quantité commandée par les firmes de biens de consommation. En cas de rationnement, on applique la règle de rationnement parallèle. Le marché d'occasion du capital internvient alors de manière subsidiaire.

Le marché des biens de consommation

Chaque firme vend un ou plusieurs biens. Chaque bien a une qualité et un prix différent. Les ménages ont un budget de consommation qui dépend de leur niveau de revenu. Le revenu détermine leur structure de préférence pour la qualité. On a vu qu'ils achètent 0 ou 1 unité de chaque bien. Sur le marché des biens, il existe plusieurs secteurs et dans chaque secteur plusieurs variétés. dans le scénaro de référence, les individus ont une structure des préférences avec une pondération décroissante avec l'ordre de création des biens, les plus récents étant considérés comme moins nécessaires. Les individus calculent l'utilité nette de toutes les variétés dans l'économie. Pour chaque secteur, et dans l'esprit de la théorie des échelles de qualité, ils choisissent la variété qui maximise leur utilité nette. Ensuite, en raison de la contrainte de budget, ils ne peuvent pas consommer tous les biens. Ils commencent par le secteur qui leur procure l'utilité nette la plus élevée et continuent jusqu'à ce que leur budget résiduel ne permette plus d'acheter un nouveau bien supplémentaire ou lorsqu'il n'y a plus de bien à acheter du fait de l'insuffisance de l'offre.

Le marché des dépôts

Comme il n'existe qu'une seule banque dans notre modèle, les agents n'ont pas le choix et laissent leurs liquidités sur le compte de la banque. La banque leur verse des intérêts sur le dépôt. Comme il n'y a pas de concurrence dans l'offre de dépôts et pour éviter une fixation monopolistique du taux d'intérêt, nous fixons le taux d'intérêt sur les dépôts comme constant sur le modèle (sachant que nous avons constaté un taux d'inflation faible ou même négatif).

Le marché des crédits

La banque utilise les dépôts de tous les agents pour accorder des prêts aux entreprises. Elle a une contrainte de ratio de liquidité qui détermine sa capacité de financement sur chaque période.

Les entreprises peuvent ne pas disposer de liquidités suffisantes pour certaines activités. Nous supposons que la banque peut financer leur achat de capital physique et leur avance sur salaire. Les entreprises qui souhaitent emprunter envoient une demande à la banque avec le montant souhaité. Il détermine la demande totale de crédit.

La banque décide en fonction de certains critères et elle dispose ensuite d'une

liste d'entreprises acceptées. Toutefois, elle peut faire face à sa contrainte de financement pour financer l'ensemble des demandes de prêts des entreprises. Dans ce cas, elle classe les entreprises en fonction de leur capacité de remboursement et accorde des prêts jusqu'à ce qu'elle ne dispose plus de liquidités suffisantes pour financer le reste des candidats.

Le marché des actions

Les entreprises émettent des actions pour financer leur activité de R&D si elles ne disposent pas d'un autofinancement suffisant. Contrairement à la banque, le fonds d'investissement a moins d'aversion pour le risque. Sa décision d'investir dans une entreprise est fondée sur l'espoir d'obtenir plus de dividendes pour ses actionnaires (les ménages) à l'avenir. Le fonds d'investissement finance deux activités de l'entreprise : les activités d'innovation des entreprises existantes et la création de nouvelles entreprises. Dans ce dernier cas, le fonds d'investissement est susceptible de financer, par l'émission, de nouvelles entreprises, ce qui leur permet à payer certaines activités au cours des premières périodes de leur existence lorsque les ventes sont encore faibles. L'offre de parts de capital est le nombre total de parts de capital émises par les entreprises existantes et les nouvelles entreprises.

Les individus épargnent une partie de leur revenu disponible, selon un ensemble de règles comportementales, sur la base de l'épargne de précaution (mise en dépôt sur le compte bancaire), et d'un motif distinct correspondant aux besoins en matière de legs (épargne d'accumulation). Ils ne détiennent pas directement les actions des entreprises et des banques mais par l'intermédiaire du fonds d'investissement. Ils achètent des actions émises par le fonds qui utilise ses liquidités pour acheter des actions émises par des entreprises.

Le fonds d'investissement décide d'abord d'investir dans la R&D des entreprises existantes. Puisqu'il avait déjà investi dans le passé, si une entreprise existante fait faillite, elle peut perdre son investissement. Toutefois, il a certains critères pour la décision. S'il dispose encore d'une certaine capacité de financement, il finance la création de nouvelles entreprises selon le taux de marge opérationnelle moyen du secteur. Le financement s'arrête lorsqu'il n'y a plus de nouveaux investissements rentables ou quand le fonds n'a plus aucune capacité de financement au cours de cette période.

