Université Panthéon - Assas

Ecole doctorale de Sciences Economiques et Gestion

Thèse de doctorat en Sciences Economiques
soutenue le 4 Juillet 2016

Essais en Théorie de la Négociation et Gouvernance

Université Panthéon-Assas

Thèse de doctorat Juillet / 2016

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Avertissement

Remerciements

I would like to express my deepest gratitude to all those who, directly or indirectly, contributed to the realization of this research.

First and foremost, I am in debt with three Professors.

I would like to thank my supervisor, Professor Bruno Deffains, for giving me the opportunity of pursuing in the research. Believing in me, he offered his time, knowledge, abilities and guidance. He motivated me to work effectively by inspiring enthusiasm, creating a supportive environment and demonstrating interest in my successes and improvements.

I would like to express my special appreciation to Professor Dominique Demougin, who guided my first steps in the scientific research and with his passion, abilities and hard work contributed immensely to my personal and professional development.

A grateful thanks to Professor Benjamin Bental for his insights, suggestions, comments, support and guidance. All the three papers of this thesis have profited of his attentive remarks and meticulous analysis.

I would like to thank the staff of the EBS Business School of Wiesbaden, who assisted me while working on the project and contributed to make my PhD experience productive and stimulating. In particular, the Department of Economics has been a source of friendships as well as good advice and collaboration. A special thanks to my friend and co-author Clemens Buchen for the pleasant time spent working together, the uncountable moments of motivating discussion and for making the times of difficulty more enjoyable with his humor and support. Part of this thesis is the result of our collaboration.

I also want to express my thanks to Professor Jenny Kragl, who gave me the opportunity to work as research and teaching assistant allowing me to finance my research and study, to broaden my experience and grow as a research scientist. Many thanks must also be given to Martina Gogova for encouraging my research, for helping me in many occasions and for the many interesting conversations on research. I am also grateful to the administrative assistants who kept us organized and were always ready to help.

Sincere thanks are offered to my friends Roberto Nisticò and Tiziana Venittelli. With their enthusiasm for research and precious advice stimulated and supported me in the realization of this research. I also wish to thank my loyal friend Sandro Perone for his moral support and his confidence in my abilities during periods of difficulty and uncertainty.

Thanks to Chiara Scarampi for her love. She has always and in all ways shown it.

Lastly, a special thanks to all my family for all their love and encouragement throughout this experience. I am grateful to my parents who supported me in all my pursuits and were always willing to help me. Thanks to my sister for cheering me up and for her vitality and dedication, which are constant sources of inspiration and stimulation.

Finally, I would like to thank all those who supported me in the last years with their attention and encouragement, and all those who are interested in reading this dissertation.

Essais en Théorie de la Négociation et Gouvernance

Résumé :

Cette thèse a pour sujet les effets que l'information a sur les incitations. Les trois articles fournissent et explorent des résultats lorsque l'information est la principale variable d'intérêt, est endogène, pas homogène entre les acteurs et évolue dans le temps d'une manière qui n'est pas nécessairement rationnelle. Le premier article étudie les problèmes de *hold-up* dans les hiérarchies verticales avec la sélection adverse montrant qu'alors que le pouvoir de négociation des travailleurs augmente, les distorsions provenant de l'asymétrie d'information disparaissent. En outre, il étudie l'effet de la scolarité et du degré d'hétérogénéité de la population de travailleurs sur la répartition du pouvoir de négociation dans les marchés réglementés. Le deuxième article assouplit l'hypothèse des croyances homogènes dans les relations principal-agent avec sélection adverse. Dans un apprentissage évolutif qui est imitatif, les principaux peuvent avoir des croyances différentes sur la répartition des types d'agents dans la population. La convergence à une croyance uniforme dépend de la taille relative de la polarisation dans les croyances. En outre, le modèle est une version d'un *cobweb* stable. Notre approche offre des explications pour l'alternance des périodes avec quantité oscillante et relativement stable. Le troisième article étudie la façon dont le contenu informatif des politiques juridiques, comme la responsabilité stricte et négligence, en cas de soucis morales, influence la conception optimale des régimes de responsabilité. Plusieurs cas récents ont montré qu'un individu ayant causé un dommage s'expose non seulement a une sanction légale — par exemple, une amende — mais aussi à un boycott sociale, la désapprobation ou la stigmatisation. L'article montre que le choix d'une stratégie dépend de façon complexe de l'importance du dommage et du "coût moral".

Descripteurs :

Négociation, Sélection Adverse, Hold-up, Théorie des Jeux Evolutive, Hétérogénéité des Croyances, Théorie des bifurcations, Boycott, Application de la Loi, la Responsabilité Stricte, Négligence.

Essays in the Theory of Negotiation and Governance

Abstract:

This thesis focuses on the effects that information has on incentives. The three papers provide and explore some results when the information is the main variable of interest, it is made endogenous, not homogeneous between actors and evolving over time in a way that is not necessarily rational. The first paper studies hold-up problems in vertical hierarchies with adverse selection showing that as the bargaining power of the worker increases, distortions coming from asymmetric information vanish. Moreover, it studies the effect of schooling and degree of heterogeneity in the workforce on the allocation of bargaining power in regulating markets. The second paper relaxes the common assumption of homogeneous beliefs in principal-agent relationships with adverse selection. In an evolutionary learning set-up, which is imitative, principals can have different beliefs about the distribution of agents' types in the population. Convergence to a uniform belief depends on the relative size of the bias in beliefs. In addition, the set-up is a version of a stable cobweb model. Our approach offers explanations for alternating periods of oscillating and relatively steady quantity. The third paper studies how the informative content of legal policies as strict-liability and fault-based, in case of moral concerns, influences the optimal design of liability regimes. Many recent cases show that an individual found to have caused harm faces not only the possibility of a legal sanction — e.g., the damages he must pay — but also social boycott, disapproval or stigma. The paper shows that the choice of a policy depends in a complex way on the magnitude of the harm and the "moral cost".

Keywords:

Bargaining, Adverse Selection, Hold-up, Evolutionary Game Theory, Heterogeneous Beliefs, Bifurcation Theory, Boycott, Law Enforcement, Strict Liability, Negligence.

Sommaire

Introduction

Economic models, results and related policies are subject to the information that actors have. The role of information and the way it is spread and obtained by individuals in the society plays a fundamental role in decision-making. As a consequence, policies are not independent on what the actors know and the way they acquire knowledge.
The paradigm of neoclassical economics for which individuals have perfect information has been often criticized and branches of economics such as game theory and contract theory deal also with the role of information and in particular with the effects that asymmetric information and incentives have on market failures. However, a large part of economics studies treat information about states of the world as an exogenous variable not dependent on the choices, as a result of a rational learning process, or as an homogeneous entity owned by the actors. This thesis is about these mentioned roles and focuses specifically on the effects that information has on incentives. In particular, this project consists of three self-contained essays which relax some of the assumptions usually stated in game theory and mechanism-design and study the role of different sets of information on actors' choices. The three papers provide and explore some results when the information is the main variable of interest, it is made endogenous, not homogeneous between actors and evolving over time in a way that is not necessarily rational.

The scope of the research I include in my dissertation is to treat the information in its broadest sense, highlighting its role in policy decisions with specific regard to the theory of negotiation and governance. Recently, Dixit (2009) has stressed the importance of economic governance as prerequisite of well functioning of economic activities and in his discussion he has given a series of broad suggestions for policy advisers, policy makers, and investors and traders. This thesis is reminiscent of these observations and humbly attempts to investigate the validity of some common assumptions in economics and delineates how conclusions are related to those assumptions. The final aim of all the papers is to study the distortion from first best solutions and how these distortions are attenuated or amplified in circumstances which I believe more concrete in real world situations.
I use concepts deriving from contract theory and evolutionary game theory and apply them to specific contexts. With particular interest on the theory of incentive, I focus on the causality between information and personal interests of agents. In the first two papers, I consider principal-agent relationships with adverse selection. The first includes bargaining and cost of information creating a hold-up problem, while the second analyzes the role of heuristic imitative behavior to study the evolution of beliefs in principal-agent models.

Lastly, the third deals with incentives in illegal acts when the societal reaction in term of stigma can be influenced by the information obtained under different legal regimes.

All the papers insist on the normative dimension concerning governance. One paper assumes the institutional set-up as given and questions on the validity of the assumption of a common belief in a principal-agent evolutionarily imitative model. Convergence and fluctuations are the main interests and the effects of these on the fundamentals of the market are analyzed. The other two papers consider the decisions of the regulator in defining the legal institutions. In the first, I study the impact of bargaining power in attenuating distortions from the first best in quantities and at the same time I discuss how the distortions can still be beneficial from a social point of view when firms are hold-up. In the third, it is defined an optimal legal design in harnessing illegal behavior when wrongdoers suffer extrinsic additional costs to the standard law sanctions.

In more specific details, in the first paper I study hold-up problems in vertical hierarchies with adverse selection. *Some contracts require one party to act first, in anticipation of reciprocal action by the other. But when the time comes, the other party may be tempted to renege on its promise.* [...] *Oliver Williamson (1985) has labelled this the problem of opportunism and hold-up* (Dixit 2009). As extension, the aim of this paper is to find a set-up which allows to better understand the interdependences between productivity, investment, firm's performance and bargaining.

Several contributions in empirical research have stressed the importance of the mentioned interdependences. For instance, Black and Lynch (2001), among others, try to answer questions like: *Does the implementation of "highperformance" workplace practices ensure better firm performance? Does the presence of a union hinder or enhance the probability of success associated with implementing these practices? Do computers really help workers be more productive?* Yet, the effect of unions and collective bargaining is still a relevant example of economics debates (for a recent reference see Lewin, Keefe, and Kochan 2012). Moreover, as stressed by Jensen and Rässler (2007), less emphasis has been given to the effect of bargaining on the firm's efficiency. I try to highlight the role of asymmetric information and hold-up problem in a theoretical model and then I perform numerical simulations to better understand how the heterogeneity of the workforce and the schooling play a role in the normative design. I focus my attention on the hold-up problem in labor contracts while large part of the literature studies buyer-seller relationships (for instance, see Gul 2001; Hermalin and Katz 2009).

The hold-up in my framework concerns the firm's upfront investment before the negotiation. As is standard, her investment creates a surplus, but the subsequent negotiation leads this surplus to be split according to the bargaining power of parties, creating a trade-off for the firm. Moreover, assuming a negotiation for the hiring process where neither the firm nor the worker know the worker's type for a future employment, I include a subsequent screening problem.

The role of bargaining in presence of asymmetric information has already been stressed in the literature —see e.g., Deffains and Demougin (2008), Bental and Demougin (2010) and recently Gogova and Uhlenbrock (2013) and Halac (2015). In presence of adverse selection, Inderst (2002) proposes the Rubinstein solution for informed workers. Yao (2012) suggests the same idea with respect to the standard non-linear pricing model, while Cabrales, Charness, and Villeval (2011) offer an experimental approach. However, the former models deal with moral hazard, while the latter ones do not consider the hold-up problem.

I focus on pre-contractual problems with hold-up. First, I relax the assumption that the principal has all the bargaining power and writes enforceable contracts making take-it-or-leave-it offers and leaving the agents to *self-select*.[1] The principal and the agent bargain on a set of menus of contracts when both parties are uninformed about the agent's type. After the negotiation, the agent discovers his type. The assumption of absence of information is motivated by the frequent possibility of observing that, in many contexts, the agent does not have any reference to understand his efficiency for a specific task. Furthermore, a negotiation *ex-ante*, for a specific task to be attempted and that assures a related payment *ex-post*, is likely observed in all the kinds of job the agent is supposed to start for the first time. Second, I assume that before the negotiation the principal chooses an investment in capital that affects the probability of hiring an agent with higher performance. More clearly, I assume that the investment in capital affects positively the probability of obtaining a production from a low-cost type and it is interpreted as a technology improvement which decreases the cost of producing for some workers. Therefore, the investment in capital enhances the expected efficiency and influences the distribution of types, making it endogenous. Hence, the investment creates a surplus to be shared between employee and employer and affects the framework in which the negotiation takes place.

In detail, I analyze a three-stage game and I solve it by backward induction. In the first

[1]These contracts differ for the production and payment and are related to the agent's type; where it is common in mechanism-design literature to refer to the "agent's type" as agent's efficiency, which is essentially the marginal cost of producing.

stage, there is a regulator who wants to maximize the social welfare and chooses how to split the bargaining power between firm and worker. The legal decision of how to design the labor contract, behind the mere effect on the resolution of the negotiation, has a direct effect on the private decision in the second stage. This last stage involves the irreversible investment in capital by the firm; such investment defines the environment of the negotiation for the last stage. Then, different investments define the framework in which the negotiation takes place: the principal, who can affect the expected efficiency, designs a particular menu of contracts that are the object of negotiation in the third stage.
The results are that as the bargaining power of the worker increases, distortions coming from asymmetric information vanish. I find that a solution of first best in quantities is obtainable, but never optimal because it reduces the incentive of the private party to increase an investment in capital. The surplus that this investment creates outweighs the distortion on quantity. However, if the agent is protected by limited liability on the net rent, an optimal solution never requires that the principal holds all the bargaining power.

The second paper, with the co-author Clemens Buchen, relaxes the common assumption of homogeneous beliefs in principal-agent relationships with adverse selection. In particular, we assume that principals have different beliefs about the distribution of agents' types in the population. We model an imitative evolutionary learning in a market which is a version of a stable cobweb model.
The reasons for fluctuations in economics include several explanations and the literature on this argument is almost uncountable. Moreover, the role of expectation and heterogeneity of beliefs is still controversial in economic theory (Kurz 1997; see Dixit 2009 for a discussion about the role of heterogeneity in economics). On the one hand, the expectations about fundamentals of the market by economic agents are used to justify cyclical behaviors. Keynes (1936) already highlighted the importance of the role of expectations and the standard cobweb model, in its basic argument, is the prototypical set-up able to model price/quantity fluctuations. On the other hand, the heterogeneity in expectations enriches the dynamic of fluctuations and is often used to show how endogenous and not repetitive cyclical behaviors emerge in markets. The seminal paper on this is Brock and Hommes (1997). They model a rational behavior of heterogeneous firms. The heterogeneity comes from the fact that some firms invest more than others to better predict expected quantity. Since the incentive to invest in prediction changes as the fluctuations of the price change, chaotic and unpredictable behavior of time series and bifurcations of variables can

be analyzed. Our model introduces heterogeneity differently in that it comes from different beliefs about the ability level in the population of agents, holding the prediction ability of firms equal for all. More specifically, in the basic adverse selection model, the principal knows that she faces an agent with a given ability drawn from a distribution of types. On the basis of the distribution, principals write court-enforceable contracts and agents self-select. We change the set-up of this base model in one crucial aspect: we assume that the population of principals is heterogeneous in that they have different beliefs about the distribution of types.

Since the pioneering work by Alchian (1950), several important theoretical contributions to the role of evolutionary mechanisms have been developed, but to the best of our knowledge, our paper is the first to introduce a bias for the uninformed market side in an evolutionary set-up; therefore appearing as an attempt to introduce adverse selection in a macro model. In particular, this simple observation is useful to make a comparison with those models that introduce heterogeneity into cobweb models (Brock and Hommes 1997; Branch and McGough 2008; Hommes 2013; Schmitt and Westerhoff 2015). These approaches model heterogeneous expectations about the price/quantity in an "unstable" cobweb model. Hence, it is worth pointing out that our modelling, which includes adverse selection, allows us to model price/quantity dynamics in a "stable" cobweb model and where most of the basic standard economic assumptions are already enough to draw conclusions.

Our model is also related to the literature on imitation in different market settings. In this regard, Vega-Redondo (1997) introduces imitation to study equilibria in a Cournot game and the idea is extended and applied to other market types in a number of other papers (see citations in Ania, Tröger, and Wambach 2002; Alós-Ferrer 2004). Yet, in assuming biased principals, we propose a different approach with respect to the literature on biases of agents; examples are Gervais and Goldstein (2007) who study the impact of self-perception ability, Santos-Pinto (2008) who extends the biases on the others' ability, de la Rosa (2011) and Wang, Zhuang, Yang, and Sheng (2014) who focus on agent's biases on the probability of success. As last connection with previous literature, our approach is tangent to the information-sharing literature (Vives 2001). However, while there principals disclose information, in our set-up we assume that any information sharing occurs unwittingly.

Our evolutionary learning model is related to the deterministic evolutionary models discussed in Fudenberg and Levine (1998). We take the basic idea of the social learning model and combine this with the imitation within reference groups by Selten and Ostmann (2001). We draw an analogy with the standard game theory approach and interpret the belief held by a principal as a sort of "pure strategy" in the game. We assume that learning takes place by imitation of other principals' beliefs. We model it claiming that the information about the beliefs is shared by word-of-mouth communication as in Banerjee and Fudenberg (2004), or alternatively, beliefs can be inferred if the menus of contracts are observable as in Ania, Tröger, and Wambach (2002). Then, we condition the probability to change beliefs on the matching, the propensity to switch, and the payoff difference between principals.

Aside from a belief about the distribution of types, we enrich the dynamic by modelling the evolution of beliefs in an aggregative game in which the profit of principals depends on the belief about the distribution of types, the specific match and the behavior of all other principals, which affects the aggregate quantity in the market. We define the conditional switch rate, which is the probability that a principal changes beliefs. To do that, we periodically allow some principals to observe the profit of a second principal.

Furthermore, each principal also forms an expectation about the quantity produced in the market. We use a simple naive expectation in that when writing contracts principals expect the total quantity to be the same as in the previous period (as in a standard cobweb model).[2] This implies that there are two interrelated variables that change over time: the distribution of beliefs and the quantity in the market.

To sum up, the contributions of the paper are twofold. On the one hand, we justify under which conditions the assumption of a common belief in the mechanism design literature can be supported under a behavioral learning model without loss of generality. We choose to model learning via an imitative process instead of the alternative Bayesian updating in line with Young (2004), who suggests that in many applications the Bayesian updating makes too great demands on the quality of the information set and the cognitive abilities of agents. Then, we try to answer the first main question: where does the economy converge in terms of different beliefs? A standard assumption about Bayesian updaters

[2]The rationale for this comes from our assumption that principals in our model do not know the salient characteristics of the market, simply because they are not aware that there are different beliefs, which have an impact on the quantity the principals produce. A model with rational expectations about the quantity would be a contradiction to this view. The assumption of naive expectations is without loss of generality in our context and allows us to better compare our model with previous ones.

rational players with perfect memory would lead to a straightforward result whenever one appeals to the Law of Large Numbers. However, the introduction of imitation makes the convergence less straightforward. We study the dynamics of different compositions of the population with the aim of understanding how heterogeneity drives the economy towards possibly different equilibria. We find that convergence to a common belief depends on the relative degree of bias of the principals. On the other hand, we show how a market with adverse selection and evolutionary learning can easily generate fluctuations and cycles of the price/quantity adding new insights to the cobweb model. In particular, in contrast to the standard cobweb model, our model generates periods of relative steady quantity, which are punctuated by large oscillations.
We point out two future avenues for empirical research. First, how limitations on the part of subjects could imply sluggish adjustment processes. Second, we stress the importance of convergence paths and emphasize how the heterogeneity can create conditions for dynamic systems to remain far away from steady states.

The third paper, which represents a joint work with Clemens Buchen and Bruno Deffains, studies how the informative content of legal policies as strict-liability and fault-based, in case of moral concerns, influences the optimal design of liability regimes. We show how the information affects compliance with laws when moral norms (i.e., social preferences) affect behavior, in addition to standard material or economic incentives.
In the Theory of Moral Sentiments, Adam Smith remarks that an individual found to have caused harm faces not only the possibility of a legal sanction — e.g., the damages he must pay — but also social disapproval or stigma. The main idea is also part of Dixit (2009): [...] *the most relevant distinction is between formal institutions of the state, enforced by its legal apparatus and using its powers of coercion if needed as a last resort, and informal social institutions, which must be self-governing using strategies available to the participants in the economic interaction themselves.* Reminiscent of these observations, we stress that the "stigma cost" is not simply a transfer of resources. In fact, it creates an additional trade-off not present in the literature (Dixit 2009: *A group can threaten to boycott collectively a ruler who violates the rights of even one of its members. But the boycott is costly* [...]).
The Law and Economics literature has studied stigma mainly in relation to criminal activity (Rasmusen 1996; Harel and Klement 2007; Zasu 2007 among others). We inquire how a concern for social disapproval, which has negative monetary impact on the wrongdoer (i.e., boycott), interacts with the incentives created by tort law and how this affects the

relative performance of different legal regimes.
We mainly refer to cases where the consumers' boycott has a monetizable negative impact on wrongdoer firms. Such behavior is largely present in nowadays economy, where the information spread about illegal acts has became efficient. Recent examples of it are Nestlé, which is the target of a boycott since the late 1970s, with the accusation of aggressively marketing breast milk substitutes, which represent a health risk for infants.[3]
Another meaningful example is represented by the production of palm oil.[4] The issue of the tropical deforestation caused by the cultivation of palm oil is growing concern worldwide, leading people to reduce the consumption of unsustainable palm oil and to take part in campaigns against the deforestation. Also some big companies are addressing their ties to unsustainable palm oil. For example, Kellogg has announced its commitment to responsibly source palm oil and avoid buying the additive from companies that destroy tropical rainforests. The company has introduced a new policy requiring the suppliers of palm oil to trace their palm oil to *known and certified sources that are environmentally appropriate, socially beneficial and economically viable* (Kellogg 2015).
One of the largest oil producers of the "Royal Dutch Shell Group", Shell Nigeria, which extracts oil in the Niger Delta, has brought many environmental devastation. Two particularly disastrous cases are the Bodo and Bonga spills, which took place respectively in 2008 and 2011. For the individuals living in the area, the poisoning of the land and water is causing serious environmental, economic and health consequences. A part from the massive fines the company is facing for the spills (4 billion dollars only for the Bonga spill), many individuals and associations have started raising their voice against this emergency. Amnesty International (2009) published a report highlighting that Shell's operations in Nigeria were violating the human rights and accusing the company for its weak commitment in cleaning up oil spills.
A more recent event that can be taken as example is the Volkswagen emission scandal.

[3]Nestlé was committed to trial, but the court found in favor of the corporation, although they were asked to change the advertising methods. Furthermore, the boycott attracted support from different authorities and from the society, and led the World Health Assembly in 1981 to develop and adopt an international code of conduct to regulate the sale of breast milk substitutes (Muller 2013).

[4] Due to its many usages (e.g., for food, cosmetics, chemical industry, etc.), the demand of palm oil is increasing rapidly and its production is growing accordingly. However, the cultivation of palm oil is occurring at the cost of the deforestation of wide areas. In the last 20 years, more than 30,000 square miles of rainforests have been wiped out (Vidal 2014). One of the main Indonesian palm oil companies, PT Kallista Alam, has been fined 30 million dollars for large-scale burning of protected swamp forest in Aceh, breaking a National Law on Environmental Protection and Management (Gartland 2014).

