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Evolutionary persistence of corruption and some effects on economic growth

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Certificamos que esta é a **versão original e final** do trabalho de conclusão que foi julgado adequado para obtenção do título de Mestre em Economia.

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Acemoglu and Robinson (2012) define critical junctures as major events or confluence of factors that disrupt the current state of affairs. This thesis is a symbol of a critical juncture in my trajectory.

I am deeply grateful to my friends and family who have supported me all along thus far, specially to those that, up until this critical juncture, have carried heavy burdens so that mine could seem a little bit lighter.

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RESUMO

São apresentados dois ensaios que modelam corrupção como um processo evolucionário e estudam, respectivamente, a evolução da corrupção e sua relação com o crescimento econômico. No primeiro ensaio, propõe-se uma abordagem evolucionária para a dinâmica da corrupção na sociedade com base em interações entre agentes com racionalidade limitada. É demonstrado que a persistência da corrupção no setor público depende da leniência de parte dos agentes privados na economia. No segundo ensaio, é desenvolvido um modelo dinâmico de crescimento com gastos produtivos do governo para estudar os impactos da corrupção persistente sobre a acumulação de capital quando as duas variáveis são endógenas e simultaneamente determinadas. Os resultados sugerem que, sob certas circunstâncias, corrupção afeta negativamente o crescimento econômico e um equilíbrio polimórfico é atingido, dependendo do conjunto de instituições vigente na economia.

Palavras-chave: Corrupção. Jogos evolucionários. Crescimento econômico.

RESUMO EXPANDIDO

Introdução

Corrupção é um fenômeno persistente de escala global. Evidências empíricas, como Mauro (1995), Mo (2001) e Svensson (2005), apontam para uma relação negativa entre corrupção e crescimento econômico. Não por acaso, à corrupção associa-se uma conotação negativa, trata-se de um fenômeno socialmente condenável. Se a corrupção é reprovável e traz efeitos deletérios para o desenvolvimento econômico, por que ela não dá sinais de extinção no longo prazo? No presente trabalho, são apresentados dois ensaios que buscam estudar, respectivamente, a evolução da corrupção e sua relação com crescimento econômico. No primeiro ensaio, propõe-se uma abordagem evolucionária para ilustrar a persistência da corrupção na sociedade. No segundo, é desenvolvido um modelo dinâmico de crescimento para estudar consequências macroeconômicas da corrupção persistente. Em ambos os ensaios, a evolução da corrupção é modelada como um processo evolucionário. De acordo com Dimant e Schulte (2016) e Hellmann (2017), o processo de escolha individual é reforçado ou enfraquecido pela influência social, o que justifica o uso da Teoria de Jogos Evolucionários para representar a dinâmica da corrupção na sociedade. Já conforme Acemoglu e Robinson (2012), corrupção institucionalizada estimula a formação e perpetuação de instituições econômicas extrativas, o que justifica sua relação com subdesenvolvimento econômico, em consonância com as evidências empíricas.

Objetivos

O objetivo geral do trabalho é estudar a relação entre corrupção persistente e crescimento econômico. São apresentados dois ensaios: para o primeiro, tem-se como objetivo específico investigar em quais circunstâncias corrupção torna-se um fenômeno persistente. Já para o segundo ensaio, o objetivo específico é investigar os impactos de longo prazo da corrupção persistente sobre o crescimento econômico.

Metodologia

Para o primeiro ensaio, propõe-se uma abordagem baseada em Jogos Evolucionários para representar a dinâmica da corrupção na sociedade, a partir de um modelo de interações entre agentes com racionalidade limitada. O uso de Jogos Evolucionários para modelar corrupção está presente nos trabalhos de Bicchieri e Rovelli (1995), Mishra (2006) e Accinelli e Carrera (2012). A abordagem evolucionária permite que seja modelada a evolução de uma determinada característica em uma população: a frequência relativa da corrupção na população mede o sucesso dessa estratégia. Nesse caso, os indivíduos seguem um comportamento *satisficing*, baseado em características intrínsecas, contudo estão sujeitos à influência social, por meio de um “efeito contágio". Essa metodologia segue aquela sugerida por Dimant e Schulte (2016) e Hellmann (2017). Para o segundo ensaio, a fim de estudar as consequências de longo prazo da corrupção persistente sobre o crescimento econômico, busca-se inserir uma dinâmica evolucionária que represente a dinâmica da corrupção na sociedade em um modelo de crescimento de gerações sobrepostas com gastos produtivos do governo. Dessa forma, pode-se estudar os impactos da corrupção persistente sobre a acumulação de capital quando as duas variáveis são endógenas e simultaneamente determinadas, o que ainda é incipiente na literatura.