3.3 Description détaillée du comportement des firmes

Le comportement des firmes de bien de consommation

L'organisation des firmes de bien de consommation est comme dans Simeco 1. Pour les types d'innovation, on introduit l'innovation de secteur et l'innovation d'imitation. Les firmes essaient d'innover en secteur si elles ont des taux de marge opérationnelle élevé ou faible (régime offensif versus défensif). Les nouveaux secteurs leur permettent d'augmenter la demande et le profit (moins de concurrence dans les nouveaux secteurs). Elles innovent en imitation pour entrer dans un autre secteur rentable. Un budget global de recherche est déterminé en fonction du chiffre d'affaires de la période précédente. Un niveau minimal du budget est requis car il doit permettre de payer le salaire des chercheurs. Le

budget permet de recruter et ensuite d'obtenir l'effort total d'innovation. Cet effort sera ensuite réparti entre plusieurs projets d'innovation afin de déterminer la probabilité d'innovation et les résultats. Contrairement à Simeco 1, on suppose ici une fonction d'effort d'innovation de type Léontief. La probabilité d'innovation en qualité est croissante avec l'effort d'innovation en qualité mais décroissante avec le niveau de qualité existant. Celle d'innovation de secteur est croissante avec l'effort d'innovation de secteur mais décroissante avec le nombre de secteur existant, pour rendre compte du rendement décroissant de la R&D de secteur quand il n'y a pas de nouvelles compétences, ce qui est le cas dans la version actuelle du modèle. Enfin, celle d'innovation d'imitation est croissante avec l'effort d'innovation d'imitation mais décroissante avec la qualité moyenne du secteur. Quand les firmes obtiennent une nouvelle qualité supérieure, on change les coefficients de production de chaque tâche: une augmentation de la demande des tâches complexes et une baisse de la demande des tâches simples. En cas d'innovation de secteur, on détermine les caractéristiques initiales du nouveau secteur, notamment la demande initiale de chaque classe de compétences (selon son degré de complexité). Un bien complexe demande plus de tâches complexes au départ.

Si une firme produit plusieurs biens, le département de production est divisé en plusieurs lignes de production ou établissements mono produit dont chacun a ses propres salariés et sa technologie de production. Toutefois les firmes peuvent transférer les salariés ou le capital entre eux. La fonction de production est Léontief comme dans Simeco 1. Le nombre d'unités efficaces dans chaque tâche est déterminé par la somme des unités efficaces des salariés réalisant la tâche.

La fixation du prix est obtenue en fixant une marge sur le coût variable unitaire. Cette marge dépend de la concurrence locale qui est maintenant définie comme la distance en rapport qualité/prix d'une firme avec ses concurrentes les plus proches. Une forte concurrence locale déprime le taux de marge.

Les firmes investissent en capital physique. Le capital dure un certain nombre de périodes et chaque année, la génération la plus ancienne disparaît. On suppose un progrès technique exogène du capital qui le rend plus efficace et par conséquent la productivité du travail. Toutefois l'augmentation d'efficacité ne concerne que la dernière génération, et l'effet sur la productivité du travail (toutes catégories confondues) n'a lieu qu'en cas d'investissement.

A la fin de chaque période, les firmes mettent une somme de coté pour avancer les salaires à la période suivante. Elles paient les salaires avant de recevoir le paiement de l'achat des individus. Comme le licenciement prend un délai de 1 an, pour respecter les règles de la méthode SFC, on veut assurer que les firmes peuvent avancer tous les salaires. Si elles manquent de liquidité à la fin de la période, elles demandent à la banque. Si la banque refuse, elles font faillite et licencient tout de suite leurs salariés. Si elle accepte, elles vont examiner les décisions d'investir en capital physique et en R&D. En cas de manque de liquidité, elles demandent à la banque pour le premier type d'investissement et au fonds d'investissement pour le second.

Le comportement de la firme de bien de capital

En fonction des commandes, la firme de bien de capital recrute ou licencie

pour produire la quantité désirée. La fonction de production du capital est aussi Léontief. Le prix du capital est déterminé en fixant une marge sur le coût variable unitaire (paiement des salaires et cotisation de chômage). Si elle fait des profits, elle verse des dividendes au fonds d'investissement. A la fin de chaque période, elle met de coté un montant pour l'avancement des salarié à la période suivante. Si elle manque de liquidité, elle demandera à la banque qui accepte toujours car l'on a une seule firme de capital dans le modèle.