In September 2015, the United States Environmental Protection Agency (EPA) reported that Volkswagen violated the Clean Air Act by installing a tampered emission control system on many cars with a diesel engine. This software was able to detect when the car was being tested, providing performance in adherence with all federal emissions levels, but switching to a separate mode and exceeding safe emission levels when driving normally. As a consequence of the scandal, government regulatory agencies have initiated investigations on Volkswagen in many countries and in the days after the news, Volkswagen's stock price fell in value by a third. Volkswagen is facing heavy fines for cheating emission tests and violating environmental laws. Many Volkswagen and Audi owners are pursuing class-actions against the brand, whereas some financial institutions have launched a boycott against Volkswagen. For example, *Scandinavia-based Nordea Bank has barred its traders from buying Volkswagen shares and bonds for six months* (Bradshaw 2015). A survey by AutoPacific has compared consumers' opinion of Volkswagen before and after the scandal and revealed that while before it 3 out of 4 vehicle owners had a positive opinion about the brand, after the news only 1 out of 4 preserved such opinion. In an interview by Grieb (2015), Ed Kim, Vice President of Industry Analysis at AutoPacific, said: *this change in consumer opinion will put a significant dent in the brands' overall sales.*

With the aim of understanding the impact from a social point of view of these additional costs and the way in which the Law should intervene, we enrich the model of public enforcement by developing a set-up of unilateral accident when strict liability and negligence rules yield insufficient incentives to control risks. Injurers are partially judgment-proof or are not always sued — e.g., it is not always feasible to prove harm or identify the injurer. The canonical model of the public enforcement of law provides an utilitarian analysis of how illegal acts — actions that impose negative externalities — are deterred by the threat of detection and sanctions; see Polinsky and Shavell (2007) for a survey. In the simplest version, the model develops in a more formal way the Becker (1968)'s analysis as first attempt to model the enforcement of law when the detection is uncertain. The analysis is carried-out developing the main trade-off between the severity of the sanction and the resources that should be spent on apprehension and detection, hence the degree of deterrence that will be achieved. Therefore, the double interrelated results. First, whenever it is feasible, sanctions should take the form of fines and be set as higher as possible because costless and substitute of the probability of detection. This is done so as to minimize the costly detection. The second result, due to Polinsky and Shavell (see, Polinsky and

Shavell 2007) concerns with the optimality of some underdeterrence; that is, not all potential violators will be deterred and not all violations will be detected because lowering detection allows saving in enforcement expenditures that overweight the alternative social costs implied by underdeterrence.

The basic model has been further developed in many directions. For instance, the hypothesis of risk averse potential violators tends to lower the amount of the prescribed fines and to increase the probability of detecting infractions (Polinsky and Shavell 1979; Kaplow 1992). Shavell (1987) discusses the role of nonmonetary sanctions as a deterrent, while Shavell (2002) stresses how *law and morality serve to channel our behaviour*: comparing legal sanctions versus informal motivation as regulators of conduct. Yet, Deffains and Fluet (2013) consider the role of a moral prescription that seems particularly relevant in a tort context.

In our paper, we start observing that the theory of Enforcement of Law is mainly based on two policies: strict liability and fault-based. Under strict liability the fine is paid whenever an individual is guilty, independently of the personal benefit obtained for committing a harmful act. Conversely, in the case of fault-based liability, the conviction depends on the defined fault standard.

In our framework, an individual's actions are not directly observable by society at large. However, adverse court judgments provide public information from which inferences can be drawn about the individuals' actions and therefore about their moral predispositions. Under either strict liability or the negligence rule, moral concerns are shown to provide individuals with some deterrence incentives. The issue is how this influences the optimal design of liability regimes, when the objective is to induce the greatest number of individuals to exert socially efficient care.

In case of imperfectly enforced legal liability — e.g., victims do not always bring suit because they have insufficient evidence to prevail in court — it has been showed that normative motivations and formal legal sanctions then complement one another — e.g., an individual held liable faces both legal damages and disesteem. Thus, informal and formal incentives interact to induce more precautions than under no-liability. A basic result in comparing policies is in Deffains and Fluet (2015). There, the negligence rule is more effective than strict liability in harnessing moral concerns. The reason is simply that trial outcomes are then more informative. Under the negligence rule, a liability ruling also ascertains that the defendant exerted inadequate care, thereby providing more precise information about his intrinsic predispositions. Socially useful incentives are therefore derived from the signalling role of "fault" or "negligence". To further explore this possibility, we extend the analysis considering "extrinsic" motives instead of "intrinsic" ones. A complete characterization of the negligence regime must now consider how courts deal with this standard. We show that when injurers can suffer of external costs imposed by the society, and by contrast with the literature results, the standard has some effects on the deterrence level. Moreover, we claim that a *non-guiltiness standard* — the fault equal to the deterrence level — is never optimal. This is in contrast with standard arguments about the superiority of fault-based under risk neutrality. Modelling the informative contents of strict liability and fault-based policies, we highlight that the choice of a law maker is to use the boycott not only as a substitute for a costly enforcement, but primarily as a tool to harness illegal behavior. We show that the choice of a policy depends in a complex way on the magnitude of the harm and the "moral cost".

1 Hold-up in Vertical Hierarchies with Adverse Selection

Abstract

This paper studies hold-up problems in vertical hierarchies with adverse selection. The principal and the agent bargain on a set of menus of contracts when both parties are uninformed about the agent's type. Moreover, the principal chooses an investment in capital that affects the probability of hiring an agent with higher performance; the investment in capital enhances expected efficiency and creates a hold-up problem.

The legal decision of how to design the labor contract determines the respective bargaining powers of employer and employee and, thus, affects the private decision of firms. The trade-off that the regulator faces is about the investment in capital, expected rent and distortion from the perfect information case. A solution of first best in quantities is obtainable, but never optimal from a social point of view.

JEL Classification: C78, D02, D82
Keywords: Bargaining, Adverse Selection, Hold-up

1.1 Introduction

This paper studies the hold-up problem in contexts with asymmetric information and deals with the effects of bargaining power on incentives of parties. The allocation of bargaining power between workers and employers raises questions on the results that it generates and in particular how private decisions, which can be welfare improving, are affected in imperfect markets.

Consider the following leading example. A firm (*principal*) makes an upfront investment which implies a reduction of costs of performing works for some future employees (*agents*). Her investment is in principle beneficial for both parties, but a subsequent negotiation can lead to a request of higher wages. This implies that part of the surplus generated by the firm is split according to the bargaining power of the parties. That is, a common hold-up problem arises. Moreover, if we consider that in some occasions in the hiring process neither the firm nor the workers know the worker's type for a future employment, a subsequent screening problem has to be considered. Hence, I assume that during the negotiation the principal and the agent face uncertainty. The assumption of a negotiation *ex-ante*, for a specific task to be attempted and that assures a related payment *ex-post*, is likely observed in all the kinds of job the worker is supposed to start for the first time or in the case the worker starts working in a new environment or group work. In regulating markets, the legal decision which necessarily affects the private choice, and therefore directly and indirectly the social welfare, is to find the optimal distribution of contractual power.

Dealing with this scenario, this paper handles two interrelated questions. First, disregarding the hold-up problem, I analyze under which conditions an ex-ante negotiation can still affect distortions caused by the asymmetric information. Second, I analyze how the allocation of bargaining is linked to the firm's investment which influences the distribution of types, making it endogenous.[1]

The idea of applying bargaining in presence of moral hazard can be found in the literature — see e.g., Deffains and Demougin (2008), Bental and Demougin (2010) and recently Gogova and Uhlenbrock (2013) and Halac (2015). For models of bargaining under incomplete information, Inderst (2002) proposes a game in two periods where the uninformed side and the informed side bargain with alternating offers and the uninformed principal updates his belief. Yet, Inderst (2003) derives conditions for subsets of parameters to show that in a set-up where there is a continuous shift in bargaining power between the two parties the efficient contracts are implemented. Yao (2012) suggests the same idea with respect to the standard non-linear pricing model, while Cabrales, Charness, and Villeval (2011) offer an experimental approach to disentangle the effect of competition — as proxy of bargaining power — between the parties on the performance and efficiency. However, the former models analyze a moral hazard set-up, while the latter ones do not consider the

[1]Although the example was on quantity and wage and although I keep in the exposition the related terminology, the set-up of this paper is suitable for any vertical hierarchy where the quality is the variable of interest.

hold-up problem. This paper is about hold-up problems in presence of adverse selection and endogenous type-distribution.

In detail, I analyze a three-stage game and solve it by backward induction. In the first stage, the regulator maximizes the social welfare and chooses how to split the bargaining power between firm and workers. The legal decision of how to design labor contracts, in addition to the mere effect on the resolution of the negotiation, has a direct effect on the private decision taken in the second stage. Here, there is an irreversible investment in capital by the firm, which defines the environment of the negotiation that takes place in the final stage. More clearly, I assume that the investment in capital has a positive effect on the probability of obtaining a production from a low-cost type. For instance, this investment can be seen as a technology improvement which decreases the cost of producing for some workers. It affects the asymmetric information problem, implies a direct cost and can generate a surplus. Hence, different investments define the framework in which the negotiation takes place: firm and worker face an expected efficiency and bargain on a menu of contracts in the third stage. In this last stage, the two parties bargain over the quantity and the related payment. Here, the investment is a sunk cost for the firm. Hence, one can consider as given the defined type-distribution. The first result stands in contrast to standard screening models. The distortion from the perfect information case vanishes as the negotiation is more in favor of workers. Moreover, for the high-cost type the agreement is always between the perfect information case and the second best, i.e., the principal has all the bargaining power. In the second stage, I analyze the firm's trade-off in investing in capital. The principal can face a more favorable distribution of types and it can be beneficial for both parties, but the share of the total generated surplus is contractible only after it has been made and depends on the distribution of the bargaining power. In this context, the choice of an utilitarian social planner who maximizes the joint monetary gain is to find the optimal allocation of bargaining power. A larger power for the agent has two effects. On the one hand, the contract is solved for a higher efficiency. More clearly, also the quantity of the high-cost type converges towards the perfect information case. On the other hand, giving more power to the worker increases the payment by the principal who shrinks the investment in capital and therefore the quantity. The mere change in bargaining power has ambiguous effects given the *status quo* of the economy. More clearly, the effect is not obvious and depends on the schooling and degree of heterogeneity in the workforce.[2]

[2]The term heterogeneity is meant as difference in the marginal costs.

However, even if the regulator can induce quantities of first best, it is possible to show that this is not welfare improving. The benefit derived from the absence of distortions is outweighed by a more likely production from a low-cost type. The regulator opts for a repartition of bargaining power to favor a higher investment in capital.

The paper proceeds as follows. Section 2 presents the set-up. Subsections analyze the three stages of the game and discuss the partial results. Section 3 deals with a numerical simulation to extend the theoretical results. Section 4 concludes.

1.2 The Model

The actors in the economy are regulator, firm, and workers. The game is sequential and the timing is defined as in the introduction. I assume that the first *move* is made by an utilitarian social planner who chooses the repartition of contractual power in order to maximize the welfare. The investment in capital made by firms is the result of legal decision and cost of capital, taking into account that the legal repartition of power influences the result of the negotiation (last stage).

The timing of the strategic game can be summarized as follows:

1. The Social Planner determines the bargaining power;
2. The principal invests in capital;
3. The negotiation between principal and agent takes place.

The principal derives benefit $S(q)$ from the production q made by the agent, where $S'(q) > 0$, $S''(q) < 0$. The principal makes a payment t to the agent, who faces a cost for producing given by $C(\theta, q) = \theta q$. Defining as θ the agent's type, formally the monetary gains for the principal is $B(q, t) = S(q) - t$, while for the agent $U(q, t, \theta) = t - \theta q$, where θ belongs to the set $\Theta \equiv \left\{\underline{\theta}, \overline{\theta}\right\}$ and $\underline{\theta}\left(\overline{\theta}\right)$ characterizes the low-cost (high-cost) type. Moreover, as the principal and the worker do not have private information on the types, the probability of being low-cost is $Pr(\underline{\theta}) \in [0, 1]$. The principal and the agent bargain over a menu of contracts.

Anticipating the outcome of the bargaining, the principal chooses the optimal investment in capital (k) as a function of his bargaining power and of the cost of capital r. For this stage, I assume that the principal, investing in capital, increases the probability of obtaining the production from a low-cost type. Hence, if the principal affords structural investments, she faces a more favorable distribution of types. In turn, this investment implies a negotiation on a menu of contracts that entails different combinations of quantities and payments. Formally, I assume that the probability distribution depends of the investment in capital $v(k) \equiv Pr\left(\underline{\theta}\middle|k\right)$, a strictly increasing and strictly concave function, $v_k > 0, v_{kk} < 0$.

I derive the subgame perfect equilibrium. Therefore, the analysis is carried out by backwards.

1.2.1 Bargaining Stage

In this last stage the bargaining power has been defined by the regulator and the investment in capital is a sunk cost. Therefore, they are treated as constant. The principal and the worker, who are assumed to be risk-neutral, bargain over a menu of contracts. The timing of the bargaining stage is summarized as follows:

1. Negotiation over a set of contracts takes place;
2. The agent realizes his type;
3. The agent selects a contract;
4. The contract is executed: production takes place and payments are made.

I apply the axiomatic Nash Bargaining solution to derive the results from the negotiation.[3] Therefore, contracts are chosen so as to maximize the product of each expected net return. The revelation principle holds also in this context and therefore I focus on the class of direct revelation mechanisms that describe *incentive compatible contracts*:[4]

$$t(q(\theta)) - \theta q(\theta) \geqslant t(\tilde{q}) - \theta\tilde{q} \quad \forall\, \tilde{q}, \theta \in \Theta \text{ and } t(\cdot) \text{ defined}$$

[3] The axiomatic Nash Bargaining solution is commonly used for wage negotiation, see Pissarides (2000).
[4] See Laffont and Martimort (2002) pages 234-235 for a detailed exposition.

Additionally, I assume that the agreement must ensure limited liability for the agent.[5] That is, for every state of the world θ, parties agree on a set where:

$$U(q,t,\theta) \geqslant 0 \quad \forall (q,t,\theta)$$

Therefore, ex-ante, both actors negotiate on a specific menu of incentive compatible contracts $\{q(\theta_i), t_i(\theta_i)\}_{\theta\in\Theta}$ which entails ex-post, for every observed quantity $q(\theta)$, a given transfer $t(\theta)$; hence a double dimension negotiation.[6]

Denoting with $\alpha \in (0,1)$ the bargaining power of the firm and highlighting that capital and bargaining power are already at the optimum in this stage, the family of asymmetric Nash solutions solves the following (NP) program:

$$\underset{\{q_i(\theta_i),t(\theta_i)\}}{Max} \mathcal{N}\Big|_{k^*,\alpha^*} = \left\{\sum_{\theta_i} Pr(\theta_i)\left[S(q(\theta_i)) - t_i(\theta_i)\right]\right\}^{\alpha} \left\{\sum_{\theta_i} Pr(\theta_i)\left[t_i(\theta_i) - \theta_i q(\theta_i)\right]\right\}^{1-\alpha}$$

subject to

$$t_i(\theta_i) - \theta_i q(\theta_i) \geqslant 0 \quad \forall \theta_i \in \Theta \tag{$PC(\theta_i)$}$$

$$t_i(\theta_i) - \theta_i q(\theta_i) \geqslant t_j(\theta_j) - \theta_i q(\theta_j) \quad \forall \theta_i \in \Theta,\ i \neq j \tag{$IC(\theta_i)$}$$

Using standard notation for $q(\theta_i)$, $t_i(\theta_i)$, $v \equiv Pr(\underline{\theta})$ and denoting with $(^*)$ quantities of first best where surplus is maximized, one obtains:

Proposition 1. *The program (NP) admits two candidate solutions:*

Candidate 1 (C1):

$$S'(q_i^*) = \theta_i \quad \forall \theta_i \in \Theta \qquad \textit{with } \mathcal{C} = \frac{E[B]}{E[U]} = \frac{\alpha}{1-\alpha}$$

Candidate 2 (C2):

$$S'\left(\underline{q}^*\right) = \underline{\theta}$$

$$S'(\overline{q}) = \left[\overline{\theta} + \frac{v}{1-v}\Delta\theta\right] - \frac{1-\alpha}{\alpha}\frac{v}{1-v}\Delta\theta\mathcal{C} \qquad \textit{with } \mathcal{C} = \frac{E[B]}{E[U]} < \frac{\alpha}{1-\alpha} \tag{1.1}$$

[5] A model where the rent of the agent is satisfied in expectation could describe a franchise contract. I discuss below the solution of this scenario.

[6] See e.g. Wang (1998) and Inderst (2003) for a double dimension in a game *à* la Rubinstein (1982).

Proof. See appendix ||

In case of an agreement on quantities of first best (C1), there are different combinations of bargaining power and investment in capital that obviously do not change the quantities, but simply change the total surplus and the way this is split between the parties. To see this, let $\underline{w}^* \equiv S\left(\underline{q}^*\right) - \underline{\theta}\underline{q}^*$, $\overline{w}^* \equiv S\left(\overline{q}^*\right) - \theta\overline{q}^*$ and $\mathbf{W} = v\underline{w}^* + (1-v)\,\overline{w}^*$ the total surplus. k changes $\mathbf{W}$ through v. The expected benefit of the principal is $E\left[B\right] = \mathbf{W} - E\left[U\right]$, while $\mathcal{C} = \frac{E[B]}{E[U]} = \frac{\alpha}{1-\alpha}$.

Conversely, in case of a negotiation which leads to results that differ from the first best in quantities (C2), the *ceteris paribus* effect of different investments or bargaining power, as well as the total effect of this last one change the fundamentals of the stipulated contract in the bargaining stage. Denoting $\overline{q}^B\left(\cdot\right)$ the quantity of bargaining implicitly defined by (1.1), I can claim:

Lemma 1. *Other things being equal, an increase of the investment in capital or an increase in the bargaining power for the firm leads to a decrease in the quantity of the high-cost type, that is* $\frac{d\overline{q}^B}{dk} = v_k \frac{\partial \overline{q}^B}{\partial v} < 0$, $\frac{\partial \overline{q}^B}{\partial \alpha} < 0$.

Proof. See appendix ||

Disregarding for the moment the hold-up problem, the first main result is:

Corollary 1. *For a given distribution of types (a given investment in capital $\overline{k}$) there exists a bargaining power $\hat{\alpha}$ such that:*

(i) for $\alpha \in (0, \hat{\alpha})$, the quantities are at the first best and firm and worker share the total expected surplus according to their bargaining power ($\mathcal{C} = \frac{\alpha}{1-\alpha}$);

(ii) for $\alpha \geqslant \hat{\alpha}$, only the quantity of the low-cost type is at the first best, while for the high-cost type the quantity of bargaining belongs to the set $\left(\overline{q}^{SB}, \overline{q}^*\right)$, where $\overline{q}^{SB}$ is the quantity obtained when the principal has all the bargaining power ($\alpha = 1$). Moreover, the share of the total expected surplus does not depend only on α, but also on the distortion from the first best quantity; ($\mathcal{C} < \frac{\alpha}{1-\alpha}$);

(iii) as the bargaining power of the worker increases, the quantity of the high-cost type is unique and increases converging continuously to the first best;

(iv) $\hat{\alpha} = 1 - \frac{v \triangle \theta \overline{q}^*}{\mathbf{W}}$.

Proof. Obviously, the Nash product attains the global maximum when $\mathcal{C} = \frac{\alpha}{1-\alpha}$. Then, suppose that for a small α candidate (C1) is the maximizer. One first has to show that as α increases the maximizer is candidate (C2). Then convergence, continuity and uniqueness conclude.

The first part is based on the results obtained in Proposition 1, where it is shown that the incentive compatible constraint of the low-cost type and the participation constraint of the high-cost type are both binding or both slack at the optimum. As α increases, the shared surplus for the agent becomes smaller until the point in which the constraints are binding. Convergence is an immediate result of Lemma 1, continuity is ensured by Berge's maximum theorem, and uniqueness by strict concavity everywhere of the Nash product w.r.t. $\overline{q}^B$: $S''(\overline{q}) + \frac{1-\alpha}{\alpha}\frac{v}{1-v}\triangle\theta\frac{\partial\mathcal{C}}{\partial\overline{q}} = S''(\overline{q}) - \frac{1-\alpha}{\alpha^2}\frac{v}{1-v}\triangle\theta\frac{\mathcal{C}}{\overline{q}} < 0$. (iv) defines the equality between the expected rents when the constraints become just binding. □

1.2.2 Capital Investment Stage

In this stage, the principal chooses her investment in capital, while α is given. In case of agreement on candidate (C1), obviously the principal can only affect the distribution of types, while the quantity of the high-cost remains constant. Conversely, when the negotiation ends on candidate (C2), the quantity of the high-cost type is a function of the investment in capital. For clarity I write $\overline{q}[v(k)]$ and $\underline{q} = \underline{q}^*$ and I avoid the superscript $(^B)$ for reasons of legibility.

The principal maximizes her profit choosing k for a given bargaining power, taking into account (1.1) and the cost of capital r:

$$\underset{k}{Max}\, E[\pi]\Big|_{q\in argmax\,\mathcal{N},\alpha=\alpha^*} = v\left[S\left(\underline{q}\right) - \underline{\theta}\underline{q}\right] + (1-v)\left[S(\overline{q}) - \overline{\theta}\overline{q}\right] - v\Delta\theta\overline{q} - rk \qquad (1.2)$$

To ensure the uniqueness of the solution of (1.2), I make use of the following Assumption:[7]

Assumption 1. $\frac{\partial^2\overline{q}(\cdot)}{\partial k^2} > 0$

[7] The Assumption could be replaced by respective assumptions on the benefit and probability functions. However, these require higher order derivative limitations.

Lemma 2. *The profit function is strictly concave in k and therefore the optimal investment in capital as function of α $(k^*(\alpha))$ is single value.*

Proof. See appendix ||

The first order condition which implicitly defines $(k^*(\alpha))$ is:

$$v_k\left\{\left[S\left(\underline{q}\right)-\underline{\theta}\underline{q}\right]-\left[S\left(\overline{q}\right)-\overline{\theta}\overline{q}\right]\right\}$$
$$+(1-v)\left[S'\left(\overline{q}\right)-\overline{\theta}\right]\frac{\partial\overline{q}}{\partial v}v_k-v_k\Delta\theta\overline{q}-v\Delta\theta\frac{\partial\overline{q}}{\partial v}v_k-r=0 \quad (1.3)$$

1.2.3 The Regulator's Trade-off

In the first stage, when the regulator chooses how to split the bargaining power, we have that $\overline{q}\left\{v\left[k\left(\alpha\right)\right],\alpha\right\}$. The regulator solves:

$$\underset{\alpha}{Max}\,\mathcal{W}=v\left[S\left(\underline{q}\right)-\underline{\theta}\underline{q}\right]+(1-v)\left[S\left(\overline{q}\right)-\overline{\theta}\overline{q}\right]-rk$$

subject to

$q\in argmax\,\mathcal{N}$ (1.1)

$k\in argmax\,E\left[\pi\right]$ (1.3)

An interior solution requires:

$$\mathcal{W}_\alpha=\frac{\partial E\left[U\left(k\right)\right]}{\partial k}\frac{\partial k}{\partial\alpha}+(1-v)\left[S'\left(\overline{q}\right)-\overline{\theta}\right]\frac{\partial\overline{q}}{\partial\alpha}=0 \quad (1.4)$$

Equation (1.4), as one of the possible ways of writing the regulator's condition for optimality, clearly underlines the different trade-offs: the relative impact that the capital has on the expected rent, the impact of an higher bargaining power on the investment in capital and the distortion form the first best.

The regulator in principle can, choosing α, induce a solution of first best in quantities. However, a higher power for the worker which keeps the quantities constant, implies a reduction of the investment in capital by the firm and undoubtedly a reduction of the total expected welfare. This rationale is synthesized in the following:

Proposition 2. *In case of hold-up, the choice of the regulator is never to induce quantities of first best.*

Proof. (by contradiction) Suppose the regulator induces (C1). Principal and agent share the total surplus according to their bargaining power: $E[\pi] = \alpha\mathbf{W}$, $E[U] = (1-\alpha)\mathbf{W}$. The principal's reaction function for candidate (C1) is the solution of her maximization problem: $k^*(\alpha) = \underset{k}{argmax}\ E[\pi] = \alpha\{v\underline{w}^* + (1-v)\overline{w}^*\} - rk$. It is defined implicitly by the necessary and sufficient condition:

$$\alpha v_k\{\underline{w}^* - \overline{w}^*\} - r = 0 \tag{1.5}$$

Moreover, $k^*(\alpha)$ is single value by strict concavity of $v(k)$. From implicit differentiation of (1.5): $\frac{\partial k}{\partial \alpha} = -\frac{v_k}{\alpha v_{kk}} > 0$.