Resultados e discussão

No primeiro ensaio, é demonstrado que a sobrevivência da corrupção no setor público depende da leniência de parte dos agentes privados na economia. Conforme parâmetros que dependem da configuração institucional da economia, tais como a alíquota tributária e o conjunto de punições aos agentes que adotam comportamentos corruptos, os únicos equilíbrios estáveis são o de ausência de corrupção ou de corrupção generalizada em ambas as populações. Essa última situação se assemelha ao proposto pelo modelo de Jain (2001). Os resultados sugerem que medidas que buscam erradicar a corrupção devem considerar a interação estratégica entre agentes públicos e privados, tal como em Litina e Palivos (2016). Os resultados do segundo ensaio, por sua vez, sugerem que, sob certas circunstâncias, corrupção torna-se um fenômeno persistente, dependendo do conjunto de instituições vigente na economia, que afeta negativamente o crescimento econômico. Especificamente, caso a punição esperada para um indivíduo que adote um comportamento corrupto não seja suficientemente alta, a corrupção perdura paralelamente à acumulação de capital, ainda que a afete de forma negativa e seja socialmente condenável.

Considerações finais

A abordagem evolucionária para modelar corrupção permite que o fenômeno seja considerado tanto do ponto de vista individual, à luz da teoria de escolha individual, quanto do ponto de vista agregado, refletindo a influência social sobre decisões individuais. Um modelo de crescimento econômico associado à abordagem evolucionária da corrupção permite que as evidências empíricas sejam reproduzidas de forma teórica. Considerando a relação negativa entre corrupção persistente e crescimento econômico, deve-se buscar formas de combater o fenômeno antes que se torne arraigado na sociedade. Para tanto, é necessário que a interação estratégica entre agentes públicos e privados seja atacada. Enquanto agentes privados se beneficiarem da corrupção no setor público, não há sinais de que se trate de uma falha de mercado que se autocorrige no longo prazo.

Palavras-chave: Corrupção. Dinâmica evolucionária. Crescimento econômico.

ABSTRACT

We present two essays where corruption is modeled as an evolutionary process and which investigate the evolution of corruption and its relation to economic growth, respectively. In the first essay, we propose an evolutionary approach to the dynamics of corruption based on pairwise strategic interactions among boundedly rational agents. We show that the thriving of public sector corruption demands the acceptance of private agents. In the second essay, we develop a dynamic growth model with productive public expenditure to study the impact of persistent corruption on capital accumulation, when both variables are endogenous and simultaneously determined. Our results suggest that, under certain circumstances, corruption negatively affects growth, and an equilibrium where both the corrupt and the non-corrupt strategy survive in the long run is reached, contingent on the economy's institutional set.

Keywords: Corruption. Evolutionary Games. Economic growth.

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1 INTRODUCTION

Transparency International, an organization of global reach based in Berlin with the purpose of promoting anti-corruption initiatives around the world, compiled a list of some of the biggest corruption scandals since its creation in 1993. The list includes episodes of public disclosure of bribes, embezzlement and fraud in governments and private companies in various countries, including Germany, Spain, Russia, Ukraine, Peru, Brazil, Venezuela, Nigeria and South Africa. (25 CORRUPTION..., 2019).

The Corruption Perceptions Index (CPI), published by Transparency International, measures a country's level of public sector corruption as perceived by experts and businesspeople, and it is widely used in empirical studies. The CPI attributes to each of 180 countries a score varying from 0 (highest level of corruption) to 100 (lowest level). According to the 2018's report, more than two-thirds of the countries scored less than 50, which indicates that corruption is widespread around the world, especially in emerging economies (CORRUPTION..., 2019). Furthermore, only 20 countries presented a substantial increase in their scores from 2012 to 2018, which points to an even more troubling truth: there is persistence of perceived corruption across and within countries, even if to varying degrees.

The problem of government authorities abusing their power to their own favor is not a novelty: Acemoglu and Verdier (1998) illustrate cases in the Soviet Union and in sub-Saharan Africa in the late twentieth century, Philp (1997) discusses a case in Australia by the end of the 1980s, and Bardhan (1997) even cites records in India that date back to the fourth century B.C. Even though very criticized, corruption seems to be, besides global, an enduring phenomenon.