L'allocation des tâches dans les firmes et la fixation des salaires

Différents concepts de salaire sont proposés dans le modèle: salaire par unité efficace de tâche différencié pour chaque firme et chaque tâche pour des besoins d'attractivité, salaire par unité de compétence pour chaque classe de tâche-compétence, qui est offert par chaque firme, le salaire individuel qui multiplie le précédent par le nombre d'unités de compétences et le ratio des heures effectuées sur le nombre légal, et enfin les salaire de réserve par unité de compétence et salaire de réserve individuel.

Si les firmes ont besoin d'un nombre plus important d'unités efficaces que celles offertes par leurs salariés, en dehors du recrutement, il existe des mécanismes d'ajustement interne qui sont classés dans l'ordre de priorité suivant: (i) heures supplémentaires (un salarié peut travailler jusqu'à 20% de plus que la durée légale annuelle), (ii) reclassement (transfert des salariés entre différentes lignes de production dans la même tâche), (iii) promotion ou déclassement depuis des tâches en sureffectif, (iv) recrutement, (v) promotion depuis des tâches non en sureffectif, (vi) formation. Ces ajustements tiennent compte des contraintes organisationnelles, légales et de savoir qui pèsent dans la réalité. Ce sont ces contraintes qui déterminent les excès de demande qui ne peuvent être satisfaits. Si on adopte une formalisation de la fonction de production avec substitution comme dans les modèles néoclassiques, il n'y a jamais d'excès de demande, a fortiori pas d'excès de demande dans des compétences précises et donc les phénomènes que nous avons évoqués dans l'introduction et qui sont au coeur de ce second modèle disparaissent.

L'évolution des compétences et la dynamique des salaires

A la fin de chaque période, le stock de la compétence utilisée par un salarié augmente avec l'apprentissage. Le stock de ses autres compétences ou des chômeurs reste invariant.

Le salaire minimum (smic) est totalement indexé sur l'indice de prix à la consommation. Il est rigide à la baisse. Les autres salaires sont indexées partiellement sur l'évolution du Smic et sont relevés en cas d'excès de demande dans la classe de compétence concernée (mais non affectés par un excès d'offre). Les tensions sur le marché du travail dans une classe de compétence entraînent une augmentation plus forte du salaire.

Résultats du simeco 2

Le scénario de base permet une croissance de long terme du PIB avec un taux d'innovation approximativement constant, après une crise économique assez longue. Le taux de chômage reste stable pendant toute la simulation de référence car la destruction des tâche par l'innovation de procédé est compensée par la création des tâches due à une meilleure diffusion des biens existants

jusqu'à la saturation et à l'apparition de nouveaux secteurs. La diffusion de nouveaux secteurs a la forme à dominante logistique, mais qui peut être modifiée par la concurrence des autres secteurs et les crises économiques.

Pour les nouveaux secteurs, dans la simulation de référence, ils ont les mêmes demandes par classe de compétence au départ. Au niveau agrégé, on constate des excès de demande des compétences élevées. Cela apporte des effets néfastes à l'économie. Toutefois, dans le scénario de référence, les excès de demande sont maintenus à un niveau raisonnable en raison de l'adaptation de l'offre de compétences. Le système éducatif forme de nouvelles générations d'individus et tient compte de la demande sur le marché du travail pour orienter l'offre via les outils d'ajustement interne décrits plus haut, outre le marché du travail. Toutefois ces excès de demande entraînent une augmentation de l'inégalité des revenus dans le modèle, inégalité au demeurant très proche du Gini existant.

La simulation de base montre l'existence d'une crise keynésienne dans le modèle. La sortie de crise est obtenue par l'émergence de nouveaux secteurs et par de jeunes entreprises qui offrent un bon rapport qualité/prix. L'économie sort de la récession par le mécanisme qui combine les caractéristiques keynésiennes et schumpéteriennes d'une manière inédite, basée sur de nouveaux produits, l'augmentation de la demande et une certaine inégalité des revenus, les individus à revenu élevé apportant les premiers achats aux nouveaux secteurs comme dans Matsuyama (2002).

Dans le second modèle, nous avons réalisé différentes expériences pour vérifier la sensibilité de nos résultats avec quelques hypothèses. Surtout, elles permettent de mieux comprendre le rôle des contraintes de compétence sur le processus de croissance.