While the regulator chooses $\alpha^* \in \underset{\alpha}{argmax}\ \mathcal{W} = \mathbf{W} - rk$ implicitly defined by:

$$\mathcal{W}_\alpha = v_k\{\underline{w}^* - \overline{w}^*\}\frac{\partial k}{\partial \alpha} - r\frac{\partial k}{\partial \alpha} \tag{1.6}$$

which using (1.5) implies: $\mathcal{W}_\alpha = r\left\{\frac{1}{\alpha} - 1\right\}\frac{\partial k}{\partial \alpha} > 0$. Therefore, the solution must be found when candidate (C2) is considered. For continuity of $\overline{q}(k)$ this appears clear for standard first order effect arguments. Continuity of the welfare w.r.t. $\overline{q}^B$ and the continuity of the value function are ensured by the uniqueness of the solution of the principal maximization problem over candidate (C2) and by Berge's maximum theorem. □

1.2.3.1 Remark

At this point one remark is needed. The analysis above assumes that the agent is protected by limited liability on the net rent and that this is satisfied in realization. A model that assumes a limited liability in expectation is also feasible and would describe a franchise contract. In this case, it is straightforward to show that the solution of the program (NP) is always on quantities of first best. Then, the investment in capital is always beneficial form a social point of view. Since different allocations of negotiation power simply translate in a transfer of surplus, the choice would be completely in favor of the principal and a screening model is the result. As a consequence, the agent is the residual claimant paying ex-ante all the expected rent. The principal's profit maximizing contract implements the first best and therefore no discontinuity arises for an $\alpha = 1$.

The result is different in the case I study, where the hold-up problem arises. The transfer of surplus between the parties is not innocuous; it leads to a decrease of the investment in capital and therefore of the possible surplus to be created.

Combining previous results:

Corollary 2. *The allocation of bargaining power is never completely in favor of one party. That is, the solution of the regulator problem is interior.*

Proof. This comes from simple inspection of (1.4). First, we have that for $\alpha = 1$: $\left.\frac{\partial \overline{q}}{\partial \alpha}\right|_{\alpha=1} = \frac{v}{1-v}\Delta\theta \frac{\mathcal{C}}{S''(\overline{q})}$, $\left.\frac{d\overline{q}}{dd}\right|_{\alpha=1} = \frac{v_k}{(1-v)^2}\frac{1}{S''(\overline{q})}$. The sign of $\frac{\partial k(\cdot)}{\partial \alpha}$ is found applying the implicit function theorem to equation (1.3) and given the strict concavity of the profit function, it is given only by the numerator:

$$\left\{-v_k\left[S^{'}(\overline{q}) - \overline{\theta}\right] + (1-v)\, S^{''}(\overline{q})\frac{d\overline{q}}{dk} - v_k\Delta\theta\right\}\frac{\partial \overline{q}}{\partial \alpha} + (1-v)\left[S^{'}(\overline{q}) - \overline{\theta} - \frac{v}{1-v}\Delta\theta\right]\frac{\partial \overline{q}}{\partial k \partial \alpha} \qquad (1.7)$$

Then, equation (1.7) becomes zero for $\alpha = 1$ where the principal maximizes for the high-cost type: $(1-v)\, S(\overline{q}) - v\Delta\theta\overline{q}$. Hence, for $\alpha = 1$, (1.4) is negative.

□

1.3 A Numerical Analysis

In this section, I consider a numerical example to derive the optimal allocation of bargaining power given the degree of heterogeneity[8] in the workforce and schooling. I assume a linear benefit function and a quadratic cost function:

$$S(q) = q$$

$$c(q;\theta) = \theta\frac{q^2}{2}$$

Moreover, the specific functional form of the probability:

[8] The term heterogeneity is meant as difference in efficiency and in particular it is captured in the magnitude of the parameter $\Delta\theta = \overline{\theta} - \underline{\theta}$.

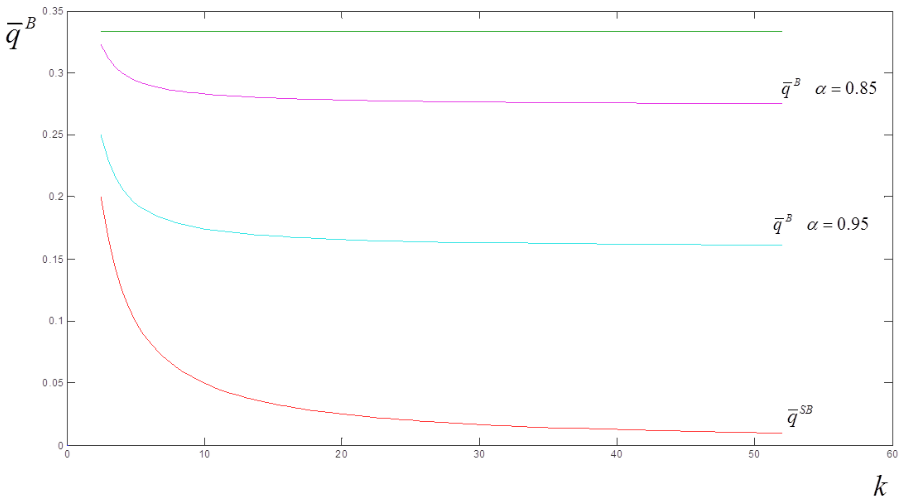


Figure 1.1: $\overline{q}^B(\cdot)$ as function of k for different α. As the bargaining power for the worker increases, for every investment in capital the quantity of the high-cost type converges to the first best.

$$v(k;\gamma) = 1 - e^{-\gamma k}$$

allows to interpret the parameter γ as *schooling*: the higher is its value the smaller is the investment in capital to induce the same probability distribution.

Figure 1.1 shows the quantity of the high-cost type as function of the investment in capital for different values of the worker's bargaining power α. The shape supports the conclusion of Lemma 1, and Assumption 1 about the convexity of $\overline{q}^B(\cdot)$ is satisfied, which implies that the optimal solution of the capital investment stage is single value.

The next set of simulations deals with the analysis of the welfare value function.

Figure 1.2 shows that an increase of the schooling parameter γ implies a higher social welfare and, at the same time, requires a lower bargaining power for the worker. The effect of more schooling should imply a reduction of the willingness to invest in capital by the principal. This in turn requires that the regulator gives a higher bargaining power to the firm to restablish the positive investment effect on the surplus.

Figure 1.3 defines the relationship between a decrease of the efficiency of the low-cost type and the bargaining power. While an increase of $\underline{\theta}$ is detrimental from a welfare point of view, the regulator should choose a higher bargaining power for the worker. This should be done because the trade off between investment in capital and distortion from the first

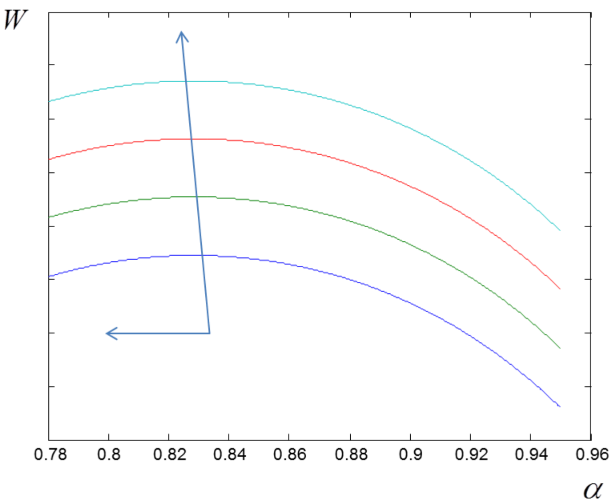


Figure 1.2: As γ increases, the welfare increases while α decreases.

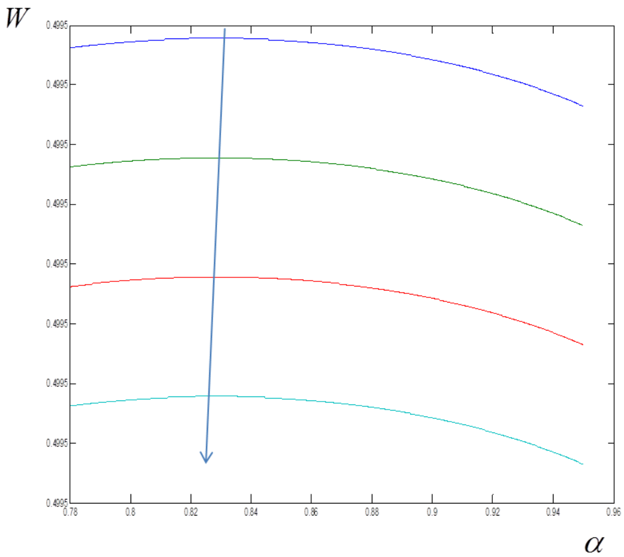


Figure 1.3: As the marginal cost of the low-cost type increases, the welfare decreases and α decreases.

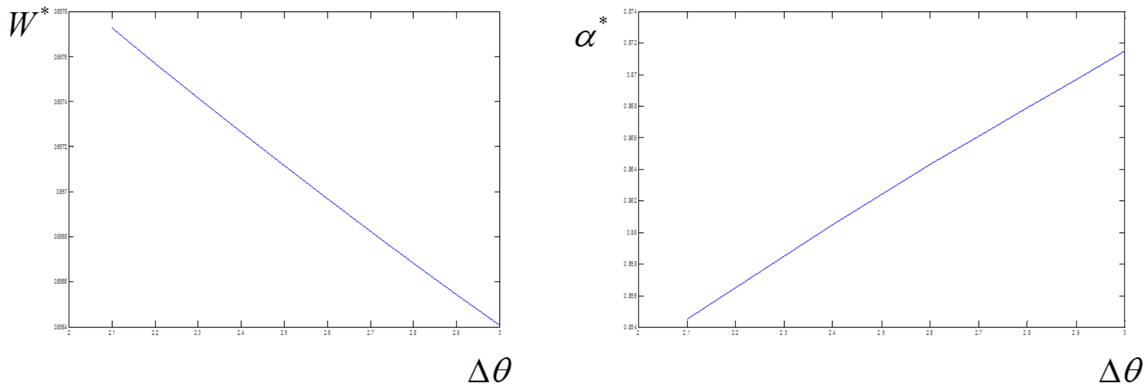


Figure 1.4: A higher efficiency for the high-cost type implies an increase of the welfare and a decrease of the bargaining power for the worker.

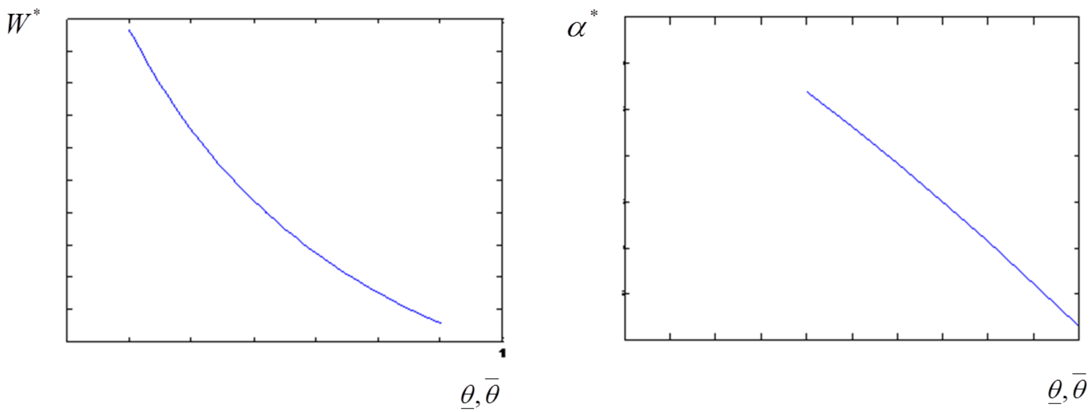


Figure 1.5: An increase in the efficiency of the workforce when the heterogeneity is kept constant. The welfare and the bargaining power for the firm increase.

best in quantity is in favor of the latter.

An opposite effect on the welfare is obtained as the high-cost type becomes more efficient (Figure 1.4). However, it appears that the bargaining power of the worker increases. The intuition should read as follows. A higher efficiency reduces the heterogeneity in the workforce, which implies a lower investment in capital. However, in this case the principal can benefit of a pool which is globally more productive. This requires a higher bargaining power for the worker.

Lastly, Figure 1.5 underlines the effect of an increase in the efficiency of the workforce (i.e., both $\overline{\theta}$ and $\underline{\theta}$ decrease) when the heterogeneity is kept constant. Here, the welfare is obviously increasing and the bargaining power for the firm is higher. The intuition is that the distortion on the quantity is less detrimental of a lower bargaining power for the worker (i.e., $\frac{\partial \overline{q}}{\partial \alpha}$ is less negative. See equation 1.16).

1.4 Conclusion

This paper deals with hold-up problems in vertical hierarchies with adverse selection. The main aim is to analyze how different economies should require different repartitions of the bargaining power between employer and employees. The point of departure is the observation that several economic environments base the hiring process on a negotiation between parties, whose outcome depends on the specific job conditions and on the allocation of the bargaining power.

The first result obtained is that a higher bargaining power for the agent reduces the distortion coming from the asymmetric information. A solution of first best in quantities is obtainable, but never optimal because it reduces the incentive of the private party to increase an investment in capital. The surplus that this investment creates outweighs the distortion on quantity. However, an optimal solution undermines the standard assumption that the principal holds all the bargaining power.

Moreover, assuming that the principal can alter the probability of finding a low-cost type, the investment in capital plays an important role in the negotiation and creates a hold-up problem. Such investment affects the firm's production function and implies different results on the worker's effort. Increasing the investment leads to a more advantageous distribution of types which in turns implies a decrease of the quantity of high-cost agent. The mere change in bargaining power depends in a complex way on the status quo of the economy and this paper shows how they depend on the schooling and on the degree of heterogeneity in the workforce.

1.5 Appendix

Proposition 1. Using standard change of variable techniques and eliminating $(PC(\underline{\theta}))$, the program (NP) is equivalent to:

$$\underset{\underline{q},\overline{q},\underline{U},\overline{U}}{Max}\ \mathcal{N}\Big|_{k=k^*,\alpha=\alpha^*} = \Bigg\{\underbrace{v\left[S\left(\underline{q}\right)-\underline{\theta}\underline{q}\right]+(1-v)\left[S\left(\overline{q}\right)-\overline{\theta}\overline{q}\right]-v\underline{U}-(1-v)\overline{U}}_{\equiv E[B]}\Bigg\}^{\alpha}\times \Bigg\{\underbrace{v\underline{U}+(1-v)\overline{U}}_{\equiv E[U]}\Bigg\}^{1-\alpha}$$

s.t.

$$\begin{aligned} \lambda_1: &\quad \underline{U}\geqslant \overline{U}+\Delta\theta\overline{q} \\ \lambda_2: &\quad \overline{U}\geqslant 0 \\ \lambda_3: &\quad \overline{U}\geqslant \underline{U}-\Delta\theta\underline{q} \end{aligned}$$

To simplify the notation, let $\mathcal{C}=\frac{E[B]}{E[U]}$ and λ's to be multipliers associated with the constraints. The Kuhn-Tucker conditions are necessary and sufficient. Variables denote the respected derivatives.

$$\overline{q}:\quad \alpha\mathcal{C}^{\alpha-1}(1-v)\left[S'\left(\overline{q}\right)-\overline{\theta}\right]-\lambda_1\Delta\theta=0 \tag{1.8}$$

$$\underline{U}:\quad -\alpha v\mathcal{C}^{\alpha-1}+(1-\alpha)\,v\mathcal{C}^{\alpha}+\lambda_1-\lambda_3=0 \tag{1.9}$$

$$\overline{U}:\quad -\alpha(1-v)\,\mathcal{C}^{\alpha-1}+(1-\alpha)(1-v)\,\mathcal{C}^{\alpha}-\lambda_1+\lambda_2+\lambda_3=0 \tag{1.10}$$

Corresponding slackness conditions (SCs)

Suppose $\lambda_1=0$. Then, from (1.8): $S'\left(\overline{q}\right)-\overline{\theta}=0$. While from (1.9):

$$\lambda_3=-\alpha v\mathcal{C}^{\alpha-1}+(1-\alpha)\,v\mathcal{C}^{\alpha} \tag{1.11}$$

With (1.11) in (1.10):

$$\frac{\lambda_2}{\alpha\mathcal{C}^{\alpha-1}} = 1 - \frac{1-\alpha}{\alpha}\mathcal{C} \tag{1.12}$$

and from this equation to have $\lambda_2 \geqslant 0$, we must have that $\mathcal{C} \leqslant \frac{\alpha}{1-\alpha}$.
Then, suppose $\lambda_2 = 0$ and therefore $C = \frac{\alpha}{1-\alpha}$. Then also $\lambda_3 = 0$.
Then, suppose $\lambda_2 > 0$. We have $\lambda_3 < 0$, which is absurd.

Candidate 1 (C1):

$$S^{'}(\overline{q}) = \overline{\theta} \tag{1.13}$$

with $\mathcal{C} = \frac{\alpha}{1-\alpha}$.

Then, suppose $\lambda_1 \neq 0$, $\lambda_2 \neq 0$, $\lambda_3 = 0$. We have:

Candidate 2 (C2):

$$S^{'}(\overline{q}) = \left[\overline{\theta} + \frac{v}{1-v}\Delta\theta\right] - \frac{1-\alpha}{\alpha}\frac{v}{1-v}\Delta\theta\mathcal{C} \tag{1.14}$$

with $\mathcal{C} < \frac{\alpha}{1-\alpha}$ and the quantity of bargaining $\overline{q}^B$ of the high cost implicitly defined.

□

Lemma 1. First, it is possible to show that the second order condition is always satisfied. Differentiating (1.14) w.r.t to $\overline{q}$, we have that the second derivative (SD) is always negative:

$$SD = S''(\overline{q}) + \frac{1-\alpha}{\alpha}\frac{v}{1-v}\triangle\theta\frac{\partial\mathcal{C}}{\partial\overline{q}} = S''(\overline{q}) - \frac{1-\alpha}{\alpha^2}\frac{v}{1-v}\triangle\theta\frac{\mathcal{C}}{\overline{q}} < 0 \tag{1.15}$$

Then, applying the implicit function theorem to equation (1.14):

$$\frac{\partial\overline{q}}{\partial\alpha} = -\frac{-\frac{1}{\alpha^2}\frac{v}{1-v}\triangle\theta\mathcal{C}}{SD} < 0 \tag{1.16}$$

While

$$\frac{d\overline{q}}{dk} = v_k\frac{\partial\overline{q}}{\partial v} = -v_k\frac{-\frac{\triangle\theta}{(1-v)^2}\left[1 - \frac{1-\alpha}{\alpha}\mathcal{C}\right] + \frac{1-\alpha}{\alpha}\frac{v}{1-v}\triangle\theta\frac{\partial\mathcal{C}}{\partial v}\Big|_{\underline{q}^*,\overline{q}^B}}{SD} \tag{1.17}$$

Then, to show that $\frac{d\overline{q}}{dk} < 0$, it is sufficient to show that $\left.\frac{\partial \mathcal{C}}{\partial v}\right|_{\underline{q}^*,\overline{q}^B}$ is negative:

$$\left.\frac{\partial \mathcal{C}}{\partial v}\right|_{\underline{q}^*,\overline{q}^B} = \frac{1}{E[U]}\left\{\left.\frac{\partial E[B]}{\partial v}\right|_{\underline{q}^*,\overline{q}^B} - \mathcal{C}\left.\frac{\partial E[U]}{\partial v}\right|_{\underline{q}^*,\overline{q}^B}\right\} =$$
$$\frac{1}{E[U]}\left\{\left[S\left(\underline{q}^*\right) - \underline{\theta}\underline{q}^*\right] - \left[S\left(\overline{q}^B\right) - \overline{\theta}\overline{q}^B\right] - \triangle\theta\overline{q}^B - C\triangle\theta\overline{q}^B\right\} =$$
$$\frac{1}{vE[U]}\left\{E[B] - \left[S\left(\overline{q}^B\right) - \overline{\theta}\overline{q}^B\right] - \mathcal{C}E[U]\right\} = -\frac{\left[S\left(\overline{q}^B\right) - \overline{\theta}\overline{q}^B\right]}{vE[U]} \quad (1.18)$$

□

Lemma 2. First, consider the expected payoff as function of two variables k and $\overline{q}^B$: $E[\pi] = \Pi\left(k, \overline{q}^B\right)$. Then, simple differentiations show:

1. $\frac{\partial^2 \Pi}{\partial k^2} = v_{kk}\int_{\overline{q}^B}^{\underline{q}^*}\left[S'(q) - \underline{\theta}\right]dq < 0$

2. $\frac{\partial^2 \Pi}{\partial \left(\overline{q}^B\right)^2} = (1 - v)\, S''\left(\overline{q}^B\right) < 0$

3. $\frac{\partial^2 \Pi}{\partial k \partial \overline{q}} = -v_k\left[S'\left(\overline{q}^B\right) - \underline{\theta}\right] < 0$

Then, $\Pi\left(k, \overline{q}^B\right)$ is strictly concave in k, strictly concave in $\overline{q}^B$ and strictly submodular, where submodularity for continuous function is equivalent to decreasing differences. That is, $\forall\ k_2 > k_1,\ q_2 > q_1$:

$$\Pi[k_2, q_2] - \Pi[k_2, q_1] < \Pi[k_1, q_2] - \Pi[k_1, q_1] \quad (1.19)$$

To show the strict concavity of the payoff, then by definition we must have $\forall k_1, k_2$ and $\lambda \in (0, 1)$:

$$\Pi\left[\lambda k_1 + (1-\lambda)\,k_2, \overline{q}^B\left(\lambda k_1 + (1-\lambda)\,k_2\right)\right] >$$
$$\lambda\Pi\left[k_1, \overline{q}^B(k_1)\right] + (1-\lambda)\,\Pi\left[k_{2,}\overline{q}^B(k_2)\right] \quad (1.20)$$

To simplify the notation, let $\tilde{k} = \lambda k_1 + (1-\lambda)\,k_2$ and since $\overline{q}^B(k)$ is single value $q_i = \overline{q}^B(k_i)$, $i = \{1, 2\}$.

Given that $\Pi\left(k,\overline{q}^B\right)$ is strictly decreasing in $\overline{q}^B$ and $\overline{q}^B(k)$ is strictly convex in k, we have:

$$\Pi\left[\tilde{k},\overline{q}^B\left(\tilde{k}\right)\right] > \lambda\Pi\left[\tilde{k},q_1\right] + (1-\lambda)\,\Pi\left[\tilde{k},q_2\right] \tag{1.21}$$

Using strict concavity of $\Pi\left(k,\overline{q}^B\right)$ w.r.t. k:

$$\begin{aligned}&\lambda\Pi\left[\tilde{k},q_1\right] + (1-\lambda)\,\Pi\left[\tilde{k},q_2\right] > \\ &\lambda^2\Pi\left[k_1,q_1\right] + \lambda\,(1-\lambda)\,\Pi\left[k_2,q_1\right] + \lambda\,(1-\lambda)\,\Pi\left[k_1,q_2\right] + (1-\lambda)^2\,\Pi\left[k_2,q_2\right]\end{aligned} \tag{1.22}$$

To conclude, we must have:

$$\begin{aligned}&\lambda^2\Pi\left[k_1,q_1\right] + \lambda\,(1-\lambda)\,\Pi\left[k_2,q_1\right] + \lambda\,(1-\lambda)\,\Pi\left[k_1,q_2\right] + (1-\lambda)^2\,\Pi\left[k_2,q_2\right] > \\ &\lambda\Pi\left[k_1,q_1\right] + (1-\lambda)\,\Pi\left[k_2,q_2\right]\end{aligned} \tag{1.23}$$

which is true given the strict submodularity of $\Pi\left(k,\overline{q}^B\right)$. □

2 Adverse Selection, Heterogeneous Beliefs, and Evolutionary Learning

This paper has been co-written with Clemens Buchen.