If corruption is so negatively seen, why does it keep happening, making the headlines in news all around the world? Our conjecture is that corruption has costs and gains on which individuals base their decisions, producing a social outcome of endemic corruption. The main goal of this thesis is to model corruption as an evolutionary process and to investigate its relation to economic growth. We present two essays on this subject. In the first essay, we propose an evolutionary approach to the dynamics of corruption in a society, based on pairwise strategic interactions among boundedly rational agents, so as to capture the influence of society's aggregate behavior as perceived by individuals on their decision-making process. We show that the thriving of public sector corruption demands the acceptance of private agents, and attempts to eradicate corruption should be concerned with the strategic interaction between public and private agents.

In the second essay, we develop a dynamic growth model to study some macroeconomic consequences of corruption, most specifically its impact to capital accumulation, considering the feedback effect between corruption and the macroeconomic variables. An extensive body of research has already been developed in the literature, yet the theoretical investigation as to the consequences of corruption to economic growth when both variables are simultaneously and endogenously determined has not been widely explored so far. That is our goal with the second essay presented in this thesis. We model corruption as an evolutionary process and show that, under certain conditions, the economy may reach an equilibrium where corruption persists parallel to capital accumulation, despite the negative effects on growth. A noteworthy merit of the model is that these two phenomena co-evolve, so that reciprocal feedbacks between corruption and capital accumulation are taken into account.

The remainder of this thesis is structured as follows: in chapter 2, we discuss some issues concerning corruption, mainly its persistent condition and its relation to economic growth. In chapter 3, we present the thesis's first essay, in which we develop the evolutionary-game model of corruption to study its characteristics in the long run. In chapter 4, we present the thesis's second essay, in which we insert an evolutionary dynamics of corruption into a dynamic model of growth, to study some marcoeconomic consequences of corruption. Finally, chapter 5 concludes.

2 A REVIEW ON CORRUPTION

Our goal in this chapter is to present a broad review of issues concerning corruption, so that the reader can be acquainted with the current research on the topic and with the matter studied in this thesis.

First, we introduce the subject by presenting some approaches to studying corruption, notably, in the first section, the emphasis placed on institutions. We then discuss the phenomenon of corruption from an individual perspective in the second section, and as a social outcome in the third. The fourth section relates corruption to economic growth, and the fifth draws some final remarks.

It should be made clear that this chapter's purpose is to serve as an introduction to the models developed in each of the thesis's essays, thus not all of the topics exposed here will be further explored throughout the thesis. Notwithstanding, by the end of this chapter, we expect to have justified the evolutionary approach undertaken in this thesis, and to have motivated the investigation on the relationship between corruption and economic growth.

2.1 DEFINING AND MODELING CORRUPTION

The first task to those who intend to study corruption is to find a concise and unambiguous definition for this phenomenon. It is not a trivial job: the definition must be broadly accepted, and yet precise enough, so as to provide a well-delimited object of study. In general, we tend to turn to our personal judgements and view it as unequivocally wrong, or unfair, associating it to moral decadency. We must be aware, though, that these are not unequivocal concepts: they lie in the eyes of the beholder. As put by Przeworski (2018, p. 64),

> *When the government steals money from the public sector, as did the Brazilian Worker's Party (PT) from the state oil company, Petrobras, we think of it as corruption. But when parties are financed by private firms, as are the Brazilian opposition parties, we do not see it as such.*

Economists usually provide an objective definition, and refer to corruption as the misuse of public office for private gain (BARDHAN, 1997; JAIN, 2001; SVENSSON, 2005).

Relying on this definition narrows our object of study to illicit practices that involve the government. Illegal activities such as drug dealing, and fund embezzlement or fraud in private companies are excluded from the analysis, since they do not involve the public office directly (although their thriving may depend on public office corruption, at least in the form of turning a blind eye). Neither lobbying, nor private contributions to political campaigns, which may be thought of as unethical, or even the passing of a law by representatives that concerns their own salary increase, for instance, are considered corrupt activities, because they are within the law[1].

Jain (2001) states that corruption arises when there is the presence of a discretionary power, with economic rents associated to it, and a moderately weak legal or judicial system, such that the odds of detection of a corrupt act are uncertain. This means that corruption happens when an agent uses her decision-making power to appropriate rents to benefit a specific individual or group of people and she does not believe that the prevailing system of checks and balances is strong enough to deter her. The existence of economic rents adds an important condition to our previously presented definition. It excludes from our study the cases in which there aren't illegal financial transactions. This type of corruption may take the form of exchange of political favors, and, unless bribes are paid, it is difficult to identify. In contrast, bureaucratic corruption corresponds to corrupt acts performed by bureaucrats in their dealings with the public, which generally involve the payment of bribes.