La première expérience consiste à changer la fonction d'utilité. L'ordre lexicographique des secteurs implique une augmentation de la contrainte sur la consommation, Comme le rapport qualité/prix des premiers biens se dégrade par manque de concurrence, on obtient une augmentation de la demande contrainte, ce qui empêche le développement de nouveaux secteurs et génère une stagnation de l'économie et un chômage élevé. Il s'agit là d'une différence majeure par rapport au schéma de diffusion de nouveaux secteurs successivement sous forme "d'oies volantes" de (Matsuyama (2002)), et pourrait être une possibilité dans le monde réel si les biens de première nécessité (énergie, logement) voient leur coût augmenter trop vite au lieu de diminuer.

La deuxième expérience mesure la sensibilité de l'intensité de l'innovation de procédé sur la croissance et l'emploi. L'innovation de procédé joue un rôle important dans l'explication de la croissance à long terme. Du côté de la demande, elle permet de réduire le prix des produits existants qui deviennent de plus en plus abordables pour un plus grand nombre d'individus. Du côté de l'offre, elle libère le facteur travail qui sera utilisé dans de nouveaux secteurs. C'est d'autant plus important que la taille de la population demeure constante dans le modèle. L'histoire de la première révolution industrielle montre l'importance des gains de productivité dans l'agriculture pour le décollage des secteurs industriels. Cependant, pour la croissance à long terme, une innovation de procédé ni trop élevée ni trop faible est une condition nécessaire. Afin d'obtenir la sta-

bilité du taux de chômage, la destruction d'emplois par l'innovation de procédé devrait être compensée par la création d'emplois en raison de l'augmentation de la demande. Si l'innovation de procédé est trop forte, elle peut conduire à un taux de chômage technologique élevé, puis à une crise keynésienne. S'il est trop faible, le prix des produits existants ne diminue pas et de nouveaux produits ne peuvent pas décoller.

Dans la troisième expérience, nous montrons que les caractéristiques des nouveaux secteurs jouent un grand rôle dans l'innovation. Dans les secteurs existants, l'amélioration de la qualité entraîne une demande accrue de compétences complexes. Si les nouveaux secteurs sont de haute technologie, il en résulte une forte concurrence entre les entreprises de ces secteurs dans les compétences complexes. L'excès de demande bloque la croissance et a un effet négatif sur l'emploi. Au contraire, lorsque tous les nouveaux secteurs sont de basse technologie, ils génèrent des excès de demande sur des compétences simples, et peuvent générer une stagnation. Ces deuxième et troisième expériences confirment que le manque d'offre dans certaines compétences, en particulier dans les compétences complexes, peut constituer un obstacle majeur à la croissance, même si l'innovation et les fonds financiers sont présents. Ces résultats doivent être considérés comme les plus fondamentaux et nouveaux du modèle, et suggèrent un nouvel axe de modèle de croissance endogène, intégrant des contraintes de compétence différenciées.

La dernière expérience montre le rôle du taux d'innovation de secteur. Lorsque le nombre de créations de nouveaux secteurs est faible, la demande est saturée et la croissance reste faible.

4 Extensions

Dans l'avenir, de nombreuses extensions et de nouvelles expériences seront envisagées.

1/Extensions sur les alliances et le réseau pour SIMECO 1

a) Dans le premier modèle, les entreprises ne tiennent pas compte de la position dans le réseau en tant que stratégie. Dans la réalité, les entreprises tentent généralement d'accroître leur centralité afin d'obtenir davantage de transfert de compétences de la part d'autres entreprises et, par conséquent, d'accroître leur résultat d'innovation. Cela peut modifier la forme du réseau émergé parce que les entreprises n'ont pas le même motif pour créer des alliances.

b) Les alliances peuvent ne plus être dyadiques. Le modèle peut être étendu à des alliances avec plusieurs partenaires pour examiner sa sensibilité à l'hypothèse de dyadisme.

2/ Extensions pour SIMECO 2

c/ De nouvelles compétences pour innover seraient nécessaires à long terme, étant donné que le taux de création de nouveaux secteurs est, selon notre hypothèse, décroissante avec le nombre de secteurs existants.

d) Dans le département de production, de nouvelles compétences de production peuvent apparaître avec de nouveaux secteurs. Elles modifieront nos

résultats en matière de concurrence parce qu'une nouvelle condition pour les entreprises existantes pour pénétrer de nouveaux marchés serait l'acquisition de nouvelles compétences. De plus, les firmes innovatrices peuvent tirer profit de leur pouvoir de monopole pendant une plus longue période parce que les nouvelles firmes ont un faible niveau de stock de nouvelles compétences alors qu'actuellement dans le modèle, elles peuvent transférer leurs employés pour fabriquer de nouveaux produits.

e/ Plusieurs compétences pourraient être nécessaires pour accomplir une tâche. Cela correspondrait à l'objectif des études empiriques récentes sur les compétences que nous avons mentionnées. De nouvelles tâches pourraient également apparaître. Cela conduirait à des extensions majeures du modèle, particulièrement nécessaires pour répondre à la question de l'impact des outils numériques comme le remplacement ou l'aide aux travailleurs, un sujet si vaste à traiter en profondeur que nous avons juger nécessaire de le laisser en suspens pour de futurs travaux.