Abstract

We relax the common assumption of homogeneous beliefs in principal-agent relationships with adverse selection. In an evolutionary learning set-up, which is imitative, principals can have different beliefs about the distribution of agents' types in the population. The resulting nonlinear dynamic system is studied. Convergence to a uniform belief depends on the relative size of the bias in beliefs. In addition, the set-up is a version of a stable cobweb model. Our approach offers explanations for alternating periods of oscillating and relatively steady quantity.

JEL Classification: C73, D82, D83, E32
Keywords: Evolutionary Game Theory, Heterogeneous Beliefs, Adverse Selection, Bifurcation Theory, Cobweb Model

2.1 Introduction

Usually in mechanism-design models players have a subjective probability distribution over a set of possible elements or outcomes, which represents information privately known to other players. More specifically, in a principal-agent relationship the principal does not know the type of agent that she is matched with, but the distribution of types is common knowledge. Given a belief about this distribution, principals write court-enforceable contracts and agents self-select. Against this backdrop of the standard model, we introduce a limitation on the part of the principals concerning their beliefs. On this basis we then study the role of evolutionary learning through imitation in a market in which production is the result of a principal-agent relationship with adverse selection and some principals' beliefs about the distribution of agent types are biased.

To fix ideas, we assume that some of the principals are optimistic about the distribution.[1] This means that they believe that the proportion of low-cost types is larger than it actually is.[2] Each principal offers a menu of contracts based on her beliefs about the agents' ability types. As a result, the profits are different depending on the belief a principal holds. Hence, we study a polymorphic population characterized by unbiased and optimistic principals. To the best of our knowledge, our paper is the first to introduce a bias for the uninformed market side in an evolutionary set-up. There is a related literature on biases of agents, for example with respect to the perception of their own ability (Gervais and Goldstein 2007), their own and others' ability (Santos-Pinto 2008) or the success probability of a project and the agent's contribution to the success (de la Rosa 2011; Wang, Zhuang, Yang, and Sheng 2014).

Aside from a belief about the distribution of types, each principal also forms an expectation about the quantity produced in the market. We use a simple naive expectation in that when writing contracts principals expect the total quantity to be the same as in the previous period. This implies that there are two interrelated variables that change over time: the distribution of beliefs and the quantity in the market.

Drawing an analogy to the standard game-theoretic terminology, the different beliefs that the principals hold about the distribution of types can be interpreted as the *strategies*, while the *payoffs* are simply the monetary gains from the principal-agent relationship. In general, one would expect that over time, in a repeated interaction, principals can learn from the strategies played by other principals. In our model, learning takes place by imitation of other principals' beliefs. This assumption is based on the following considerations. Information about the beliefs is shared by word-of-mouth communication as in Banerjee and Fudenberg (2004). Alternatively, beliefs can be inferred if the menus of contracts are observable as in Ania, Tröger, and Wambach (2002). In both cases it is assumed that the

[1]The discussion is carried out with the assumption of an optimistic bias. However, the study in this paper is not restricted to this assumption and a pessimistic bias would lead to a specular model with specular results.

[2]This is different from Arifovic and Karaivanov (2010), who start from an adverse selection model evolving over time assuming that principals are unable to solve the correct maximization problem.

information is shared truthfully since there is no strategic advantage from not revealing it.

Imitation in a game-theoretic setting is developed by Björnerstedt and Weibull (1996), Vega-Redondo (1997) and Schlag (1998), where individuals imitate those strategies that offer higher profits. Apesteguia, Huck, and Oechssler (2007) synthesize these approaches and test the theory with an experiment. Selten and Ostmann (2001) study an imitation equilibrium in which higher profits also determine who will be imitated. In addition, they introduce the notion of the reference group, which comprises all other players any individual would at all consider imitating. The precise definition of reference group is made in each case on the basis of the problem at hand. For example in a spatial sense as in Selten and Apesteguia (2005), where firms imitate only neighboring firms. Or, as in Rothschild and Stiglitz (1976) and Ania, Tröger, and Wambach (2002), the reference group for principals — while not so named — includes contracts that are similar enough to one's own contract. We contribute to this literature.

The probability to change beliefs depends on the matching, the propensity to switch, and the payoff difference between principals. We partially follow Selten and Ostmann's (2001) notion of reference groups. There, it is stated that individuals tend to compare with similar others (i.e., membership of the same reference group). However, we recognize that to imitate only individuals of a given group can be a too restrictive assumption. Therefore, we rather assume a mechanism that describes the willingness of individuals to compare themselves with others. To be concrete, for simplicity, consider a model with two types of agents. There is one group including the principals matched with a high-cost agent and the second with those matched with a low-cost agent. This lets us define a *propensity to compare* for each principal, which expresses the willingness to compare with a randomly chosen different principal. Hence, we do not restrict the comparison to a given member of a reference group, but rather we conceive of a probability distribution over the possible subsets of the population. Each element of the distribution represents the willingness of a given principal to compare herself with others. Whereas this assumption represents an extension of the notion of reference groups in economics, it is a common view in the *social comparison theory*, which is commonplace in other disciplines. Starting with Festinger (1954), psychologists point out that individuals tend to carry out "social comparisons" preferably (but not exclusively) with similar others. The latter point suggests that our principals treat information gained from different reference groups differently. A precursor to our approach in experimental economics is the work by Todt (1972). The subjects in these early experiments tended to be more open to imitation if the situation of the other party was perceived to be more similar to their own.

The focus on just two possible beliefs comes from the following consideration. One could imagine a population in which each principal holds her own prior belief about the distribution. Then, the switching process described above should sooner or later lead to a situation in which the polymorphism of the population consists of either two remaining strategies or a stable configuration with more than two beliefs present. While the latter case would require an analysis of the conditions under which a configuration of multiple beliefs can coexist, the former is a study of convergence towards a unique belief. We focus on this case keeping in mind that this is a "reduced" problem since we start the analysis at a moment in time in which a potentially large number of beliefs has already been eliminated from the population and where the only polymorphism consists of two beliefs.[3]

The natural question in our evolutionary set-up is: where does the economy converge in terms of different beliefs? If we assumed rational players able to revise beliefs as Bayesian updaters, then with an appeal to the Law of Large Numbers the answer would be straightforward. As more information accumulates over time, with perfect memory Bayesian updating would ultimately lead to all principals playing the same, unbiased strategy. However, the introduction of imitation makes the convergence less straightforward.

We analyze learning by imitation using a deterministic dynamic model. This lets us draw direct comparisons to papers that see a market as a cobweb model. In contrast to that literature, in our specification the source of the heterogeneity of firms is different from what is usually assumed. The seminal paper on this is Brock and Hommes (1997). There, the heterogeneity comes from the fact that some firms invest more than others to better predict expected quantity. Since the incentive to invest in prediction changes as the fluctuations of the price change, chaotic and unpredictable behavior of time series and bifurcations of variables can be analyzed. Our model introduces heterogeneity differently in that it comes from different beliefs about the ability level in the population of agents, holding the prediction ability of firms equal for all.

To sum up, the contributions of the paper are twofold. On the one hand, we justify

[3]Including the belief which turns out to be the true one (and not assuming a situation characterized by two biases) is less restrictive and comes from the aim of showing a possible coexistence of beliefs or a convergence towards a biased belief. A situation with two biases would mean, therefore, assuming that such convergence has already happened. However, a model with only biased beliefs would not substantially change the dynamic.

under which conditions the assumption of common belief in the mechanism-design literature can be supported under a behavioral learning model without loss of generality. We show that the convergence to a common belief depends on the relative degree of optimism of the biased principals. On the other hand, we show how a market with adverse selection and evolutionary learning can easily generate fluctuations and cycles of the quantity, adding new insights to the cobweb model. In particular, in contrast to the standard cobweb model, our model generates periods of relative steady quantity, which are punctuated by large oscillations.

Since the pioneering work by Alchian (1950), several important theoretical contributions to the role of evolutionary mechanisms have been developed. Models in this tradition can be roughly grouped along two lines. On the one hand, some of them come directly from evolutionary game theory and its attempt to study social interactions when the common assumption of rationality is relaxed.[4] On the other hand, a large class of learning models have been developed with the aim of understanding what drives economic decisions depending on different degrees of sophistication of players (Fudenberg and Levine 1998; Young 2004). These strands are interrelated in numerous ways, as evolutionary models are used to describe learning processes. Our paper follows the latter tradition.

Our model is also in the tradition of a literature on imitation in different market settings. For example, Vega-Redondo (1997) studies equilibria in a Cournot game, where players can imitate each other. The model is extended and applied to other market types in a number of other papers (see citations in Ania, Tröger, and Wambach 2002 and Alós-Ferrer 2004). Moreover, our approach is similar in spirit to the information-sharing literature (Vives 2001). There, principals can play a strategy to disclose information learned about agent's cost functions, because they were matched in an employment relationship. Of course, the difference in our model is that any information sharing occurs unwittingly and not as a strategic play.

The paper proceeds as follows: the next section introduces the interaction of the different groups in the model. First there is interaction between principals and agents in the stage game of the model. Then, we set up and describe the interaction among principals with different beliefs. This entails defining a mechanism that allows principals to modify their beliefs and therefore change their contract offers in the stage game. The resulting dynamic system is extensively studied in Section 3. Finally we offer some concluding remarks

[4] An introduction and overview can be found in Sandholm (2011), Weibull (1995), or Gintis (2009).

in Section 4.

2.2 Population Interactions

The first step is to set up a framework that is general enough for our aims. We will discuss its robustness in the concluding remarks. We start by defining a standard principal-agent game. There are two large populations of principals and agents with an equal size. Each principal wants to delegate a task to an agent in order to produce a quantity q. Agents are heterogeneous with regard to their ability to produce the quantity. They have a linear cost function defined as $C(q,\theta) = \theta q$. As is standard, we assume that $\theta \in \left\{\underline{\theta}, \overline{\theta}\right\}$, where $\overline{\theta} > \underline{\theta}$. The proportion of agents with marginal cost $\underline{\theta}$ is $v \in (0,1)$, which implies that the proportion of agents with marginal cost $\overline{\theta}$ is $1 - v$. In the next step the stage game will be defined.

2.2.1 Stage Game

Principals are heterogeneous in that they hold different beliefs about the distribution of agents' abilities. We assume that each principal has a belief $\phi \in \{\rho, v\}$ with $\rho > v$. In other words, some principals believe that the proportion of efficient agents in the population is larger than it really is. We will sometimes refer to those biased principals as *optimistic*.

The agent's production provides a benefit to a principal i, which is measured by a function $S(q_t^i, \tilde{q}_t)$, where q_t^i is the quantity produced by the agent working for principal i in period t and $\tilde{q}_t$ is a sufficient statistic of the aggregate quantity in the market. The precise definition of $\tilde{q}_t$ will be given below.

Timing

Time is discrete. At the beginning of a generic period t, the fraction of principals who write contracts on the basis of belief v is denoted by α_t and then the fraction of principals using ρ is given by $1 - \alpha_t$. Principals write contracts according to their beliefs $\{v, \rho\}$ and on the basis of an expected benefit they will obtain at the end of the period. In what follows, we indicate realized variables at the end of a generic period with subscript $t+1$. Next we give a functional form to the benefit that the principal expects to gain at the end of the period (Vives 2001):

$$S\left[q_{t+1}, \mathbb{E}_t\left(\tilde{q}_{t+1}\right)\right] = \beta q_{t+1} - \frac{\left(q_{t+1}\right)^2}{2} + \delta q_{t+1} \mathbb{E}_t\left(\tilde{q}_{t+1}\right)$$

We assume β to be a positive constant and $\delta \in (-1, 0)$ which is a measure of the degree of substitutability between principals' outputs. The variable $\mathbb{E}_t\left(\tilde{q}_{t+1}\right)$ denotes the expectation a principal forms at the beginning of a period about the value of $\tilde{q}_{t+1}$ at the end of the period, when all production is carried out. We make the following assumption about this expectation.

Assumption 2. *In each period t, each principal has a naive expectation about the sufficient statistic of the aggregate quantity in the market: $\mathbb{E}_t\left(\tilde{q}_{t+1}\right) = \tilde{q}_t$.*

The rationale for this assumption is the following. Principals in our model do not know the salient characteristics of the market, simply because they are not aware that there are different beliefs, which have an impact on the quantity the principals produce. Rational expectations about the quantity would run contrary to this view of the role of principals and therefore are not useful in this respect. The simplest version of adaptive expectations are naive expectations as in our assumption, which take only one preceding period into account.[5] The timing for each period can be summarized as follows:

1. Each agent realizes his type.
2. Principals write contracts according to their beliefs about the distribution of types and according to naive expectations about the aggregate quantity $\tilde{q}_{t+1}$.
3. Each agent is matched with a principal and the agent decides whether to accept the contract or not.
4. Contracts are executed: quantities are produced, profits and payments to agents are realized.

Contracts

At the beginning of each period, principals write contracts which entail a rent for each quantity observed at the end of the period. Given the possibly different beliefs, the following notation will be used. The quantities produced in a period are indicated by $\underline{q}_t^{\phi}$ for the

[5] For an overview of the role of expectations see Evans and Honkapohja (2001).

low-cost type and $\overline{q}_t^{\phi}$ for the high-cost type. When the contracts are executed, the realized quantity implies a profit for each principal, which then depends only on her quantity and the aggregate $\tilde{q}_t$.

We restrict our analysis to direct revelation mechanisms that are truthful. This can be done since the agent's rent is only a function of his principal's contract and of the aggregate quantity in the market in the previous period. In this case it suffices to define the rent simply as the difference between the wage and the cost of production for the agent. Moreover, we assume that matching is type-independent.[6]

Summarizing in a more formal way, in a generic time t, each principal writes contracts according to $\{v, \rho\}$ and the expectation of $\tilde{q}_{t+1}$. While the reference period is t, we specify the realized payoffs and the realized quantity with an index $t+1$. The reason for this comes directly from our assumption about the timing. While the contracts are stipulated in t, only when the principal has observed the realized quantity the contract is honored. Hence, in t each principal defines a mechanism $\langle q_{t+1}(\theta), w_{t+1}(\theta)\rangle$ which entails a transfer w_{t+1} for each observed quantity in $t+1$. Therefore, the rent is $U(q_{t+1}(\theta), w_{t+1}(\theta), \theta) = w_{t+1}(\theta) - \theta q_{t+1}(\theta)$. Moreover, we assume that agents are protected in every state of the world by limited liability on the rent. Formally, each principal maximizes expected profits given the usual incentive (IC) and participation constraints (PC):

$$\underset{q_{t+1}, w_{t+1}}{\text{Max}} \phi \left\{ S\left[\underline{q}_{t+1}, \mathbb{E}_t(\tilde{q}_{t+1})\right] - \underline{w}_{t+1} \right\} + (1-\phi)\left\{ S\left[\overline{q}_{t+1}, \mathbb{E}_t(\tilde{q}_{t+1})\right] - \overline{w}_{t+1} \right\}$$

s.t

$$U(q_{t+1}(\theta), w_{t+1}(\theta), \theta) = w_{t+1}(\theta) - \theta q_{t+1}(\theta) \geqslant 0 \qquad \forall\, \theta \in \left\{\underline{\theta}, \overline{\theta}\right\} \qquad (PCs)$$

$$U(q_{t+1}(\underline{\theta}), w_{t+1}(\underline{\theta}), \underline{\theta}) \geqslant U\left(q_{t+1}\left(\overline{\theta}\right), w_{t+1}\left(\overline{\theta}\right), \underline{\theta}\right) \qquad (IC(\underline{\theta}))$$

$$U\left(q_{t+1}\left(\overline{\theta}\right), w_{t+1}\left(\overline{\theta}\right), \overline{\theta}\right) \geqslant U\left(q_{t+1}(\underline{\theta}), w_{t+1}(\underline{\theta}), \overline{\theta}\right) \qquad \left(IC\left(\overline{\theta}\right)\right)$$

Given the standard nature of the maximization problem the following Proposition is

[6] In absence of this assumption, the revelation principle might be invalid, see e.g. Pavan and Calzolari (2010). It might be argued that this makes the agents' role somewhat overly passive, because in our model agents are not able to realize that there are different rents to be earned dependent on the principal. Otherwise agents would have a clear preference for a type of principal, which would make the matching type-dependent. One could introduce congestion effects of matching to ensure that all types of principals still receive matches as in Guerrieri, Shimer, and Wright (2010). Since we focus entirely on the dynamic of the belief of agents and the quantities, we refrain from this in order to keep the model as simple as possible.

straightforward.

Proposition 3. *Given different beliefs and the same naive expectations about $\tilde{q}_{t+1}$, the quantities for the low-cost types are equal, or $\underline{q}_t^v = \underline{q}_t^\rho$, while for the high-cost type we have $\overline{q}_t^v > \overline{q}_t^\rho$. The rent $U(\cdot, \overline{\theta})$ for the high-cost type is equal to zero for both types of principals, while for the low-cost type the rent $U(\cdot, \underline{\theta})$ is higher with a v-principal than a ρ-principal.*

A formal derivation of the values of the variables and a proof can be found in the Appendix. The intuition of Proposition 3 should be understood in the following way. For the low-cost agent both types of principals stipulate the same, first best quantity. However, the ρ-principal offers a smaller rent, because she mistakenly believes that there are more low-cost agents than there really are. For the high-cost type both contracts offer the same rent, but the v-principal stipulates a bigger quantity. This is so because the odds of being matched with a low-cost agent appear too large for the ρ-principal. Since the quantity for the high-cost type is decreasing in the odds of being matched with one, the quantity of the optimistic principal is set too low.

Quantities

At the end of each period contracts are executed and the total quantity is produced in the market. Profits of principals are realized on the basis of the type of agent and the aggregate quantity. We denote the expected quantity over the different types at the end of a period for a principal with belief ϕ by $\mathbb{E}_\theta\left[q_{t+1}^\phi(\theta)\right] = v\underline{q}_{t+1}^\phi + (1-v)\overline{q}_{t+1}^\phi$ and with $\tilde{q}_t = \int_i q_{t,i}\, di$ the aggregate quantity in the market, where i is an indicator of the principals in the population. Given the different proportions of principals with different beliefs, an informal appeal to the Law of Large Numbers allows us to write the aggregate quantity at the end of a period as:

$$\tilde{q}_{t+1} = \int_i q_{t+1,i}\, di = \alpha_t \mathbb{E}_\theta\left[q_{t+1}^v(\theta)\right] + (1-\alpha_t)\,\mathbb{E}_\theta\left[q_{t+1}^\rho(\theta)\right] \tag{2.1}$$

Profits of principals

For contracts stipulated in a period t, the realized profits for each θ and for a given belief are functions $\underline{\pi}_{t+1}(\tilde{q}_{t+1}, \tilde{q}_t, \phi, \underline{\theta})$ and $\overline{\pi}_{t+1}(\tilde{q}_{t+1}, \tilde{q}_t, \phi, \overline{\theta})$, while the expected profits are $\mathbb{E}_\theta[\pi_{t+1}(\tilde{q}_{t+1}, \tilde{q}_t, \phi, v)]$. In the last term, the presence of $\tilde{q}_t$ comes from the fact that each quantity $q_{t+1}(\theta)$ is defined as a function of $\tilde{q}_t$ (Assumption 1). The following Proposition concerns the differential profits for each type of principal given the type of agent.

Proposition 4. *Given different beliefs and the same naive expectations about the total quantity, for any realization* $\theta \in \left\{\underline{\theta}, \overline{\theta}\right\}$*, the realized profits* $\pi^{\phi}_{t+1}(\cdot, \theta)$ *are such that:*

$\underline{\pi}^{\rho}_{t+1} > \underline{\pi}^{v}_{t+1}$ *with*

$$\underline{\pi}^{\rho}_{t+1} - \underline{\pi}^{v}_{t+1} = (\Delta\theta)^2 \frac{\rho - v}{(1-\rho)(1-v)} \tag{2.2}$$

$\overline{\pi}^{v}_{t+1} \lesseqgtr \overline{\pi}^{\rho}_{t+1}$ *with*

$$\overline{\pi}^{v}_{t+1} - \overline{\pi}^{\rho}_{t+1} = \Delta\theta \frac{\rho - v}{(1-\rho)(1-v)} \left[\delta\left(\tilde{q}_{t+1} - \tilde{q}_t\right) + \frac{1}{2}\Delta\theta\left(\frac{v}{1-v} + \frac{\rho}{1-\rho}\right)\right] \tag{2.3}$$

Again, the derivations of functions can be found in the Appendix. Parts of the results in Proposition 4 are a direct result from Proposition 3. Since the unbiased v-principal increases the rent for the low-cost agent, but produces the same quantity as the biased ρ-principal, profits must be smaller. This can be seen from equation (2.2). On the other hand, as can be seen in equation (2.3) the difference in profits for the high-cost agent depends on the change of the quantity $\tilde{q}$ from one period to the next. The v-principal makes a larger profit than the ρ-principal if the quantity decreases or is constant from one period to the next. The reverse is true if the change is positive and large enough. The latter result is connected to the production quantities that the contracts stipulate. In general, optimistic principals decrease the quantity for both types of agents and, as a result, low-cost agents matched with them earn a smaller rent. If, however, the match is with a high-cost agent (higher marginal costs) the marginal benefit of a smaller rent is outweighed by the marginal benefit of a higher quantity, and then unbiased principals earn a higher profit with the high-cost agent.

Given our timing and the specification of our benefit function, we remark that our model is mathematically equivalent to a model where principals form expectations about the price instead of the quantity, where the relationship is given by a linear demand function.[7] This simple observation will be useful to make a comparison to those models that introduce heterogeneity into cobweb models (Brock and Hommes 1997; Branch and McGough 2008; Hommes 2013; Schmitt and Westerhoff 2015). These approaches model heterogeneous

[7]This equivalent model can be summarized as follows:

expectations about the price in an unstable cobweb model. Hence, it is worth pointing out that our modeling of the quantity is equivalent to modeling price dynamics with a linear demand in a stable cobweb model.

To summarize, the basic stage game defines an aggregative game in which the profit of principals in a particular period depends on the belief about the distribution of types, the specific match and the behavior of all other principals, which affects the aggregate quantity in the market.

2.2.2 Evolutionary Learning by Imitation

Our evolutionary learning model is related to the deterministic evolutionary models discussed in Fudenberg and Levine (1998). We take the basic idea of the social learning model and combine this with the imitation within reference groups by Selten and Ostmann (2001).

Recall that we interpret the belief held by a principal as a sort of pure strategy in the game. Each principal "plays" the pure strategy, which can be either υ or ρ and earns a profit at the end of a period. The next step is to define the conditional switch rate, which is the probability γ that at the end of a period a principal changes beliefs, either from υ to ρ, or the other way around. To do that, we periodically allow some principals at the end of a period to observe the profit of a second principal. For each principal two scenarios are possible. Either she meets a principal from the same reference group, who got matched with the same type of agent, or from a different reference group, i.e., a principal who got matched with a different type of agent. In our model, we find three mechanisms to justify why principals infer whether or not they come from the same reference group. Either because of a mechanism based on word-of-mouth communication as in Banerjee and

1. Each principal maximizes:

$$\underset{q_{t+1},t_{t+1}}{\text{Max}}\ \phi\left\{\mathbb{E}_t\left[P_{t+1}\right]\underline{q}_{t+1}-\frac{\underline{q}_{t+1}^2}{2}-\underline{w}_{t+1}\right\}+(1-\phi)\left\{\mathbb{E}_t\left[P_{t+1}\right]\overline{q}_{t+1}-\frac{\overline{q}_{t+1}^2}{2}-\overline{w}_{t+1}\right\}$$

under (ICs) and (PCs), and therefore a linear supply function is obtained.