Collier (2002) draws attention to the cultural relativity, that is, how the political culture may influence what citizens regard as a corrupt behavior: while in collectivist and individualistic societies nepotism is a standard procedure, it is of rare incidence in egalitarian cultures[2]. Only in the latter it is a consensus among the population that nepotism is a corrupt behavior that should be severely punished. The stealing or misuse of public resources by officials is regarded, though at varying degrees, as a punishable corrupt behavior in the three types of political culture.

Considering the difficulties of finding a clear-cut definition of corruption, not contingent on specific rules that vary with different legal systems, the most appropriate for this thesis is to treat corruption as the use of public office for the illegal pursuit of rents aimed at private gains. In each of the subsequent essays, we will narrow this definition a bit further, but in a broader sense, we attain ourselves to this type of corruption.

Having a concise definition for the phenomenon, modeling corruption comes naturally, or at least more effortlessly. Some scholars have set agency problems to study corruption, such as the models put forward by Rose-Ackerman (1975) and Acemoglu and Verdier (1998), where a bureaucrat is assigned to a task in which she may abuse her power and not deliver the expected outcome in exchange for personal financial gains. In the former paper, the bureaucrat is subject to bribes offered by firms that attempt to sell a service to the government or to win a government contract. In the latter, the bureaucrat who is supposed to enforce a contract between two parties may

[1] These examples are drawn here merely for illustration, since the exact account of legally defined corrupt activities varies with country: "[...] the same acts are legal in some countries and illegal in other systems - US political financing practices would constitute corruption in most democracies [...]" (PRZEWORSKI, 2018, p. 64).

[2] Collier (2002) defines collectivist political cultures as those where a ruling elite controls the political power, which is often inherited through family ties; individualistic cultures as those where politics is viewed as business and public officials serve the citizens because they expect to be adequately compensated for their effort; and egalitarian cultures as those which prioritize the public interest and well-being.

unfairly side with one of them to extract rents from the other. These studies focused on the consequences of corruption in specific frameworks.

However, prominent earlier papers were more concerned with the evolution of corruption in society and have focused on modeling markets for corruption. Lui (1986) provides a more general, two-period overlapping generations model in which bribes are offered to public officials, whose decision to accept them depends on their degree of honesty and on the probability of being audited. The overlapping generations' structure is important to incorporate a dynamical element into the model: an official will not accept any bribe in the future if she has been audited and punished in the present. Multiple stationary equilibria are presented as the outcome of model: one is associated to a low level of corruption, and the other to a high one. If the economy reaches the latter, say, because of a society too lenient towards corruption, or with a low average degree of honesty, it stays there as the government's deterrence effort becomes less effective.

Multiple equilibria also appear in Andvig and Moene's (1990) model. Contrasting with Lui (1986), the authors model both the supply and demand sides of corrupt services in the form of bribes, and find equilibria that depend on the distribution of intrinsic moral costs among bureaucrats, which act as a deterrent for accepting bribes. In the case of three equilibria, only the ones with the lowest and the highest levels of corruption are stable, which means that as the perceived fraction of corrupt individuals increases, so does the prevalence of corruption, such that the economy is trapped in a high corruption level.

Both works count on individual's subjective features: in Lui's (1986) paper, equilibrium selection depends on a parameter that represents the idiosyncratic degree of honesty each public official has; in Andvig and Moene's (1990), the distribution of intrinsic moral costs among bureaucrats determines the shape of the supply function of corrupt services and, consequently, how many equilibria there are. Subjective moral values are identified by these authors as relevant determinants for the incidence of corruption in a society. After all, even alleged market-based definitions of corruption rely on prior conceptions of public office and proper behavior which are external to the market structure, as claimed by Philp (1997).

More notably, in Andvig and Moene's (1990) model, the prevalence of corruption as perceived by individuals influences their decisions. This is so because, as Bardhan (2006) summarizes, the more frequent corruption is, the lower chances of being informed against face those who offer corrupt services, and the lower costs of finding an official willing to engage in an illicit deal face those who demand them. Equilibrium selection depends on coordination of expectations about people's behavior.