Les fonctions comportementales de certains agents doivent être examinées plus en détail.

f) Les caractéristiques financières doivent faire l'objet d'une étude plus approfondie et pourraient être développées. Pour la banque, le taux d'intérêt peut être déterminé sur le marché du crédit lorsque les interactions entre la banque et les entreprises ont lieu. Plusieurs banques peuvent être créées et être en concurrence pour attirer les dépôts des particuliers. Celà peut conduire à de nouveaux résultats sur les cycles et crises et nous pourrions obtenir de nouveaux mécanismes pour sortir de la crise keynésienne dans le modèle.

g) Pour le secteur de bien de capital, la concurrence peut être modélisée comme dans le secteur de la consommation. Plusieurs firmes de bien de capital peuvent être créées. Elles pourraient disposent d'un département de recherche et l'évolution de la productivité du capital deviendrait endogène.

h) Le comportement d'investissement des particuliers et du fonds d'investissement pourrait être étendu et nous pourrions introduire plus d'expériences. Actuellement, le fonds d'investissement, lorsqu'il décide de créer de nouvelles entreprises, donner la priorité aux anciens secteurs. Si de nombreux secteurs ont un taux de marge opérationnelle supérieur à un certain niveau, il crée des entreprises dans les premiers secteurs. Nous pouvons réaliser une expérience où il classe le taux de marge moyenne de tous les secteurs et commence par le secteur où le taux est le plus élevé. Comme chaque secteur n'a pas les mêmes caractéristiques et n'a pas besoin du même nombre d'employés (effet d'innovations de procédés antérieures), certains résultats peuvent changer parce que la demande et l'emploi changeront.

i) Le prix d'une action de capital reste constant à 1 euro dans le modèle. Nous pouvons introduire un marché financier simple où l'interaction entre la demande et l'offre de parts de capital déterminera son prix. Le fonds d'investissement aura un nouvel objectif de maximiser la valeur de son stock d'actions.

j) Le gouvernement peut devenir plus actif. Il peut utiliser un régime d'impôt progressif. Les expériences en matière de politique budgétaire peuvent clarifier le rôle de la répartition des revenus sur la demande, l'innovation et la croissance.

Dans la littérature, il existe un débat sur la question de savoir si une répartition égale ou inégale des revenus stimule l'économie. Par exemple, l'existence des individus avec un niveau de revenu élevé favorise l'émergence de nouveaux produits. Ces derniers étant chers au début en raison du manque d'innovation de procédé, les individus les plus riches ont un budget résiduel plus important et ils les consommeront. Leur demande initiale devrait être assez importante pour permettre aux entreprises de ces secteurs de survivre. Au fil du temps, lorsque l'innovation en matière de procédés devient plus forte, leur prix diminue et ils deviennent plus abordables pour le reste de la population. Nous passons d'une consommation de niche à une consommation de masse. Toutefois, si la répartition des revenus est trop inégale, l'écart entre les plus riches et la classe moyenne est important, et la transition d'un marché de niche à un marché de masse ne peut avoir lieu. Un exemple de l'importance de l'inégalité des revenus est le cas de la société dualiste que nous trouvons lorsque l'innovation de procédé est forte.

k) Nous pouvons ajouter de nouvelles politiques pour ajuster plus rapidement ou plus lentement les compétences, et elles auront des effets sur la croissance et l'emploi. En fait, en France, la formation continue ne dépend pas seulement des entreprises, mais aussi de Pôle emploi qui peut former des chômeurs. Cela les aide à acquérir de nouvelles compétences et à favoriser leur retour au travail. La formation continue peut être étendue à d'autres situations que celle que nous avons envisagée : formation uniquement lorsqu'un emploi est vacant et impossible à pourvoir sur le marché du travail. En France, chaque salarié dispose d'un compte formation personnel et peut utiliser ce montant pour suivre des formations afin d'acquérir de nouvelles compétences. On peut aussi donner de l'intérêt aux entreprises pour la formation. Il permet une plus grande adaptation à l'évolution de la demande de compétences.