2. Principals have naive expectations about the price: $\mathbb{E}_t\left[P_{t+1}\right]=P_t$.
3. The demand is linear: $Q_{t+1}=A-BP_{t+1}$.
4. Market clears: the prices are computed on the demand function.

The connection to our model is established for $\beta=\frac{A}{B}$ and $\delta=-\frac{1}{B}$. Our choice of the interval for $\delta\in(-1,0)$ defines a standard stable cobweb model (in the absence of any kind of heterogeneity of expectations about any variable).

Fudenberg (2004), or because the contracts and profits are observed, or simply because the quantities are observed, since principals with low-cost agents obtain equal quantities.[8] What is important is that we condition the probability of switching on whether or not a principal comes from the reference group. As mentioned above, this is inspired by social comparison theories in psychology (Festinger 1954). There, it is stated that individuals are more likely to compare themselves with somebody else, the more similar the situation of the other appears. In our model this means that the propensity to compare with another principal depends on the reference group. The notion of reference groups — while not so named — is already present in Rothschild and Stiglitz (1976) and their formalization in Ania, Tröger, and Wambach (2002). Principals are able to copy contracts that are similar to their own, because principals observe all menus of contracts present in the population.

Learning takes place by imitation of other principals' beliefs. This assumption is based on the following considerations. Information about the beliefs is shared by word-of-mouth communication (see above). Alternatively, beliefs can be inferred if the menus of contracts are observable. In both cases it is assumed that the information is shared truthfully since there is no strategic advantage from not revealing information.

In what follows we assume that the comparison will be only between principals who come from the same reference group. Translated to our model this means that the probability that a principal compares her result with a principal who got a different match is set equal to zero. This immensely simplifies the following exposition and analysis and the intuitions are not hidden behind the algebra. Our results still hold when this assumption is relaxed (see section 2.3.4 below).

In addition, we condition the probability to switch beliefs on the absolute difference in profits, where a larger profit differential increases the probability. We assume that principals are memoryless about past plays or past switches.

Hence, in what follows we will define a *proportional imitation rule* (see Schlag 1998 and references therein for a discussion on different imitation rules) as the rule for principals to switch within reference groups. Given the proportion of low-cost types v and the proportion α_t of principals using v, we need to define a conditional switch rate from one belief to the other. We have the following probabilities: $P(\phi \rightsquigarrow \neg\phi) = \alpha_t\,(1-\alpha_t)$ is the probability that a principal with a belief ϕ meets a principal with the different belief. Since we assume that matching between principals and different types of agents is type-independent, the

[8] We thank an anonymous referee for drawing attention to the last point.

probability that two principals were matched with a low-cost agent is simply $(v)^2$ and the probability that both were matched with a high-cost agent is given by $(1-v)^2$. Hence, we have the probabilities that two principals with different beliefs and in the same reference group meet:

$$\gamma_t^{v\rho} = P(v \rightsquigarrow \rho)\, v^2 = \alpha_t (1-\alpha_t)\, v^2$$

$$\gamma_t^{\rho v} = P(\rho \rightsquigarrow v)\,(1-v)^2 = \alpha_t (1-\alpha_t)(1-v)^2$$

In words, $\gamma_t^{v\rho}$ is the probability that a v-principal would consider switching to belief ρ, with a similar interpretation of $\gamma_t^{\rho v}$. Next, we need the probability of switching to the other strategy. The simplest way to capture the idea that the higher the profit differential the more likely a principal switches to the other belief is to make the switching probability linearly dependent on the payoff difference. Formally, the switching probability can then be expressed as the product $\Omega \cdot \left[\pi_{t+1}^{\phi} - \pi_{t+1}^{\neg\phi}\right]$, where Ω is chosen to scale the payoff difference in such a way that it can be used as a probability. The economic interpretation is straightforward. Given a difference in payoffs, the higher Ω the higher the *propensity to switch*. It will be specified in more detail below.

Putting the pieces together, the dynamic over time is described by the following equation:

$$\alpha_{t+1} = \alpha_t + \gamma_t^{\rho v}\left\{\Omega\left[\overline{\pi}_{t+1}^{v} - \overline{\pi}_{t+1}^{\rho}\right]\right\} - \gamma_t^{v\rho}\left\{\Omega\left[\underline{\pi}_{t+1}^{\rho} - \underline{\pi}_{t+1}^{v}\right]\right\}$$

The equation should be read as follows. The fraction of v-principals in the next period is equal to the fraction in the previous period plus all ρ-principals who switch to v minus all v-principals who switch to ρ. From Proposition 4 we know that the term $\overline{\pi}_{t+1}^{v} - \overline{\pi}_{t+1}^{\rho}$ can be positive or negative depending on the magnitude and direction of fluctuations of the quantity in the market. If the term is negative the direction of proportional imitation is reversed, which means that the v-principal switches to ρ with the given probability. The resulting equation is equivalent.[9] Substituting the specific switch rates defined above we arrive at the discrete change of α from one period to the next:

$$\alpha_{t+1} = \alpha_t + \alpha_t(1-\alpha_t)\,\Omega\left\{(1-v)^2\left[\overline{\pi}_{t+1}^{v} - \overline{\pi}_{t+1}^{\rho}\right] - v^2\left[\underline{\pi}_{t+1}^{\rho} - \underline{\pi}_{t+1}^{v}\right]\right\} \tag{2.4}$$

[9]To see this, write the dynamic for $\overline{\pi}_{t+1}^{v} < \overline{\pi}_{t+1}^{\rho}$ as $\alpha_{t+1} = \alpha_t - \gamma_t^{\rho v}\left\{\Omega\left[\overline{\pi}_{t+1}^{\rho} - \overline{\pi}_{t+1}^{v}\right]\right\} - \gamma_t^{v\rho}\left\{\Omega\left[\underline{\pi}_{t+1}^{\rho} - \underline{\pi}_{t+1}^{v}\right]\right\}$, which is equivalent.

2.3 Equilibria, Stability and Dynamics

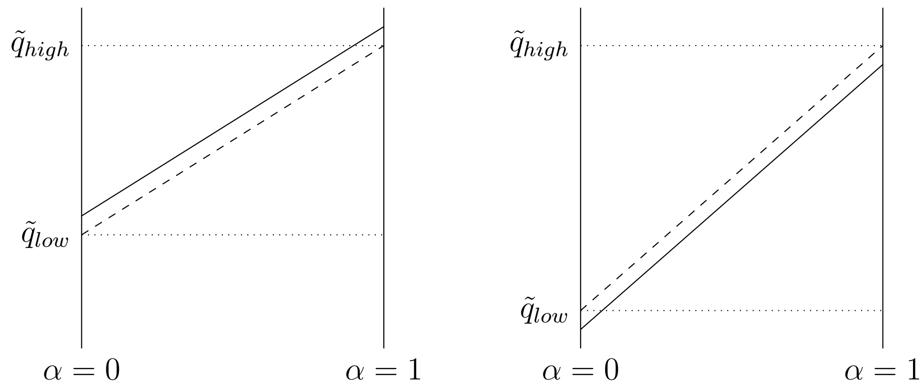
The economy in our model is governed by equations (2.1) and (2.4). Having set up the basic model describing our economy, the next step is to analyze its evolution. It is worth pointing out that we are not interested in explaining why a population starts with a specific initial value of the distribution of beliefs. Rather, we want to analyze how the population evolves, what are the steady states and how those depend on the initial conditions. In what follows, we will first study possible fixed points of the system. We will derive conditions for the existence of two fixed points of a monomorphic population in which each principal has the same belief (either v or ρ). The presence of two steady states comes from our assumption about the irrationality of principals. It is worth to be clear on the meaning that we give to "irrationality" here. It is true that principals act in a rational way in writing contracts according to their beliefs; the irrational behavior comes from their inability to update their priors in a Bayesian fashion. This is so because the information set available to principals is limited. Taken together, a steady state in which each principal has belief ρ cannot be ruled out a priori.

In addition to the two fixed points, under certain conditions, infinitely many fixed points are possible in which the population is polymorphic. In other words, both beliefs coexist. The next step is to analyze the stability of the fixed points and conditions for convergence to any of them. Again, both the stability and convergence crucially depend on the relationship between the beliefs v and ρ. Then we show that in addition to the fixed points cyclical patterns can be obtained providing the possibility of a stable and ongoing evolving polymorphic configuration. In relation to that, the analysis derives conditions for local bifurcations that arise for different parameter values. Due to the nonlinearity of the system the analysis of its global behavior is more difficult.[10] Helped by computer-assisted proofs we are able to derive conditions for global bifurcations of limit cycles of the system.

2.3.1 Fixed Points

In order to analyze what determines the change of the variables from one period to the next, we rewrite equations (2.1) and (2.4) and rearrange using the functional forms of the

[10]In general, a bifurcation is a change in the qualitative structure of a dynamic system for changes in some parameter. For an introduction to dynamic systems that puts an emphasis on the discussion of local and global bifurcations see Guckenheimer and Holmes (1983).



(a) $k < 0$ **(b)** $k > 0$

Figure 2.1: Two phase diagrams with α on the horizontal and $\tilde{q}$ on the vertical axis. The dashed line shows the locus of points where $\tilde{q}_{t+1} = \tilde{q}_t$, the solid lines show the locus of points where $\alpha_{t+1} = \alpha_t$. Panel (a) ((b)) shows the case where $k < 0$ ($k > 0$) as defined in the text. $\tilde{q}_{high}$ ($\tilde{q}_{low}$) is the fixed point-quantity associated with $\alpha = 1$ ($\alpha = 0$).

quantities and profits. The algebraic derivation can be found in the Appendix.

$$\alpha_{t+1} = \alpha_t + \alpha_t (1 - \alpha_t) a\Omega\Big\{(1-v)^2\{\delta\Big[\beta - \overline{\theta} + (\delta - 1)\widetilde{q}_t - (1 - \alpha_t) c\Big] + b\} - v^2\Delta\theta\Big\} \tag{2.5}$$

$$\widetilde{q}_{t+1} = \beta - \overline{\theta} + \delta\widetilde{q}_t - (1 - \alpha_t) c \tag{2.6}$$

where $a = \Delta\theta\frac{\rho - v}{(1-\rho)(1-v)}$, $b = \frac{1}{2}\Delta\theta\left(\frac{v}{1-v} + \frac{\rho}{1-\rho}\right)$ and $c = \Delta\theta\frac{\rho - v}{1-\rho}$ are used to simplify the expressions.[11]

These last two equations define a nonlinear map Γ from a state $X_t = [\alpha_t, \widetilde{q}_t]$ to $X_{t+1} = \Gamma(X_t)$. Given the nonlinearity, before attempting to analyze the global behavior we start identifying the steady states and their local stability. The nullclines of the system are plotted in Figure 2.1. The dashed line gives the combination of points where $\tilde{q}_{t+1} = \tilde{q}_t$ from equation (2.6) and the solid line gives the locus of points where $\alpha_{t+1} = \alpha_t$ from equation (2.5).

To better describe the fixed points and their dependence on the beliefs we introduce

[11]To ensure that α never leaves the unit interval the long form of equation (2.5) should be written as: $\alpha_{t+1} = \min\{1, \max\{\alpha_t + \alpha_t (1 - \alpha_t) a\Omega\{(1-v)^2 \{\delta \left[\beta - \overline{\theta} + (\delta - 1)\widetilde{q}_t - (1 - \alpha_t) c\right] + b\} - v^2\Delta\theta\}, 0\}\}$.

the condition $k \equiv (1-v)^2 b - v^2 \Delta\theta = 0$. This k determines the relative location of the nullclines. For $k > 0$ (< 0) the nullcline giving the steady states for the quantity $\tilde{q}_{t+1}$ is below (above) the one for α (see Figure 2.1). The third case (not shown) is $k = 0$, when the two diagonal nullclines overlap. From Figure 2.1, it is clear that the system admits two or infinitely many fixed points, where the latter occurs only when $k = 0$. Focusing on the two non-degenerate cases (where the nullclines do not overlap) we can claim:

Lemma 3. *Whenever $k = (1-v)^2 b - v^2 \Delta\theta \neq 0$, the nonlinear system admits two hyperbolic steady states $X^0 = (0, \tilde{q}_{low})$, $X^1 = (1, \tilde{q}_{high})$ with*

$$\tilde{q}_{low} = \frac{\beta - \overline{\theta}}{1-\delta} - \frac{c}{1-\delta}$$

$$\tilde{q}_{high} = \frac{\beta - \overline{\theta}}{1-\delta}$$

The quantities $\tilde{q}_{low}$ and $\tilde{q}_{high}$ are simply the intersections of the nullcline associated with the quantity (the dashed line in Figure 2.1) with the vertical parts of the nullclines for α. Next, in order to study the stability the Jacobians are evaluated at the steady states:

$$J\left(X^0\right) = \begin{bmatrix} 1 + a\Omega k & 0 \\ c & \delta \end{bmatrix} \qquad J\left(X^1\right) = \begin{bmatrix} 1 - a\Omega k & 0 \\ c & \delta \end{bmatrix}$$

Using the usual definitions related to local bifurcations, from the Jacobians the following Proposition immediately follows:

Proposition 5. *Given beliefs v and ρ, the following holds for the system defined in (2.5) and (2.6).*

1. *The system has always either*

   (a) *a stable and an unstable fixed point, which are both hyperbolic (for $k \neq 0$), or*

   (b) *two non-hyperbolic fixed points and infinitely many fixed points (for $k = 0$).*

2. *The system has a local fold bifurcation for both fixed points if $k = 0$.*

3. *The system undergoes a transcritical bifurcation. For $k < 0$ X^0 is the stable and X^1 is the unstable fixed point. It is the other way around for $k > 0$.*

The proof for Proposition 5 involves a simple inspection of the eigenvalues of the Jacobians. The two eigenvalues are δ and $1 \pm a\Omega k$. Then, for $k = 0$ one eigenvalue crosses the unit circle for both points (fold bifurcation). Moreover, for k changing sign one point has both eigenvalues smaller than one, while the other becomes a saddle point exchanging stability (transcritical bifurcation). This implies that for $k < 0$ the point X^0 is a stable hyperbolic steady state, which corresponds to the situation depicted in Figure 2.1a. Accordingly, the reverse case of $k > 0$ is shown in Figure 2.1b, in which X^1 is stable.

2.3.2 A Qualitative Remark

At this point, two interrelated remarks are needed concerning first the value for Ω and second a possible *shutdown policy* of principals, which in the literature of mechanism-design refers to a situation in which principals choose to write contracts only for the low-cost type (e.g., Laffont and Martimort 2002, chapter 2). Concerning the latter point, we make clear that a linear demand and supply function in the standard cobweb model with naive expectations lead necessarily to fluctuations in the quantity (and therefore in the price) such that negative values are unavoidable unless more restrictive assumptions are imposed. Therefore, it appears clear that high values of the quantity $\tilde{q}_t$ in a preceding period could lead principals (who solve the maximization problem with naive expectations about $\tilde{q}_t$) to adopt a *shutdown policy* for the high-cost type. In our dynamic context, a shutdown policy would apply whenever the gain from a negotiation with this type is, in expectation, negative.

Turning to the first point, we remind the reader that when we introduced the propensity to switch Ω in the previous section we simply defined it as a parameter needed to bound the expression to unity such that it could be considered a probability. This standard normalization is the basis to define the well-known replicator dynamic and the assumption there is innocuous, because it does not affect the global dynamic (Weibull 1995). However, here we deal with a discrete set-up and the same does not necessarily apply unless we are close enough to the fixed points such that the system is topologically equivalent to its linearization. The following Lemma shows that for a qualitative analysis this problem can be easily avoided.

Lemma 4. *For every two different Ω and Ω' there exists $\Delta\theta' = \overline{\theta}' - \underline{\theta}'$, such that the system with Ω and $\Delta\theta$ is topological equivalent near the steady state to the system with Ω'*

and $\Delta\theta'$.

The proof is in the Appendix. The result in Lemma 4 implies that the normalization of the parameter Ω is not problematic for a local qualitative analysis of the dynamic system given a rescaling of $\Delta\theta$. Moreover, the configuration of the steady states as sink and saddle points is not affected. Therefore, in principle, it is always possible to construct examples avoiding the economically meaningless result of a negative quantity and hence a possible analysis of a shutdown policy. For a global analysis with quantitative results this could be taken into account simply assuming that in some periods (given some wide fluctuations of the quantity) there are principals who write contracts only for low-cost types. This would imply possible lag periods, in which only principals who got a low-cost agent consider to switch. The results would be essentially the same only complicating the calculus.

2.3.3 Global Behavior

Next, we move from a local analysis to a global analysis of the dynamic system. Given the phase diagram of our map made of a possible saddle-sink connection and of a space where the nullclines are parallel, intuition suggests that the study of convergence should be only related to the identification of the sink acting as an attractor and a saddle, with an invariant unstable manifold, acting as a repeller. As seen, this can be done easily observing that the critical value $k = (1-v)^2\, b - v^2\Delta\theta \neq 0$ implies the magnitude of the eigenvalues and therefore the topological structure of the fixed points. Therefore, any preliminary analysis should start from the relationship between the different beliefs described by k. At the same time, a study of the convergence has to include the possible sources of uncertainty, namely homoclinic and heteroclinic tangles and limit cycles.

The first step is to exclude a possible homoclinic or heteroclinic orbit, which belongs to the intersection of the stable and unstable manifolds and which would lead to the existence of a *strange attractor*. In our model, the stable manifold is simply the vertical axis passing through the α of the steady state, while the unstable manifold as usual is hard (or even impossible) to identify. In the literature it is sometimes approximated by iterated points on the corresponding unstable eigenvector in order to find an intersection. Alternatively, the absence of an intersection can be detected by the absence of any chaotic behavior in the bifurcation diagrams for long-period time series. This is the approach we pursue. We refer the reader to Figures 2.2 and 2.3, which report bifurcation diagrams[12] associated with δ and ρ. The diagrams plot the long-run behavior of the system. Inspection of the bifurcation reveals the absence of topological chaos.

Having excluded the first source of a possible unpredictable behavior, the next step is to investigate the existence of a limit-two cycle. The analogy of our set-up with the standard "stable" cobweb model is helpful in this regards (see footnote 7). It is well known that in a linear specification, where the demand and supply function have the same slope in absolute value, the model exhibits cyclical behavior. The mere observation that our map describes a standard linear model with a shifting supply curve suggests a possible presence of similar patterns.

However, with this in mind, we first analyze the global convergence to a monomorphic state where all the principals have the same beliefs. As will be clear shortly, this represents the most probable dynamic evolution and therefore we start with it. Second, we examine the conditions under which a polymorphic state exists. This is done by studying how the presence of a limit-two cycle can generate a "trapping" orbit; that is, the cycle acts as an attractor having some economic implications.

2.3.3.1 Convergence to a Monomorphic State

In absence of any sources of uncertainty the convergence is straightforward. It suffices to inspect equation $k \equiv (1-v)^2 b - v^2 \Delta\theta \neq 0$. If it holds with equality it defines a critical value ρ^c as a function of the true distribution $(v, 1-v)$ of agents' types in the economy. Hence, we refer to ρ^c as an indicator of the *degree of optimism* and to *overoptimistic* principals, who have a belief higher than ρ^c. Given that the sign of k determines the magnitude of the two eigenvalues, it is sufficient to analyze how it depends on the relationship between v and ρ. With this aim, we first observe:

Corollary 3. *Whenever the proportion of low-cost agents is greater than half of the population ($v > \frac{1}{2}$), there exists a critical value ρ^c such that for every values $\rho > \rho^c$ the fixed point X^1 is a sink while X^0 is a saddle node; the opposite is true for $\rho < \rho^c$.*

Corollary 3 is a direct consequence of Proposition 5 and the proof is based on a simple

[12] The bifurcation diagrams were produced using the E&F Chaos program as described in Diks, Hommes, Panchenko, and van der Weide (2008). The following parametrization is used: $\beta = 100, \overline{\theta} = 24, \underline{\theta} = 22, v = 0.6, \Omega = 0.01$

algebraic and calculus analysis. It has some economic implications synthesized in the following:

Theorem 1. *Whenever the conditions for the existence of the limit-two cycle are not satisfied and some principals are optimistic, then the following holds:*

1. *For a low degree of optimism ($\rho < \rho_c$), the population will converge to a state where all principals are optimistic (X^0).*

2. *For a high degree of optimism ($\rho > \rho_c$), the population will converge to a state where all principals are unbiased (X^1).*

3. *Whenever $v \leq \frac{1}{2}$ any $\rho > v$ is greater than ρ_c and then the population will converge to a state where all principals are unbiased (X^1).*

Proof. Given the absence of heteroclinic or homoclinic tangles, the proof is immediate. In fact, in the absence of an attracting limit-two cycle there are only two fixed points, one stable and the other unstable. Then, since the only source of uncertainty (the cycle) is not present, it is sufficient to observe that as ρ increases and thereby surpasses ρ_c where the critical value k is zero, the two fixed points exchange stability. Given Corollary 3 the result is immediate. Regarding the third part of the Theorem it is straightforward to show that any ρ_c such that $k = 0$ is greater than any $v \leq \frac{1}{2}$. □

The Theorem states the relationship between the degree of optimism and the convergence of the dynamic system. The economic rationale can be formulated as follows. The market is characterized by oscillations due to both the naive expectation about the aggregate quantity and the switching of beliefs. In the presence of oscillations being a ρ-principal (and therefore producing less) works as an insurance against large oscillations in the aggregate quantity, because it dampens both the negative and the positive externality effects that the aggregate quantity has on the principal's profit. If $\rho < \rho_c$ this works in favor of the ρ-principal because the marginal benefit of a smaller detrimental effect of large negative oscillations is greater than the opportunity cost that comes from missing out on the beneficial effect of large positive oscillations. This implies that on average ρ-principals are better off with both types of agents and the population converges to $\alpha = 0$. If, however, $\rho > \rho_c$ the opportunity cost is larger than the benefit and the opposite is true (second part of Theorem 1).

It also follows from the Theorem that principals are better off when $\alpha = 0$. This must be the case because individual profits increase if the aggregate quantity in the market is reduced. In our model this can be dubbed a "cartel of the ignorant", because the collusion is not the result of a coordinated action, but the spillover effects of the imitative learning of its members.

2.3.3.2 A Possible Polymorphic State

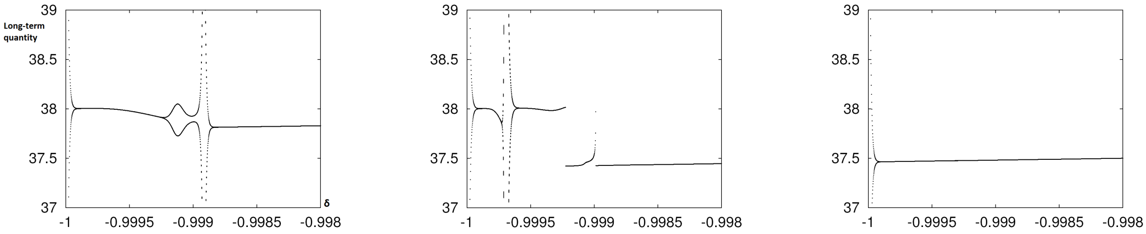
In this section, we want to show the possibility of an equilibrium in which both types of principals coexist in proportions that change over time. From a mathematical point of view, given the absence of a unique interior intersection of the nullclines, the only way is to find conditions for the existence of an attracting orbit. In order to study this, we start by claiming:

Theorem 2. *For δ close enough to -1 and $|\rho - \rho_c|$ small enough, the map $\Gamma(X)$ admits at least one limit-two cycle:*

$$\Gamma(X') = X'' \text{ and } \Gamma(X'') = X' \text{ for } X' \neq X''$$

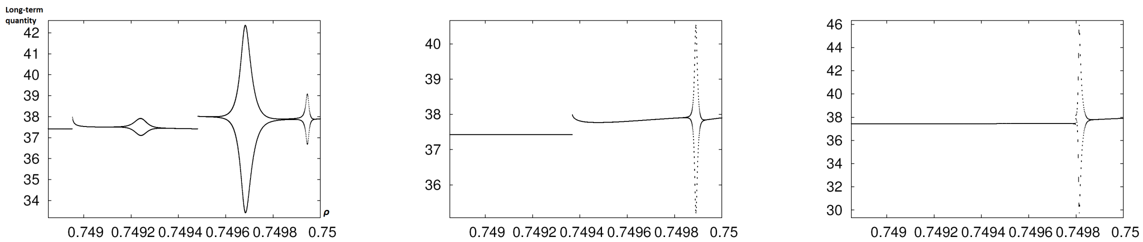
The proof of the Theorem can be found in the Appendix, where we also give a system of nonlinear equations with explicit solution from which one can obtain the limit cycle. However, here we give a more intuitive explanation. First, as suggested above, the existence of a limit-two cycle is feasible because although the underlying cobweb model is stable, the possible shifting of the supply function can induce a cyclical pattern.[13] Therefore, the orbit can simply consist of two points, which constitute the limit-two cycle and the population would indefinitely jump back and forth between the two points. Second, there is an additional way in which an attracting orbit can emerge. As seen above, $\rho = \rho_c$ implies the fold bifurcation. Then the steady states could, in principle, have a *strong resonance* with eigenvalues $-1, 1$. This means that for values close to the strong resonance a nontrivial solution of the map can arise due to the presence of a saddle-node and of a possible limit-two cycle. The presence of the latter can affect the global behavior whenever it undergoes a *Neimark-Sacker bifurcation*, i.e., two complex eigenvalues which have modulus equal to

[13]In our model δ is the ratio between the slope of the demand and supply function, where we normalize the slope of the latter to 1. Therefore, if $|\delta| = 1$ we would have the standard limit two cycle in the stable cobweb model. See also footnote 4.