The coordination of expectations, in turn, relies on individual learning processes under given prevailing institutions (MANTZAVINOS; NORTH; SHARIQ, 2004). Therefore the findings of La Porta et al. (1999) that countries with common law origins (Britain and former colonies) are perceived to be less corrupt than those with civil law origins, and of Treisman (2000) that former British colonies are also perceived to be less corrupt than former colonies from other European countries. Both of these aspects are related to the history of a nation, to the creation, development and dissemination of its political institutions.

Institutions play a key role in determining the incidence of corruption in a society. They can be defined as a set of traditions, customs, norms, beliefs, or rules (formal or informal) that structure human behavior and social interaction (NORTH, 1991). According to Acemoglu and Robinson (2012), political institutions determine economic institutions, which shape the economic incentives individuals face. Besides, institutions are also important in establishing the punishments for deviant behavior, that act as “counter-incentives" for individuals. Having in mind a rational choice-theoretical framework, corruption can be viewed as a decision an individual makes for a given incentives and punishments structure, which is shaped by formal and informal institutions.

Should corruption be perceived as widespread by individuals, it might become an informal institution. Were this the case, corruption would be part of the prevailing culture in a society, in the sense put by Bardhan (2006), in that it would coordinate people’s expectations such that the economy might end up trapped in a high corruption equilibrium (as in Lui’s (1986) and Andvig and Moene’s (1990) models).

The persistence of corruption may also be explained by Acemoglu and Robinson (2012). According to them, extractive political and economic institutions[3] engender a vicious circle of inequality and poverty that aid to further strengthen these very same institutions and their extractive character. Widespread corruption, while an informal institution, is a highly extractive one, responsible for concentrating resources in the hands of few and for lowering economic growth, as will be discussed in the next sections. As such, it should come as no surprise that it may be entrenched in society, deeply rooted in the behavior of those who benefit from it.

Social interaction, in this case, would take its toll by disseminating corruption as an informal institution, working as a propagation mechanism. As put by Hellmann (2017), individuals are not “good" or “bad", just as they shall not be considered “corrupt" or “non-corrupt", as if these were characteristics inherent to them. Instead, their behavior toward corruption depends on their interactions with other individuals. As corruption spreads throughout society, it ceases to be a deviant behavior and, conversely, it becomes “[...] institutionalized as an informal system of norms and practices that shapes individuals’ strategic thinking and behavior" (HELLMANN, 2017, p. 148).

Dimant and Schulte (2016) argue in a similar fashion, justifying that “[...] a

[3] Acemoglu and Robinson (2012, p. 70-95) define extractive political institutions as those that are not centralized or pluralistic enough to form a strong state and balance political power among different sectors of society, and extractive economic institutions as those that do not provide a level playing field (by enforcing property rights or providing an unbiased system of law) that allows and encourages people to participate in economic activities as they wish.

rational decision-maker might end up engaging in seemingly irrational behavior [. . .]" (p. 14) because of the underlying social environment. According to the authors,

> *At an individual level, the rational-self reaches the decision to behave corruptly by simply weighing the expected costs against the expected benefits. In addition, the psychological assessment supports this decision because one observes peer behavior of the same kind, thus triggering behavioral conformity. The decision to engage in deviant behavior, however, might go against the norms, values, and moral virtues one was raised with, which could trigger the consideration of long-term consequences such behavior might have in terms of social welfare (DIMANT; SCHULTE, 2016, p. 30).*

This approach, defended by Hellmann (2017) and Dimant and Schulte (2016), acknowledges the important role of cultural aspects, such as reputation, as pointed by Bardhan (2006), in coordinating people's behavior.

This motivates our approach based on Evolutionary Games. We make use of Evolutionary Games because they can reproduce the evolution of a certain characteristic (corrupt) in a population. The relative frequency of corruption in a population measures the corrupt strategy's success rate. Furthermore, Evolutionary Game Theory implies that agents' rationality is bounded to some extent (VEGA-REDONDO, 1996, p. 3; SAMUELSON, 1997, p. 15). Agents have limited information about the environment in which they act, thus it "[. . .] is no wonder that we usually resort to certain relatively simple rules that, according to our past experience, have worked out reasonably well" (VEGA-REDONDO, 1996, p. 3). This corroborates the Mantzavinos, North and Shariq's (2004) idea of the individual learning process as an instrument for equilibrium selection.