(a) $\rho = 0.7499$ **(b)** $\rho = 0.749$ **(c)** $\rho = 0.74$

Figure 2.2: Bifurcation diagrams of δ for different values of ρ



(a) $\delta = -0.999$ **(b)** $\delta = -0.9989$ **(c)** $\delta = -0.9988$

Figure 2.3: Bifurcation diagrams of ρ for different values of δ

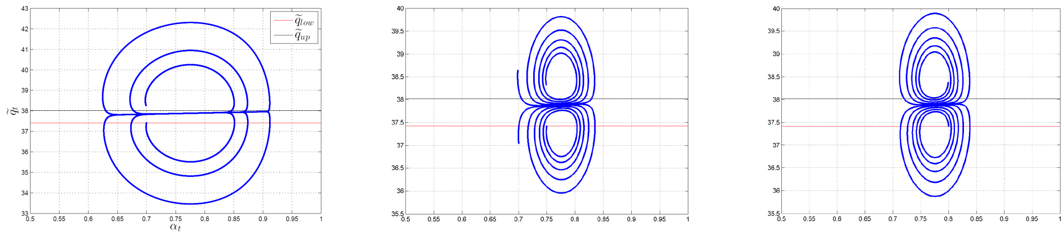
unity.[14]

In our case the Jacobian of the second iterate $\Gamma^{(2)}(X)$ has a nontrivial expression and only a numerical solution can be obtained. As will become evident, the numerical analysis that we perform supports an interaction between the invariant closed curve emerging from the Neimark-Sacker bifurcation and the unstable manifold of the saddle-node.

Following this logic, our analysis proceeds in two steps. First, we confirm the expectation of the existence of a cyclical behavior by inspecting a series of bifurcation diagrams. Second, on the basis of this numerical analysis, we show that the Jacobian indeed strongly confirms the existence of a bifurcation.

As explained above, the bifurcation diagrams in Figures 2.2 and 2.3 report convergence results for different values of the parameters. The parametrization is such that $\rho_c = 0.75$. In Figure 2.2 three different values for ρ are used. It can be seen that as ρ approaches the critical value the bifurcation shows a limit cycle for a value of δ around -0.999.

[14] The Neimark-Sacker bifurcation is the discrete version of a *Hopf* bifurcation. See for example Kuznetsov (1998) or Wiggins (2003) for detailed explanations.



(a) $\alpha_0 = 0.7$, $\widetilde{q}_0 = \widetilde{q}_{low}$ **(b)** $\alpha_0 = 0.75$, $\widetilde{q}_0 = \widetilde{q}_{low}$ **(c)** $\alpha_0 = 0.8$, $\widetilde{q}_0 = \widetilde{q}_{low}$

Figure 2.4: Three phase diagrams for different initial conditions. $\widetilde{q}_t$ is on the vertical and α_t is on the horizontal axis. The colored lines show the values of the two quantities of the steady states.

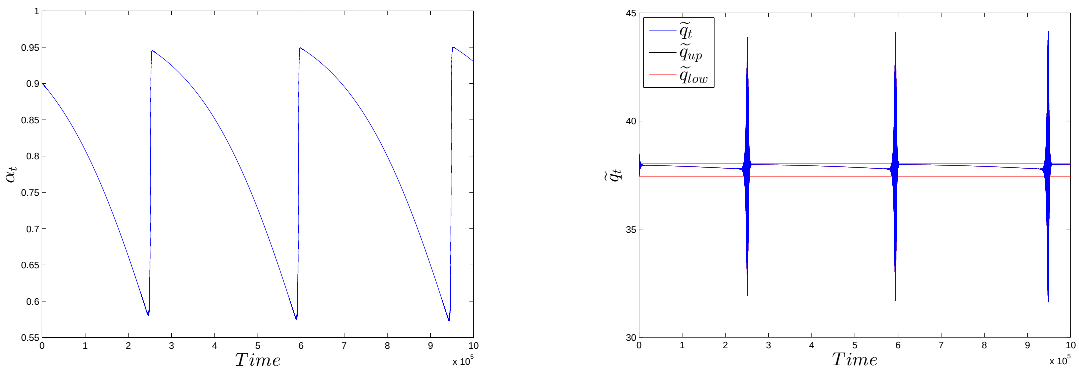
Figure 2.3 provides the complementary analysis as it shows the bifurcation for ρ using different values of δ. From the figure it can be concluded that as δ approaches -0.999 the bifurcation in terms of ρ hints at a cyclical behavior. Next, we compute some numerical simulations of the Jacobian of the second iterate of the system in order to identify values for a possible bifurcation of the limit-two cycle.[15] Using the bifurcation diagrams to obtain possible candidate values for ρ and δ, we find for $\rho = 0.7499$ and $\delta = -0.999$ two complex eigenvalues with modulus equal to $|\lambda| \approx 1$, while for $\rho = 0.745$ and $\delta = -0.999$ the eigenvalues are not complex. Therefore, the continuity of the system lets us conclude that there must exist a combination of ρ and δ where the modulus is exactly equal to 1. As a consequence, we are able to claim that there exists a point for which the limit-two cycle undergoes a Neimark Sacker bifurcation. To complete the analysis, we refer to a common result in dynamic systems, which says that the fixed point undergoing a Neimark Sacker bifurcation is surrounded by an isolated closed invariant curve for values "after" or "before" the critical value of the parameter (Kuznetsov 1998: 125-137).

In Figure 2.4 the phase diagrams for three different initial conditions can be seen. The diagrams clearly show a non-convergence and an irregular behavior which is not repetitive even for periods of length greater than the one reported here.

The corresponding time series for the quantity and for the proportion of types are reported in Figure 2.5.

The time series for the quantity and α show long periods of relative calm, in which the quantity does not vary a lot from one period to the next. What is important is that in these long periods there is underproduction, because the quantity stays below the equilibrium

[15] The numerical simulations used in this paper are based on our Mathematica, Matlab and E&F Chaos codes. The codes are available upon request.



(a) Time Series for $\widetilde{q}$ **(b)** Time Series for α

Figure 2.5: Time series for the quantity (a) and the proportion of v-principals (b) with initial conditions $\alpha_0 = 0.9$ and $\tilde{q}_0 = \tilde{q}_{up}$.

quantity. These long periods of underproduction are then punctuated by large oscillations of the quantity, in which both overproduction and underproduction occur.

2.3.4 Remarks

Before we conclude, we would like to return to some of the assumptions made in the model and discuss their implications.

First, the assumption we made about the reference groups for comparison can be relaxed. So far, we have only considered the reference group including all the principals who were matched with the same type. However, it is readily possible to assume that also a reference group with other principals can play a role in the imitation. In this case, the general formalization of the model includes a probability representing the *propensity to compare*. This implies that principals are not precluded to compare themselves with any other principals independently of the match.[16] In our model the propensity to compare with a different type-matching principal is set equal to zero. If this is not the case, the result of our main Theorem would slightly change. This can be summarized in the following.

[16]The change in the reference group would change equation (2.4) in the following way. With ξ as the propensity to compare with principals with a different match: $\alpha_{t+1} = \alpha_t + \alpha_t(1 - \alpha_t)\Omega((1-v)^2\left[\overline{\pi}^v_{t+1} - \overline{\pi}^\rho_{t+1}\right] - v^2\left[\underline{\pi}^\rho_{t+1} - \underline{\pi}^v_{t+1}\right] + \xi\left\{v(1-v)\left[\overline{\pi}^v_{t+1} - \overline{\pi}^\rho_{t+1}\right] - v(1-v)\left[\underline{\pi}^\rho_{t+1} - \underline{\pi}^v_{t+1}\right]\right\})$. The critical k then changes to $\tilde{k} = k + \xi v(1-v)(b - \Delta\theta)$.

Corollary 4. *Whenever an optimistic or pessimistic bias is present and the propensities to compare are different, there is a critical value such that the population can converge to a monomorphic biased state. Moreover, if the propensities to compare are equal, any level of optimism leads the population towards an unbiased result while the opposite is true for pessimism.*

As we have seen, in the absence of a cycle, the economy converges to one of the two steady states according to the degree of optimism: a high degree leads to the unbiased equilibrium. Enlarging the reference group and allowing different propensities to compare leaves the structure of the results intact. More precisely, if we assume that the propensity to compare with a different match is less than or equal to the propensity to compare with the same match, we have that the maximum level of optimism ρ_c is lower, but still drives the economy to a biased state. Therefore, whenever the propensity to compare with different matches increases, the over-optimism threshold decreases.

Second, we assume that there are just two types of agents whereas the mechanism-design literature allows also for a continuity of types. From a formal point of view, it is possible to include continuity of abilities. Then the belief of the biased principal is represented by a cumulative distribution function, which is first-order-stochastic dominated by the true one. In order to allow a comparison between principals one should define a norm for each matched ability level. This would clearly add complexity to the algebra of the model, but would not add anything of substance to our results.

Third, we choose the benefit function and the cost function in order to obtain a linear demand and supply function. This is done so we are able to achieve a comparability with a literature that examines heterogeneity of market participants in the framework of cobweb models (Hommes 2013). In fact, our adverse selection story adds complexity and fluctuations to a stable linear cobweb model, whereas usually the complexity comes from the use of an unstable cobweb model or nonlinear demand and supply functions.

2.4 Conclusion

Our paper introduces an evolutionary learning model with beliefs into an adverse selection problem. We relax the common assumption of homogeneous beliefs: principals have one of two possible beliefs about the distribution of the ability of agents in that some overestimate the true fraction of low-cost agents. In our model the evolutionary learning takes place in the form of a non-Bayesian updating characterized by imitation. The higher the fraction of principals with a particular belief and the higher the payoff difference between two randomly chosen principals the higher the probability to switch to the other belief. We study convergence towards different compositions of the population showing how heterogeneity drives the economy towards possibly different equilibria. The aim is to describe how, in an environment where the evolution of beliefs takes place under an imitative process, the common assumption of uniform and unbiased belief is not always and necessarily "without loss of generality". We show that if the relative bias is moderate the learning process leads to a uniformly biased population, while the reverse is true for large biases. In addition, we study conditions for bifurcations and cyclical behaviors. The latter results provide also new insights into cobweb models showing how a learning in adverse selection can generate alternating occurrence of steady quantities and cycles.

Our model suggests two future avenues for empirical research. First, it should take into account possible heterogeneity of beliefs of the subjects populating economic models and possibly sluggish adjustment processes that come from limitations on the part of subjects. Second, the study of stability of steady states should be complemented by a detailed analysis of convergence paths, with particular emphasis on conditions for dynamic systems to remain far away from steady states.

2.5 Appendix

Proposition 3. As is standard, the quantities of the efficient and inefficient type are defined implicitly by: $S'_{\overline{q}}(\cdot) = \underline{\theta}$, $S'_{\underline{q}}(\cdot) = \overline{\theta} + \frac{\phi}{1-\phi}\Delta\theta$. Using the specific functional form for $S(\cdot)$, we obtain:

$$\underline{q}_t^v = \underline{q}_t^\rho = \beta + \delta\tilde{q}_{t-1} - \underline{\theta} \tag{2.7}$$

$$\overline{q}_t^\phi = \beta + \delta\tilde{q}_{t-1} - \overline{\theta} - \frac{\phi}{1-\phi}\Delta\theta \tag{2.8}$$

with $\Delta\theta = \overline{\theta} - \underline{\theta}$.
From $\rho > v$, follows: $\underline{q}_t^v = \underline{q}_t^\rho > \overline{q}_t^v > \overline{q}_t^\rho$ □

Proposition 4. Given equation 2.8, computing the difference in quantities for the inefficient type we obtain: $\overline{q}_{t+1}^v - \overline{q}_{t+1}^\rho = \Delta\theta\left[\frac{\rho}{1-\rho} - \frac{v}{1-v}\right]$. For the differences in payoffs, taking into account that the rent for the inefficient type is zero, we obtain:

$$\underline{\pi}_{t+1}^\rho - \underline{\pi}_{t+1}^v = -\Delta\theta\overline{q}_{t+1}^\rho + \Delta\theta\overline{q}_{t+1}^v = \Delta\theta\left[\overline{q}_{t+1}^v - \overline{q}_{t+1}^\rho\right] = (\Delta\theta)^2\frac{\rho - v}{(1-\rho)(1-v)}$$

$$\overline{\pi}_{t+1}^v - \overline{\pi}_{t+1}^\rho = \left[\overline{q}_{t+1}^v - \overline{q}_{t+1}^\rho\right]\left\{\beta - \overline{\theta} - \frac{\left[\overline{q}_{t+1}^v + \overline{q}_{t+1}^\rho\right]}{2} + \delta\tilde{q}_{t+1}\right\} =$$
$$\Delta\theta\frac{\rho - v}{(1-\rho)(1-v)}\left\{\delta\left[\tilde{q}_{t+1} - \tilde{q}_t\right] + \frac{1}{2}\left(\frac{v}{1-v} + \frac{\rho}{1-\rho}\right)\right\}$$

□

Derivation of the nonlinear map

Proof. The derivation of equation (2.6) is straightforward. Using it in equation (2.3) to eliminate its dependence on $\tilde{q}_{t+1}$ gives:

$$\overline{\pi}_{t+1}^v - \overline{\pi}_{t+1}^\rho = a\Delta\theta\delta\left\{\left[\beta - \overline{\theta} + (\delta - 1)\tilde{q}_t - (1-\alpha_t)\,c\right] + b\right\}$$

Then, using the expressions for the differences in realized payoffs in the replica equation

(2.4), we obtain (2.5). □

Lemma 4. The following proof works on the basis of the center manifold Theorem (see for example Kuznetsov 1998: 50). The Theorem claims that whenever the system is close enough to a steady state the stable and unstable manifolds are tangent to the respective stable and unstable eigenvectors of the linearized system. Given the Theorem, the proof can be formulated as follows:

Given the Jacobians in the steady state, the two eigenvalues are δ and $1 \pm a\Omega k$. Since $|\delta| < 1$, the corresponding eigenvectors are the stable ones, they are invariant and correspond to the vertical line in $\alpha = 0$ and $\alpha = 1$. Then, for an Ω' it is sufficient to define a rescaling of $\Delta\theta$ such that $a\Omega k = a'\Omega' k'$. The rest follows from the center manifold Theorem. □

Theorem 2. To simplify the algebra, let $\Phi \equiv a\Omega$, $R \equiv \Phi (1-v)^2 \frac{\delta}{1+\delta} c$,$S \equiv \Phi k$. From equation (2.6), the solution of the second iterate for the quantity must solve:

$$q^{(2)} = \frac{\beta - \overline{\theta}}{1-\delta} - (1-\alpha_\tau) \frac{\delta}{1-\delta^2} c - (1-\alpha_{\tau+1}) \frac{1}{1-\delta^2} c \tag{2.9}$$

Equation (2.5), using (2.9) and after some algebraic reformulations can be written for a generic time τ as:

$$\alpha_{\tau+1} \left[1 + \alpha_\tau (1-\alpha_\tau) R\right] = \alpha_\tau \left[1 + \alpha_\tau (1-\alpha_\tau) R\right] + \alpha_\tau (1-\alpha_\tau) \tag{2.10}$$

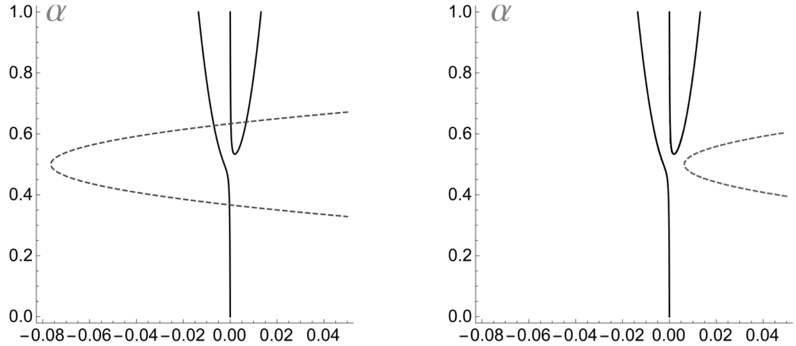
The same relationship obviously holds for $\alpha_{\tau+1}$, $\alpha_{\tau+2}$. Using both relationships, denoting $\alpha^{(2)}$ the second iterate, rearranging and using an adjunct variable H, we obtain:

$$\left[H + \left(1-\alpha^{(2)}\right) S\right] \left[H - \alpha^{(2)} S\right] [2H - 1] + H^2 = 0 \tag{2.11}$$

$$H = 1 + \alpha^{(2)} \left(1 - \alpha^{(2)}\right) R \tag{2.12}$$

Equations (2.11) and (2.12) determine $\alpha^{(2)}$, (2.10) determines $\alpha_{\tau+1}$ and (2.9) determines $q^{(2)}$.

While equation (2.9) is linear, the solution for $\alpha^{(2)}$ can be in the set of complex numbers. We note that R is a function of δ while S is not. Observe that $\delta < 0$ implies $R < 0$ which converges to $-\infty$ for $\delta \to -1$. Equation (2.12) describes a parabola with minimum in



(a) $\delta = -0.9988$ **(b)** $\delta = -0.9987$

Figure 2.6: Two examples for the graphs of equations (2.11) and (2.12), where the latter is the dashed line. In both the following values were used: $\beta = 100, \overline{\theta} = 24, \underline{\theta} = 22, \upsilon = 0.6, \rho = 0.745, \Omega = 0.01$ for two values for δ.

$\alpha^{(2)} = \frac{1}{2}$ and equal to $H_{min} = 1 + \frac{R}{4}$; therefore $\delta \to -1$, implies $H_{min} \to -\infty$. Then, to conclude the proof it is sufficient to show that it is possible to obtain a real solution for equation (2.11). Solving (2.11) for α gives:

$$\alpha = \frac{2H + S}{2S} \pm \frac{1}{2}\sqrt{\frac{2HS^2 - 4H^2 - S^2}{S^2(2H-1)}}$$

Therefore it is possible to choose an S small enough without affecting R such that a real solution exists, i.e., the graphs of (2.11) and (2.12) in the $\alpha - H$-plane have an intersection. See Figure 2.6 for an illustration.

□

3 Boycott, Stigmatization, and Law Enforcement

This paper has been co-written with Clemens Buchen and Bruno Deffains.

Abstract

The Theory of Enforcement of Law is mainly based on two different choices: strict liability and fault-based (Polinsky and Shavell 2007). Under strict liability the fine is paid whenever an individual is guilty, independently of the personal benefit obtained for committing a harmful act. Conversely, in the case of fault-based liability the conviction depends on the defined fault standard. In this paper, we study the determinants of compliance with laws when moral norms (i.e., social preferences) affect behavior, in addition to standard material or economic incentives. In this context, the moral cost is not simply a transfer of resources. In fact, it creates an additional trade-off not present in the literature. We claim that an optimal policy cannot be detached from this consideration. We show that a non-guiltiness standard — the fault equal to the deterrence level — is never optimal. This is in contrast with standard arguments about the superiority of fault-based under risk neutrality. In this scenario, we show that the choice of a policy depends in a complex way on the magnitude of the harm and the moral cost.

JEL Classification: K13, K42, O17

Keywords: Boycott, Social Preferences, Regulatory Offenses, Law Enforcement, Strict Liability, Negligence, Legal Standard, Compliance, Deterrence.

3.1 Introduction

This paper is about the determinants of compliance with legal rules when moral norms (i.e., social preferences) affect behavior in addition to standard material or economic incentives. Economists have traditionally emphasized a pure deterrence model of law enforcement where the key policy instruments are the severity and likelihood of formal sanctions such as damages or fines. It is now generally agreed that such a narrow view performs poorly in describing and predicting behavior in many situations. For instance, there is considerable evidence that tax compliance or compliance with environmental regulations is far greater than a purely self-interested cost-benefit calculation would suggest (see Nyborg and Rege 2003; Slemrod 2007). Behavior is also shaped by personal and societal values and by social rewards and sanctions. Our aim is to draw implications for the efficient design of legal rules.

The paper contributes to an emerging field of research in regulatory policy which draws on the empirical findings of the "behavioral economics" or "economics and psychology" approaches. This literature has much emphasized complementarities between incentives and other motives of behavior. In other words, pecuniary incentives may crowd out — or conversely crowd in — informal incentives based on moral and ethical norms, intrinsic motives, image concerns and other forms of social or other-regarding preferences (see e.g., the surveys by Frey and Jegen 2001 and Bowles and Polania-Reyes 2012). From a Law and Economics perspective, the issue is how normative motivations interact with formal sanctions and the extent to which they are substitutes or complements (see, among others, Tyran and Feld 2006; Lazzarini, Miller, and Zenger 2004; Zasu 2007; Galbiati and Vertova 2008). An obvious implication is that efficient legal sanctioning and enforcement should take these phenomena into account (Bowles and Hwang 2008; Benabou and Tirole 2011). Crowding effects may also have implications for the choice of the "substantive" legal rule itself (Deffains and Fluet 2013). Moreover, laws or regulations are more likely to be complied with if they are perceived as appropriate and fair (Posner 2000; McAdams and Rasmusen 2007).

Social preferences affect compliant behavior through many channels. The model described below explores some of these channels in the context of the enforcement of legal liability regimes. The main point is related to the impact of the negligence standard when individuals have moral concerns.

Many recent cases show that an individual found to have caused harm faces not only the possibility of a legal sanction — e.g., the damages he must pay — but also social boycott, disapproval or stigma. The Law and Economics literature has studied stigma mainly in relation to criminal activity (Rasmusen 1996; Harel and Klement 2007; Zasu 2007 among others). The paper inquires how a concern for social disapproval and stigmatization interacts with legal incentives created by tort law and how this affects the relative performance of different legal regimes. We mainly refer to cases where the stigmatization manifests as consumers' boycott which has a monetizable negative impact on wrongdoer firms. Recent examples are Nestlé, which is the target of a boycott since the late 1970s, with the accusation of aggressively marketing breast milk substitutes, which represent a health risk for infants.[1]

A more recent event that can be taken as example is the Volkswagen emission scandal. In September 2015, the United States Environmental Protection Agency (EPA) reported that Volkswagen violated the Clean Air Act by installing a tampered emission control system on many cars with a diesel engine. This software was able to detect when the car was being tested, providing performance in adherence with all federal emissions levels, but switching to a separate mode and exceeding safe emission levels when driving normally. As a consequence of the scandal, government regulatory agencies have initiated investigations on Volkswagen in many countries and in the days after the news, Volkswagen's stock price fell in value by a third. Volkswagen is facing heavy fines for cheating emission tests and violating environmental laws. Many Volkswagen and Audi owners are pursuing class-actions against the brand, whereas some financial institutions have launched a boycott against Volkswagen. For example, *Scandinavia-based Nordea Bank has barred its traders from buying Volkswagen shares and bonds for six months* (Bradshaw 2015). A survey by AutoPacific has compared consumers' opinion of Volkswagen before and after the scandal and revealed that while before it 3 out of 4 vehicle owners had a positive opinion about the brand, after the news only 1 out of 4 preserved such opinion. In an interview by Grieb 2015, Ed Kim, Vice President of Industry Analysis at AutoPacific, said: *this change in consumer opinion will put a significant dent in the brands' overall sales.*

Another meaningful example is represented by the production of palm oil.[2] The issue

[1]Nestlé was committed to trial, but the court found in favor of the corporation, although they were asked to change the advertising methods. Furthermore, the boycott attracted support from different authorities and from the society, and led the World Health Assembly in 1981 to develop and adopt an international code of conduct to regulate the sale of breast milk substitutes (Muller 2013).

[2]Due to its many usages (e.g., for food, cosmetics, chemical industry, etc.), the demand of palm oil is increasing rapidly and its production is growing accordingly. However, the cultivation of palm oil is

of the tropical deforestation caused by the cultivation of palm oil is a growing concern worldwide, leading people to reduce the consumption of unsustainable palm oil and to take part in campaigns against the deforestation. Also some big companies are addressing their ties to unsustainable palm oil. For example, Kellogg has announced its commitment to responsibly source palm oil and avoid buying the additive from companies that destroy tropical rainforests. It has introduced a new policy requiring the suppliers of palm oil to trace their palm oil to *known and certified sources that are environmentally appropriate, socially beneficial and economically viable* (Kellogg 2015).

In the present paper, we consider the unilateral accident model when the strict liability and negligence rules yield insufficient incentives to control risks. Injurers are partially judgment-proof or are not always sued, e.g., it is not always feasible to prove harm or identify the injurer. Some potential injurers are nevertheless assumed to exert socially efficient care. Many experimental or field studies have shown that social image concerns are important motivators of prosocial behavior (Dana, Cain, and Dawes 2006; Ellingsen and Johannesson 2008; Andreoni and Bernheim 2009; Ariely, Bracha, and Meier 2009; Funk 2010; Lacetera and Macis 2010 among others). In our framework, an individual's actions are not directly observable by society at large. However, adverse court judgments provide public information about the individuals' actions. Under either strict liability or the negligence rule, moral concerns are shown to provide individuals with some deterrence incentives.

A basic result (Deffains and Fluet 2013) is that the negligence rule is more effective than strict liability in harnessing illegal behavior in presence of intrinsic moral concerns. The reason is simply that trial outcomes are then more informative. Under strict liability, an adverse ruling merely ascertains that the defendant caused harm, not that he took inadequate precautions. Under the negligence rule, a liability ruling also ascertains that the defendant exerted inadequate care, thereby providing more precise information about his intrinsic predispositions. Socially useful incentives are therefore derived from the signaling role of "fault" or "negligence".

To further explore this, we extend the analysis considering "extrinsic" motives instead of "intrinsic" predispositions. In our model, tortfeasors consider the stigmatization that

occurring at the cost of the deforestation of wide areas. In the last 20 years, more than 30,000 square miles of rainforests have been wiped out (Vidal 2014). One of the main Indonesian palm oil companies, PT Kallista Alam, has been fined 30 million dollars for large-scale burning of protected swamp forest in Aceh, breaking a National Law on Environmental Protection and Management (Gartland 2014) would come from a possible boycott in the event of detection, which from their point of view constitutes an additional fine. In the case of strict liability the loss from stigmatization is independent of the level of care because the boycotter treats each offender equally since the court ruling does not contain this piece of information. Under fault-based (negligence) liability the court ruling provides higher informational content. This is so, because under a negligence rule in addition the court determines the level of care. This allows the potential boycotter a more fine-grained differentiation of the intensity of the stigmatization as he or she can distinguish between wrongdoers "far away" and "close to" the prescribed fault. We show that when injurers can suffer external costs imposed by the society, and by contrast with the literature, the standard has some effects on the deterrence level.

Section 2 presents the literature. In section 3, we develop the basic setup. Section 4 discusses the optimality and compares strict liability and negligence. Section 5 concludes.

3.2 Literature

Shavell (2002) proposes a general discussion of legal sanctions versus informal motivation as regulators of conduct. The risk of lawsuits induces precautions to prevent accidental harm to third parties. In the economic model of legal liability, incentives to exercise care reduce to the "implicit prices" set by tort rules (see e.g. Brown 1973; Landes and Posner 1987; Shavell 1987). Casual observation suggests that other motivations are often also at work. Most people exercise some care out of intrinsic concerns about hurting others or because they fear social disapproval if they are thought not to mind. In this paper, we augment the standard, unilateral model of tort to include such concerns.

The paper is also related to the literature about the public enforcement of law (see e.g. Polinsky and Shavell 2007 for a survey). The canonical model provides a utilitarian analysis of the use of governmental agents — inspectors, tax auditors, prosecutors — to detect and sanction violators of legal rules. Illegal acts — actions that impose negative externalities — are deterred by the threat of sanctions. In the simplest version of the model, the questions addressed are the severity of the sanction and the resources that should be spent on detecting violations, hence the degree of deterrence that will be achieved. The basic results are then: (i) when feasible, sanctions should take the form of fines and be set very high so as to minimize detection costs; (ii) generally speaking, not all potential violators will be deterred and not all violations will be detected. The basic model has been further developed in many directions. In particular, introducing risk aversion on the part of potential violators tends to lower the amount of the prescribed fines and to increase the probability of detecting infractions (Polinsky and Shavell 1979; Kaplow 1992); "general" as opposed to "specific" enforcement — whether public monitoring is directed at a specific type of infraction or simultaneously covers many types — yields some proportionality between the social harm associated with infractions and the fines imposed on infractors. Deffains and Fluet (2013) consider the role of a moral prescription that seems particularly relevant in a tort context. Kaplow and Shavell (2002) remark that there is a strong norm to avoid harming others and to compensate for the harm that one does cause. The prescription is a variant of the immemorial "golden rule" (i.e., do unto others as you would have them do unto you). Individuals are assumed to feel guilt or bad conscience when they do not abide by it. This provides an internalized source of motivation to prevent damaging events. Moreover, individuals have a preference for social approval. They care about the esteem earned if they are believed to have good predispositions and the disesteem if not. The moral norm is therefore also a social one in the sense that, in addition to intrinsic motivation, compliance is enforced by approval or reproach from others. The issue is how such "normative motivations" interact with formal legal sanctions to influence behavior. It is often formulated in terms of whether law and informal incentives are substitutes or complements (See e.g. Posner 2000; Bohnet, Frey, and Huck 2001; Brekke, Kverndokk, and Nyborg 2003; Lazzarini, Miller, and Zenger 2004; Kaplow and Shavell 2007; Shavell 2002; Zasu 2007, and McAdams and Rasmusen 2007 for a survey).

The behavioral economics literature has much emphasized the possibility that pecuniary incentives may undermine informal motivations; e.g., the much quoted study by Gneezy and Rustichini (2000) on the crowding-out effect of fines and the survey by Frey and Jegen (2001). If crowding-out effects are sufficiently strong, legal liability in the tort context could well be counterproductive and reduce precautions to prevent accidental harm. Conversely, it could be that informal motivations and legal sanctions combine to generate too much incentives. For instance, Cooter and Porat (2001) ask whether courts should deduct 'nonlegal sanctions' from legal damages to avoid overdeterrence.

Deffains and Fluet (2013) consider two benchmarks: no-liability versus perfectly enforced legal liability (both strict liability and the negligence rule). In the absence of legal liability, injurers take precautions, if at all, solely out of moral or image concerns. In fact, when such concerns are sufficiently strong, injurers could go so far as to willingly compensate their victims ex post, thereby imposing upon themselves the same penalties as under the strict liability legal regime. Anticipating this, they would therefore choose ex ante to exert efficient care. To allow a role for legal liability, the authors introduce an upper bound on the extent to which preferences differ from the standard model. This precludes spontaneous compensation ex post. Under no-liability, individuals are then shown to take suboptimal precautions but nevertheless to exert some care to avoid causing harm. By contrast, perfectly enforced legal liability crowds out informal incentives completely, e.g., tortfeasors incur no social disapproval. However, precautions are then socially efficient, as in the standard model. There is no overdeterrence: when legal liability is introduced, informal incentives either disappear or lose their bite. In case of imperfectly enforced legal liability, e.g., victims do not always bring suit because they have insufficient evidence to prevail in court, it has been showed that normative motivations and formal legal sanctions then complement one another, e.g., an individual held liable faces both legal damages and disesteem. Thus, informal and formal incentives interact to induce more precautions than in the absence of legal constraint. The main conclusion is that under the negligence rule, there may be motivational crowding-in. Because of the signal sent by a negligence ruling, image concerns tend to induce bunching on the legal due care standard. Thus, when enforcement is imperfect, the negligence rule may do much better than strict liability because of the individuals' concern for social approval.

The present paper extents the analysis with a welfare comparison of the different legal regimes. We share with the previous literature the idea that the determinants of compliance with laws include moral norms (i.e., social preferences) in addition to standard material or economic incentives. In this context, the moral cost is not simply a transfer of resources. Under strict liability the fine is paid whenever an individual is guilty independently of the personal benefit obtained for committing a harmful act. Conversely, in the case of fault-based liability the conviction depends on the defined fault standard. Consequently, we identify and analyze an additional trade-off that is not considered in the literature. We claim that an optimal policy cannot be detached from this consideration. We show that a non-guiltiness standard — the fault equal to the deterrence level — is never optimal. This is in contrast with standard arguments about the superiority of fault-based under risk neutrality. In this scenario, we show that the choice of a policy depends in a complex way on the magnitude of the harm and the moral cost.

3.3 The Model

Consider a population of risk neutral individuals (*Firms*). Each of them derives a private benefit g_i from performing a wrongful act which has a negative externality effect h. This harmful damage is independent of the gains which are uniformly distributed in the population over the support $[0, 1]$. Moreover, we assume that $h < 1$; that is, some individuals have a benefit which exceeds the harm caused.

A Social Planner (SP) chooses a probability of detection p and a fine s to maximize the social welfare. By assumption the SP never observes ex-ante the gain which is private information for individuals, but he knows the distribution of gains. The fine cannot exceed the individuals' wealth which is assumed equal for all and normalized to 1. The welfare equals the gains and harms caused in the population minus the expenditure cost for detection.

A person who commits the harmful act pays an expected fine ps and moreover a "social moral cost" described by $C(\theta; \alpha)$. Hereafter, we refer to it as moral cost. In this function, α is the fraction of the individuals who are willing to express disapproval for the firm committing the harmful act (stigmatizing the wrongdoer) whenever they get information about the illegal behavior. In other words, α can also be interpreted as the probability that the stigmatization occurs. The variable θ is the exogenously given intensity of the stigma. What is important is that whereas α is independent of the institutional choice of the liability rules, the intensity θ will depend on whether the law foresees strict liability or fault-based liability.

We suppose that the per-capita expenditure by the government is a function of the probability of detection $c(p) = \frac{p^2}{2}$.[3] Moreover, we assume that the government budget constraint for financing p breaks even:

$$\tau + \phi ps = c(p)$$

with τ defining the per-capita tax and ϕ the proportion of guilty individuals. Hence, τ and ϕ are endogenous.

To summarize, there is one population of both potential tortfeasors and potential condemnors of the wrongdoer. The two subsets can overlap and all members are risk neutral.

[3]The choice of a quadratic cost function simplifies the analysis, but is not crucial for the main trade-offs that will be analyzed.

The assumption of risk neutrality of the judging individuals is without loss of generality for the comparison of policies (see explanations in footnote 6 below).

3.3.1 Strict Liability

Under strict liability the fine is paid whenever a person is guilty independently of the personal benefit which is therefore irrelevant ex-post for the SP. Considering that judgments are public events,[4] the moral cost is paid only if the person is found guilty by the court and in this context we assume a moral cost function of the form $C(\theta;\alpha) = \theta\alpha$. Accordingly, a person commits the harmful act if $g \geqslant p\,(s + \theta\alpha)$ and therefore the social welfare is:

$$W^{SL} = 1 + \int_{p(s+\theta\alpha)}^{1} [g - h - p\theta\alpha]\, dg - \frac{p^2}{2} \tag{3.1}$$

Standardly, the fine s does not enter directly in the social welfare because it is simply a transfer of resources in the case of a risk neutral specification. However, this is not the case for moral costs, which have a double impact affecting the welfare directly and indirectly. Moral costs directly reduce the benefit of the wrongdoer without being offset by an increase in the utility of a third party. Indirectly they work as a deterrent mechanism.

The SP maximizes (3.1) choosing s and p facing the countervailing effect of the latter. Then, the fine is maximum and set by assumption equal to the wealth. The proof for maximality is standard: keep $p(s + \theta\alpha)$ — the level of deterrence — constant increasing (costlessly) s and decreasing p to decrease the enforcement expenditures; that is, the standard Becker-argument is still valid in this context. However, more interestingly, now the reasoning about the maximal magnitude of a fine is even stronger since a higher probability would have an additional negative effect represented by the direct cost $p\theta\alpha$.

The first-order condition for the SP's maximization problem can be expressed as follows:

$$(1 + \theta\alpha)(h - p) = \int_{p(1+\theta\alpha)}^{1} \theta\alpha\; dg + p \tag{3.2}$$

The left-hand side represents the marginal benefit of increasing the probability of detection, which is a marginal increase in the deterrence. The right-hand side gives the marginal costs, which consist of two components. The first is the above mentioned additional burden

[4]More precisely, we admit that the general public is assumed to be informed only of the court's ruling, not of the detailed evidence disclosed at trial. It follows that "social esteem" depends on information available at large in the general public.

on the tortfeasor, whereas the second part is the increased cost of detection for the society. Solving the first order condition to find the probability of detection, we have:

$$p^{SL} = \frac{(1+\theta\alpha)\,h - \theta\alpha}{2 - (\theta\alpha)^2} \tag{3.3}$$

To guarantee an interior solution, we assume that the harm is always large enough: $h > \frac{\theta}{1+\theta}$.

3.3.2 Fault-based Liability

In the case of fault-based liability the problem changes, because the conviction by the state depends on the defined fault standard $\hat{g}$. We assume that different standards produce different intensities of the moral cost. More precisely, we assume that the new cost is described by:

$$C(\theta + \kappa(\hat{g}, g)\,; \alpha) = [\theta + \kappa(\hat{g}, g)]\,\alpha$$

In practice, we assume that the informative content of fault-based is higher than strict-liability and this implies that the total cost depends on how "far" a guilty person's benefit is from the fault (see Deffains and Fluet 2013). As it will be clear shortly, this assumption implies that the fault itself affects the deterrence level. This is in contrast with the literature where the fault neither works as complement nor as substitute of the probability of detection.

As a consequence, a person will commit the harmful act if $g \geqslant \tilde{g}$. Therefore, $\tilde{g}$ is the deterrence level which solves implicitly:

$$\widetilde{g} = p\,\{w + [\theta + \kappa(\tilde{g})]\,\alpha\} \tag{3.4}$$

We make use of the following assumptions:

(A0) (*normalization*) $\underline{g} = 0$, $\bar{g} = 1$

(A1) (*possible negative societal reaction*) $\kappa(\cdot) \in [-\theta, 1-\theta)\ \forall g \in \left[\underline{g}, \hat{g}\right), \forall \hat{g} \in [\tilde{g}, \bar{g}]$

(A2) (*zero at the fault*) $\kappa(\hat{g}) = -\theta$

(A3) (*proclivity to the standard*) $\kappa_g(\cdot) < 0\ \forall \hat{g} \in [\tilde{g}, \bar{g}]$

(A4) (*accordance to the standard*) $\kappa_{\hat{g}}(\cdot) > 0 \; \forall g \epsilon \left[\underline{g}, \bar{g}\right]$

Hence, the moral cost is different for each benefit g and in particular: (A1) the society can punish less under fault-based liability as compared to strict liability; (A2) whenever an individual is exactly at the fault and therefore not guilty, the moral cost is zero; (A3) the society punishes less whenever the opportunity cost is closer to the standard; (A4) increasing the standard increases the moral cost for each guilty person. In what follows, for simplicity we define a *policy of fault-based* as a tuple $\langle p^F, \hat{g} \rangle$. Observe that under assumptions (A2) and (A3), (A1) is a corollary.

Under (A2)-(A4), we can claim:

Lemma 5. *Other things being equal, an increase of the probability of detection, an increase of the fault standard, or an increase of the number of condemning people, increases the deterrence level.*

Proof. Applying the implicit function theorem and using (A3) and (A4), the results are straightforward:

$$\frac{\partial \tilde{g}}{\partial p} = \frac{1 + [\theta + \kappa(\tilde{g})]\,\alpha}{1 - p\kappa_{\tilde{g}}(\tilde{g})\,\alpha} > 0 \tag{3.5}$$

$$\frac{\partial \tilde{g}}{\partial \hat{g}} = \frac{p\kappa_{\hat{g}}(\tilde{g})\,\alpha}{1 - p\kappa_{\tilde{g}}(\tilde{g})\,\alpha} > 0 \tag{3.6}$$

$$\frac{\partial \tilde{g}}{\partial \alpha} = \frac{p\,[\theta + \kappa(\tilde{g})]\,\alpha}{1 - p\kappa_{\tilde{g}}(\tilde{g})\,\alpha} \geqslant 0 \tag{3.7}$$

□

From Lemma 5 it also follows that with a fault-based rule the probability of detection and the social moral costs are substitutes in changing the deterrence level. More importantly, the fault itself is a deterrence tool. It means that even under the assumption of risk neutrality, the fault loses its passive role in harnessing illegal behavior.

Lemma 6. *An optimal policy $\left\langle p^F, \hat{g} \right\rangle$ always requires $\hat{g} \geqslant \tilde{g}$ and the minimum fault equals the probability of detection $\hat{g}_{\min} = p^F$.*

Proof. The first part is done by contradiction. Suppose $\tilde{g} > \hat{g}$. Then, the given probability of detection is not a deterrent and therefore for every optimal policy it is needed to decrease the costly probability; the result is then a consequence of Lemma 5 ($\frac{\partial \tilde{g}}{\partial p} > 0$). The second part follows immediately from (A2) when $\tilde{g} = \hat{g}$. □

A suitable functional form for $\kappa(\hat{g}, g)$ which satisfies (A2)-(A4) and allows an easy tractability of the problem is:

$$\kappa(\hat{g}, g) = (\hat{g} - g) - \theta$$

Given our functional form for $\kappa(\hat{g}, g)$, it should be noted that all the individuals with an opportunity cost close enough to the standard ($\hat{g} - g < \theta$), pay a social moral cost lower than the one they would pay under a strict liability policy.

Moreover, we assume that besides the more informative effect that the fault-based policy can have, it requires a government expenditure to define the level of the fault.[5] In particular, we assume a fixed appraisal cost for each detected individual equal to F. Accordingly, the total expected cost for defining the fault is simply $\int_{\tilde{g}}^{1} pF dg$ and then the welfare under fault-based liability becomes:

$$W^F = 1 + \int_{\tilde{g}}^{1} (g - h)\, dg - \int_{\tilde{g}}^{\hat{g}} p\left[\theta + \kappa(\cdot)\right] \alpha dg - \int_{\tilde{g}}^{1} pF dg - \frac{p^2}{2} \tag{3.8}$$

The first-order conditions for an interior solution are:

$$\frac{\partial W^F}{\partial p} = 0 \Leftrightarrow \frac{\partial \tilde{g}}{\partial p}(h - p + pF) = \int_{\tilde{g}}^{\hat{g}} \left[\hat{g} - \tilde{g}\right] \alpha dg + F(1 - \tilde{g}) + p \tag{3.9}$$

$$\frac{\partial W^F}{\partial \hat{g}} = 0 \Leftrightarrow \frac{\partial \tilde{g}}{\partial \hat{g}}(h - p + pF) = \int_{\tilde{g}}^{\hat{g}} p\alpha dg \tag{3.10}$$

The first equation expresses the marginal benefit (left-hand side) and marginal cost (right-hand side) for the probability of detection keeping the fault constant. The marginal costs consist of three terms. The first accounts for an increase in stigmatization because of

[5] Determining whether a party has been negligent is often a highly fact-intensive process. Adducing proof of negligence may therefore be economically costly and time consuming. For example, showing how carefully the defendant acted on a particular occasion may involve more cost and time than showing that the defendant was involved in a particular activity for which strict liability is imposed. Expert testimony is more likely to be required or permitted to prove negligence than to prove the defendant's involvement in such an activity. Evidence of compliance with, or violation of, a customary practice is admissible because it is relevant to negligence, but it is unlikely to be relevant in a strict liability action. Because an unexcused violation of an applicable safety statute constitutes negligence, whether a statute was violated may be at issue in negligence but not in strict liability cases.

the higher detection rate, the second represents the increase in appraisal costs because more infractions are detected and the third is the linear marginal cost of a higher probability of detection. The second equation records the first-order condition for the fault. Again, the left-hand side is the marginal benefit of the fault keeping the probability of detection constant. The right-hand side represents the marginal increase in the stigmatization costs, because the higher the fault, the higher the cost for all infractions that are not within the fault (see also Assumption (A4) above).

One immediate observation is that including social moral costs leads to a solution in contrast with standard argument about the superiority of fault-based under risk neutrality, namely the *non-guiltiness standard*. Usually, this is shown observing that a standard optimal policy requires to split the society in two parts: individuals who do not commit the act because the expected cost outweighs the benefit and individuals who respect the fault (Deffains and Fluet 2013). In our model, this would translate in ($\hat{g} = \tilde{g}$). However, as it is clear from the first-order conditions w.r.t. $\hat{g}$ this is only a special case in our model and in particular:

Corollary 5. *An optimal fault-based policy $\hat{g}^*$ under social moral costs never requires a non-guiltiness standard and it is never at the first best $\hat{g} \neq h$.*

Proof. The proof is immediate and relies on an algebraic manipulation of the first-order conditions w.r.t. $\hat{g}$, which leads to:

$$\hat{g}^* = h + p^F F \tag{3.11}$$

□

Since a closed form solution for fault-based is not obtainable, the following claim will be helpful later.

Corollary 6. *Under a non-guiltiness standard policy ($\hat{g} = \tilde{g} = p^F$) the optimal probability of detection and the fault are:*

$$p^F = \frac{h - F}{2(1 - F)} = \hat{g} \tag{3.12}$$

3.4 Discussion

Having determined the probability of detection for each policy (and the fault) we now define under which conditions one policy performs better than the other. Denote the value functions of the respective welfares as $W^{SL}(*) \equiv W^{SL}\Big|_{p^{SL}}$, $W^{F}(*) \equiv W^{F}\Big|_{p^{F},\hat{g}}$ and the value function of fault-based under the non-guiltiness standard as $W^{F}\Big|_{p^{F}=\hat{g}}$.

We have for strict liability:

$$W^{SL}\Big|_{p^{SL}} = \left[\frac{1}{2} - h\right] + \left(p^{SL}\right)^2 - \frac{\left(p^{SL}\right)^2 (\theta\alpha)^2}{2} \tag{3.13}$$

while for fault-based liability under non-guiltiness standard:

$$W^{F}\Big|_{p^{F}=\hat{g}} = \left[\frac{1}{2} - h\right] + \left(p^{F}\right)^2 (1 - F) \tag{3.14}$$

The derivations can be found in the appendix.

Whereas the welfare of fault-based liability under non-guiltiness standard is obviously independent of the moral cost, we have:

Lemma 7. *$W^{SL}(*)$ is strictly convex w.r.t. α everywhere. Moreover, for a small enough harm ($\frac{\theta}{1+\theta} < h \leqslant \frac{2}{2+\theta}$) the value function is always decreasing for every α, while for a large harm ($\frac{2}{2+\theta} < h < 1$) it is U-shaped.*

Proof. See appendix ||

And for fault-based liability:

Lemma 8. *$W^{F}(*)$ is strictly increasing in α and bounded from below by $W^{F}\Big|_{p^{F}=\hat{g}}$.*

Proof. See appendix ||

Combining Lemma 3 and 4, we have the following result:

Proposition 6. *For large negative externalities (h large enough) there exist α^* and α^{**} such that:*

i) for $\alpha \in (0, \alpha^*)$ and for $\alpha \in (\alpha^{**}, 1)$ strict liability policy is welfare maximizing;

ii) the opposite is true for $\alpha \in (\alpha^*, \alpha^{**})$;

iii) for an appraisal cost small enough at least one intersection between the two value functions always exist.

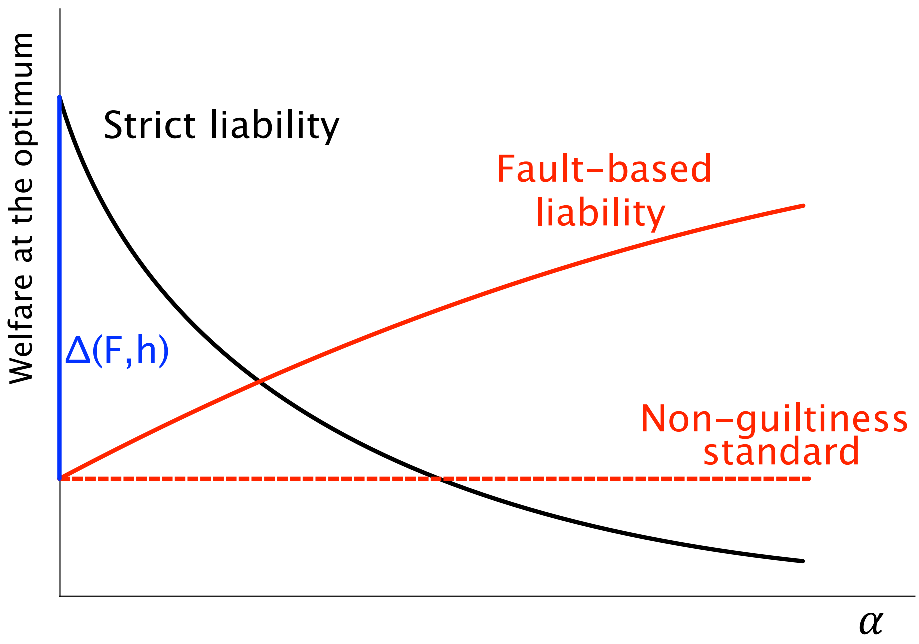


Figure 3.1: Liability rules comparison when the negative externality is small enough.

Proof. See appendix ||

Proposition 6 gives the main result. Here we give the intuition. If h is small and the appraisal costs F are not too high, there exists a threshold for α such that strict liability performs better than fault-based liability for smaller values of α, while the opposite is true for values above this threshold. This case is depicted in Figure 3.1. The non-guiltiness standard acts as lower bound for the welfare of fault-based and in case of no moral costs ($\alpha = 0$), the difference to strict liability depends on the magnitude of the appraisal cost and the damage ($\Delta(F, h)$). For all $\alpha > 0$ — that is, whenever there are social moral costs — the optimal policy will never be given by a fault-based policy cum non-guiltiness standard. This is in contrast with standard arguments about the superiority of fault-based legal regimes under risk neutrality. Intuitively, non-guiltiness is never optimal, because implementing it would always imply to forego the opportunity to use the standard as an additional tool to affect the deterrence level.

It is true that in the case of small h the superiority of strict liability is due to the introduction of the appraisal costs. What is more, introducing social moral costs amplifies the superiority of the fault-based regime as compared to the standard literature. However,

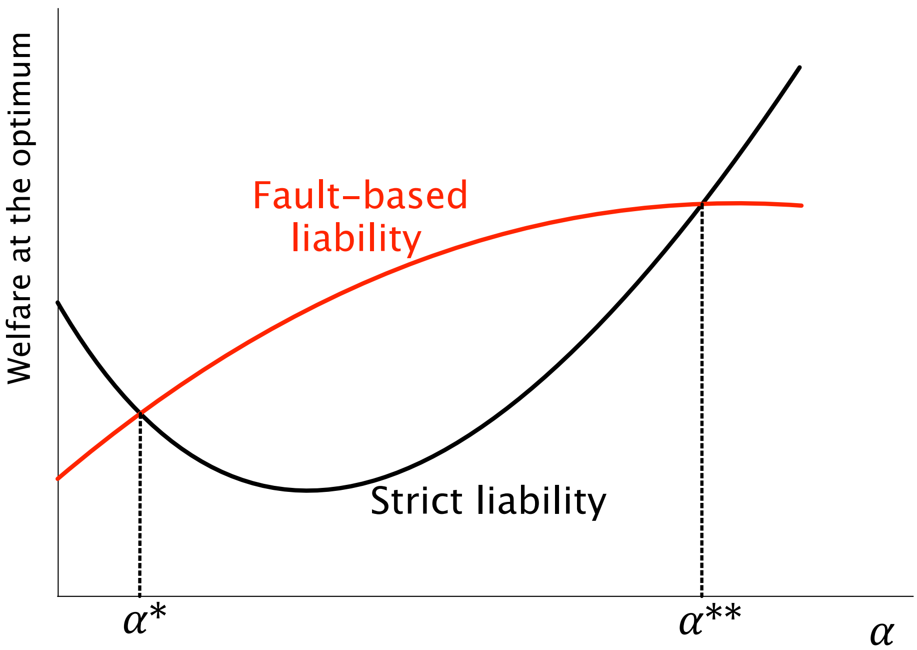


Figure 3.2: Liability rules comparison when the negative externality is large enough.

and importantly, this is not anymore true if the harm increases.

For large h the welfare comparison is shown in Figure 3.2. From Lemma 3 we know that for large h the welfare of strict liability is U-shaped. This implies that there is potentially a second intersection of the two value functions. This shows that the superiority of fault-based is not lost only because of an additional expenditure that comes from the appraisal costs. To explain the rationale behind this claim, it is worth to recall the basic trade-off created by the presence of social moral costs. On the one hand, α works as a substitute for the probability of detection in the deterrence level, which allows the SP to save enforcement costs. On the other hand, the social moral costs are not a transfer of resources and therefore the higher α the higher the burden on the wrongdoer.

If the harm is relatively large, the SP wants to avoid infractions and therefore keep the deterrence high. For relatively small α the aforementioned trade-off is best solved by a fault-based rule, because the benefit of a low probability of detection outweighs the negative effect coming from the social moral costs. More clearly, the fault-based regime allows to better spread this non-transferable cost, because the reaction of the society differs according to the "distance" of the wrongdoer from the standard. However, if α increases, the pendulum swings towards strict liability. Now, this relatively high social cost should be avoided and this can be done if the deterrence increases. Therefore, the choice of a law maker is to use it not only as a substitute for a costly enforcement, but primarily as a tool to harness illegal behavior. Strict liability is more effective in this sense because it can entirely use the stigmatization. Applying strict liability, and therefore not giving information about the level of guiltiness, increases the cost for all offenders compared to fault-based, tightening the incentive to infract regardless of the personal benefit.[6]

3.5 Concluding Remarks

The paper introduces stigmatization effects into a standard unilateral tort model. The tortfeasor takes the potential negative montary effect of stigmatization into account. The model specifically draws on the different informational content of different liability regimes, strict liability or negligence rules. Since in the case of negligence courts have to engage in fact-finding to ascertain whether the wrongdoer adhered to the fault or not, the specific gain from the infraction is known. This implies that in the latter case stigmatization can depend on the gain of the tortfeasor, whereas in the case of strict liability it does not. Put simply, in strict liability the monetary effect of stigmatization is a constant, whereas in a negligence regime it depends on how far away the gain is from the fault. We model this as a linear relationship, but of course other functional relationships can be envisioned.

The main aim is then to study the welfare under either liability regime. The relative superiority depends both on the prevalence of stigmatization in the society and the level of the harm. If the harm is relatively small, negligence rules will tend to perform better as long as the additional appraisal costs are not too large. On the other hand, if the harm is large, there is the possibility that strict liability performs better if the prevalence of stigmatization is large enough. If a high enough fraction of the population is willing to engage in stigmatization strict liability is superior beacuse it can entirely use the stigmatization as

[6]These results remain if the assumption of risk neutrality for the condemners is relaxed. Suppose there is an additional population of individuals who condemn, but do not commit a harmful act. Moreover, for simplicity, assume that the taxation is only imposed on the firm level. In this case, an individual would suffer a disutility whenever the deterrence level increases. Formally, the society at large faces in expectation the additional term $\phi U(w) + (1-\phi) U(w-h)$. In this scenario, the marginal benefit of increasing p is $\frac{\partial \phi}{\partial p}\left[U(w) - U(w-h)\right]$. Hence, there is an incentive of the SP to keep the deterrence level higher according to the degree of risk aversion. However, given the linearity in ϕ the shapes of the value function is unaltered, but the threshold of h that makes strict liability better than fault-based liability is reduced.

a tool to harness illegal behavior.

Broadening the types of incentive that tortfeasors take into account leads to conclusions that are not in line with the previous literature. In a model of risk neutral individuals the conclusion about the superiority of fault-based liability follows from the additional tool for the law maker. On the one hand, fines are irrelevant because they constitute a redistributive source of wealth. On the other hand, the fault-standard can be chosen so that it equals the deterrence level. Therefore, even if for a utilitarian law maker fault-based liability and strict liability are indifferent in terms of efficiency, the choice should be in favor of the former. In our model this is not necessarily the case because the boycott costs do not have a positive counterpart; hence, the countervailing effect of increasing the probability of detection. The main result of this paper is about this trade-off and the normative conclusions of having the strict liability policy as welfare maximizing policy also in presence of risk neutrality.

3.6 Appendix

Derivations of the value functions

Nota bene: To keep the derivations legible, we denote the respective probabilities p^F and p^{SL} only in the final step.

Welfare at the optimum under strict liability:

$$\begin{aligned} W^{SL}(*) &= \left[\frac{g^2}{2} - hg - p\theta\alpha g\right]_{\tilde{g}}^{1} - \frac{p^2}{2} = \left[\frac{1}{2} - h\right] - p\theta\alpha - \frac{\tilde{g}^2}{2} + h\tilde{g} + p\theta\alpha\tilde{g} - \frac{p^2}{2} = \\ &= \left[\frac{1}{2} - h\right] - \frac{\tilde{g}^2}{2} - \frac{p^2}{2} + h\tilde{g} - p\left(\theta\alpha - \theta\alpha\tilde{g}\right) \end{aligned}$$

using the first-order condition (3.2) and the fact that $\tilde{g} = p\left(1 + \theta\alpha\right)$ we write:

$$\theta\alpha - \theta\alpha\tilde{g} = (1 + \theta\alpha)\, h - p\left(1 + \theta\alpha\right) - p = (1 + \theta\alpha)\, h - \tilde{g} - p$$

Therefore:

$$W^{SL} = \left[\frac{1}{2} - h\right] - \frac{\tilde{g}^2}{2} + \frac{p^2}{2} + p\tilde{g}$$

substituting $\tilde{g}$:

$$W^{SL}\Big|_{p^{SL}} = \left[\frac{1}{2} - h\right] + \left(p^{SL}\right)^2 - \frac{\left(p^{SL}\right)^2 (\theta\alpha)^2}{2}$$

Welfare at the optimum under fault-based liability:

Substituting the functional form for κ, (3.4) , (3.5) , (3.6) , and (3.7) reduce to:

$$\tilde{g} = \frac{p\left(1 + \hat{g}\alpha\right)}{1 + p\alpha} \tag{3.15}$$

$$\frac{\partial\tilde{g}}{\partial p} = \frac{1 + \hat{g}\alpha}{\left(1 + p\alpha\right)^2} > 0 \tag{3.16}$$

$$\frac{\partial\tilde{g}}{\partial\hat{g}} = \frac{p\alpha}{1 + p\alpha} > 0 \tag{3.17}$$

$$\frac{\partial \tilde{g}}{\partial \alpha} = \frac{p(\hat{g} - p)}{(1 + p\alpha)^2} \geqslant 0 \tag{3.18}$$

$$\begin{aligned} W^F &= \left[\frac{g^2}{2} - hg\right]_p^1 - pF(1-p) - \frac{p^2}{2} = \left[\frac{1}{2} - h\right] - p^2 + ph - pF + p^2F = \\ &= \left[\frac{1}{2} - h\right] - p^2(1-F) + p(h-F) \end{aligned}$$

using the first-order conditions:

$$W^F\Big|_{p^F} = \left[\frac{1}{2} - h\right] + \left(p^{FB}\right)^2 (1-F)$$

Lemma 7. Applying the envelope theorem to (3.1), we have:

$$\frac{\partial W^{SL}}{\partial \alpha}\Big|_{p^{SL}} = p^{SL}\theta\left(h - 1 + p^{SL}\theta\alpha\right) \tag{3.19}$$

which proves that the $W^{SL}\Big|_{p^{SL}}$ function can be decreasing or increasing. For the second part of the proposition, differentiating (3.19) w.r.t. α:

$$\begin{aligned} \frac{\partial^2 W^{SL}\Big|_{p^{SL}}}{\partial \alpha^2} &= \frac{\partial p^{SL}}{\partial \alpha}\theta\left(h - 1 + p^{SL}\theta\alpha\right) + p^{SL}\theta^2\alpha\frac{\partial p^{SL}}{\partial \alpha} + \left(p^{SL}\theta\right)^2 \\ &= \frac{\partial p^{SL}}{\partial \alpha}\theta\left(h - 1 + 2p^{SL}\theta\alpha\right) + \left(p^{SL}\theta\right)^2 \end{aligned} \tag{3.20}$$

It is easy to show that:

$$\frac{\partial p^{SL}}{\partial \alpha} = \frac{\theta\left(h - 1 + 2p^{SL}\theta\alpha\right)}{2 - (\theta\alpha)^2} \tag{3.21}$$

Using (3.21) in (3.20):

$$\frac{\partial^2 W^{SL}\Big|_{p^{SL}}}{\partial \alpha^2} = \frac{\left[\theta\left(h - 1 + 2p^{SL}\theta\alpha\right)\right]^2}{2 - (\theta\alpha)^2} + \left(p^{SL}\theta\right)^2 > 0$$

For the second part of the Lemma set (3.19) equal to zero to find that the minimizer is $\alpha^m = \frac{2(1-h)}{\theta h}$. For $h > \frac{2}{2+\theta}$, $\alpha^m < 1$, and then the conclusion follows.

□

Lemma 8. To show the first part, apply the envelope theorem to (3.8) when $\kappa(\hat{g},g) = (\hat{g}-g)-\theta$:

$$W^F\Big|_{p^F,\hat{g}} = \frac{\partial\tilde{g}}{\partial\alpha}(h-p+pF) - \frac{p}{2}(\hat{g}-\tilde{g})$$

Substituting the value of $\frac{\partial\tilde{g}}{\partial\alpha} = \frac{p(\hat{g}-p)}{(1+p\alpha)^2}$, $\hat{g}-\tilde{g} = \frac{\hat{g}-p}{1+p\alpha}$ and using the value of the standard at the optimum $\hat{g} = h + p^F F$, we obtain the claim:

$$W^F\Big|_{p^F,\hat{g}} = \frac{p}{2}\frac{(\hat{g}-p)^2}{(1+p\alpha)^2} > 0$$

For the second part, observe that a policy $\hat{g} = p$ for a positive α is equivalent to a policy $\hat{g} = p$ for $\alpha = 0$ and that the value function is strictly increasing in α.

□

Proposition 6. Showing that for F small enough the two value functions have at least one intersection is an obvious consequence of the shapes. Then, we need to show that the two value functions have two intersections for h large enough. The first intersection is straightforward to show and it is again a consequence of the shapes of the two value functions. To show the second one we need to study two possibilities.

1) The probability of detection p^F has a lower bound. In this case, $\hat{g}^* = h + p^F F$ converges to 1 as h increases. For continuity p^F reaches the lower bound for a h large enough and therefore $\hat{g}^* = 1$. This means that the welfare maximizing policy is strict liability.

2) p^F has no a lower bound, but converges to zero as h increases such that $\hat{g}^* = h+p^F F$ is always satisfied and $\hat{g}^*$ does not cross the unity. In this case, it is straightforward to show that for h large enough, such that $W^{SL}(*)$ is U-shaped, $W^{SL}(*)$ crosses $W^F\Big|_{p^F=\hat{g}}$ twice where the second intersection is for $\alpha < 1$. Conclusion follows from Lemma 4 which shows that $W^F\Big|_{p^F=\hat{g}}$ is the lower bound for a fault-based policy and from $\frac{\partial W^F}{\partial\alpha}\Big|_{p^F,\hat{g}} \to 0$ as $p \to 0$.

□

Conclusion

This research deals with the role of the information in its broadest sense in economic models. In particular, in three self-contained papers, the thesis focuses on the role of the information in policy decisions, with specific regard to the theory of negotiation and governance.

The first paper studies the optimal allocation of bargaining power when there is asymmetric information, and hold-up problems are considered. In principal-agent models it is often assumed that the principal makes take-it-or-leave-it offers. Therefore, behind the adverse selection framework, the implicit assumption is that the principal has all the bargaining power and takes the information as given. However, there are several economic environments where the hiring process involves a negotiation between parties and the investment in capital can influence the efficiency of workers and therefore can be seen as a cost for the principal to increase ex-ante the information (i.e., obtaining a more favorable distribution). The result of negotiations depend on the specific conditions in which the job takes place and on the allocation of the bargaining power. As a consequence, one can argue that the problem of a regulator who wants to maximize the social welfare might be to find the optimal distribution of contractual power, taking into account the different contexts. Studying this scenario, the paper shows that the allocation of bargaining power can reduce distortions from the perfect information benchmark. However, I highlight that, except in the case of franchising contracts, it is never optimal if the power is in favor of one party. Then, a numerical example is used to study normatively the effect that schooling and heterogeneity in the workforce can have on the optimal design of an efficient allocation of bargaining power.

The second paper introduces the heterogeneity in beliefs in a market with adverse selection. Here the information is the main variable of interest. We question about the validity of a unique belief when learning is based on the imitation of successful individuals. We justify under which conditions the assumption of a common belief in the mechanism-design literature can be supported under a behavioral learning model without loss of generality. Then, we try to answer our main question: where does the economy converge in terms of different beliefs? We study the dynamics of different compositions of the population with the aim of understanding how heterogeneity drives the economy toward possibly different equilibria. We find that convergence to a common belief depends on the relative degree of bias of the principals if the interaction between principals can be considered as an aggregative game with naive expectations. Furthermore, in contrast to the standard cobweb model, our model generates periods of relative steady quantity, which are punctuated by large oscillations. This shows how the introduction of adverse selection and learning can engender endogenous fluctuations when the fundamentals of the market are unchanged.

The third paper studies how the informative content of legal policies as strict liability and fault-based, in case of moral concerns, influences the optimal design of liability regimes. Here, the information induces compliance with laws when moral norms (i.e., social preferences) affect behavior, in addition to standard material or economic incentives. In case of imperfectly enforced legal liability — e.g., victims do not always bring suit because they have insufficient evidence to prevail in court — the normative motivations and formal legal sanctions are complement one another. The paper characterizes the optimal legal policy when the information spread in the society depends on the policy itself. We claim that the negligence regime must now consider how courts deal with this possibility. We show that when injurers can suffer of external costs imposed by the society, and by contrast with the literature results, the standard has some effects on the deterrence level. Moreover, we claim that a *non-guiltiness standard* — the fault equal to the deterrence level — is never optimal. This is in contrast with standard arguments about the superiority of fault-based under risk neutrality. Modelling the informative contents of strict liability and fault-based policies, we highlight that the choice of a law maker is to use the boycott not only as a substitute for a costly enforcement, but primarily as a tool to harness illegal behavior. We show that the choice of a policy depends in a complex way on the magnitude of the harm and the "moral cost".

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Essais en Théorie de la Négociation et Gouvernance

Résumé:

Cette thèse a pour sujet les effets que l'information a sur les incitations. Les trois articles fournissent et explorent des résultats lorsque l'information est la principale variable d'intérêt, est endogène, pas homogène entre les acteurs et évolue dans le temps d'une manière qui n'est pas nécessairement rationnelle. Le premier article étudie les problèmes de *hold-up* dans les hiérarchies verticales avec la sélection adverse montrant qu'alors que le pouvoir de négociation des travailleurs augmente, les distorsions provenant de l'asymétrie d'information disparaissent. En outre, il étudie l'effet de la scolarité et du degré d'hétérogénéité de la population de travailleurs sur la répartition du pouvoir de négociation dans les marchés réglementés. Le deuxième article assouplit l'hypothèse des croyances homogènes dans les relations principal-agent avec sélection adverse. Dans un apprentissage évolutif qui est imitatif, les principaux peuvent avoir des croyances différentes sur la répartition des types d'agents dans la population. La convergence à une croyance uniforme dépend de la taille relative de la polarisation dans les croyances. En outre, le modèle est une version d'un *cobweb* stable. Notre approche offre des explications pour l'alternance des périodes avec quantité oscillante et relativement stable. Le troisième article étudie la façon dont le contenu informatif des politiques juridiques, comme la responsabilité stricte et négligence, en cas de soucis morales, influence la conception optimale des régimes de responsabilité. Plusieurs cas récents ont montré qu'un individu ayant causé un dommage s'expose non seulement a une sanction légale — par exemple, une amende — mais aussi à un boycott sociale, la désapprobation ou la stigmatisation. L'article montre que le choix d'une stratégie dépend de façon complexe de l'importance du dommage et du "coût moral".

Descripteurs : Négociation, Sélection Adverse, Hold-up, Théorie des Jeux Evolutive, Hétérogénéité des Croyances, Théorie des bifurcations, Boycott, Application de la Loi, la Responsabilité Stricte, Négligence.

Essays in the Theory of Negotiation and Governance

Abstract:

This thesis focuses on the effects that information has on incentives. The three papers provide and explore some results when the information is the main variable of interest, it is made endogenous, not homogeneous between actors and evolving over time in a way that is not necessarily rational. The first paper studies hold-up problems in vertical hierarchies with adverse selection showing that as the bargaining power of the worker increases, distortions coming from asymmetric information vanish. Moreover, it studies the effect of schooling and degree of heterogeneity in the workforce on the allocation of bargaining power in regulating markets. The second paper relaxes the common assumption of homogeneous beliefs in principal-agent relationships with adverse selection. In an evolutionary learning set-up, which is imitative, principals can have different beliefs about the distribution of agents' types in the population. Convergence to a uniform belief depends on the relative size of the bias in beliefs. In addition, the set-up is a version of a stable cobweb model. Our approach offers explanations for alternating periods of oscillating and relatively steady quantity. The third paper studies how the informative content of legal policies as strict-liability and fault-based, in case of moral concerns, influences the optimal design of liability regimes. Many recent cases show that an individual found to have caused harm faces not only the possibility of a legal sanction — e.g., the damages he must pay — but also social boycott, disapproval or stigma. The paper shows that the choice of a policy depends in a complex way on the magnitude of the harm and the "moral cost".

Keywords: Bargaining, Adverse Selection, Hold-up, Evolutionary Game Theory, Heterogeneous Beliefs, Bifurcation Theory, Boycott, Law Enforcement, Strict Liability, Negligence.