That is precisely what we aim to achieve by proposing an evolutionary dynamics for corruption. Since corruption requires secrecy, agents are not certain about the payoff yielded from acting corruptly until they do so. Also, they don't have information *a priori* about other agents' behavior concerning corruption. They may even be ignorant as to the aggregate outcome, that is, the incidence of corruption in society. Rather, they must rely solely on their own perception. Agents are always boundedly rational in this context.

This approach is not new in the literature. Mishra (2006) develops a model to assess the persistence of corruption using Evolutionary Game Theory and shows that a low punishment for non-compliant behavior leads to a self-fulfilling belief that everybody engages in non-compliant behavior, so that corruption becomes the social norm and the only surviving strategy in the long run. Bicchieri and Rovelli (1995), in turn, argue that a corrupt equilibrium is evolutionarily unstable given the presence of irreducibly honest individuals along with cumulative social costs.

In the following section, we explore the determinants of corruption at an individual level and its relation to other deviant behaviors, mainly tax evasion. Then, we discuss the aggregate outcome of corruption and its relation to the macroeconomic environment, especially to growth.

2.2 CORRUPTION AS AN INDIVIDUAL DECISION

Corruption is, after all, a social concern. It stems, nonetheless, from individual decisions. The first equilibrium models of corruption have emphasized the individual decision-making aspect of it[4]. More recently, Accinelli and Carrera (2012) rely on this perspective and argue that the choice to be corrupt is derived from individuals' expectations about society's approval. They propose an evolutionary-game model where individuals choose to be corrupt or not by rationally imitating others. Specifically, each individual in the society reviews her strategy at a given rate and change it whenever it is rational to do so, that is, whenever the alternative strategy's payoff is higher than the current one's. In addition, in their framework, an individual may also change her strategy because she does not know the alternative expected payoff, but she is dissatisfied with her current payoff. As a result, corruption is extinguished only when non-corrupt individuals do not change their strategy, a state which the authors associate to the effectiveness of institutions in detecting and punishing corrupt activity.

If we are to consider corruption from the individual standpoint, we must understand the incentives and punishments structure. According to Jain (2001), the net utility of corruption to an agent depends on five main factors: the agent's legal income; her illegal income (earned from corrupt activity); the strength of political institutions; society's moral values; and the probability of detection and punishment.

Concerning the first two factors, the main incentive to act corruptly emerges from the very own possibility of financial gain. This potential gain, however, comes from an illicit activity, which must be kept under secrecy either to avoid detection from authorities or to avoid being shunned by peers from adopting a deviant behavior. It is natural, thus, that a corrupt agent keeps a “low profile" and avoids conspicuous consumption, in order to conceal her illegal income. Yet this additional income must be drained somehow. Unless it is directed to a relatively more productive activity (growth-inducing private capital investment, for instance), there will be less resources in the economy to be applied in productive expenses (infrastructure, education, health etc.).

A corrupt agent may direct her illicit income to a foreign economy (off-shore accounts or tax havens). This would be qualitatively similar to tax evasion, in terms of decreasing public revenue[5]. In this case, the corrupt agent who does not comply to declare or pay her due taxes may also have to bribe a tax inspector to turn a blind eye on the embezzlement. This tax inspector might just have to do the same thing, and it becomes clear the pernicious overall effect on economic growth of this vicious circle of

[4] See, for instance, Rose-Ackerman (1975), Lui (1986) and Andvig and Moene (1990).

[5] We can consider the case of a bureaucrat who embezzles public money and keeps it under her mattress or invests it in a foreign economy. Even though we are primarily concerned with public sector corruption, we can also think of a civil agent (not a public official) who fails to declare or to pay her taxes (her unreported income has the same destination as the bureaucrat's). Either way, there is a shortfall on domestic public budget.

corruption triggered by tax evasion.

Several studies relate tax evasion to corruption. Cerqueti and Coppier (2011) explore the effects of the interaction between fiscal evasion and corruptible tax inspectors in a Ramsey model of growth in which tax revenues are destined to the provision of a productive public good. An increase in the tax rate depresses growth through lower private capital accumulation. This effect, however, is more than compensated by the higher provision of the public good and by the increased number of evaders who are caught[6]. Therefore, growth is induced by public rather than by private investment.

These results concur with the model presented by Sanyal, Gang, and Goswami (2000), where an increase in the tax rate or in the monitoring effort may deteriorate public finances if the change is accompanied by a movement in the level of corruption in the same direction. Intuitively, when public officials view a higher tax rate as an opportunity to demand higher bribes for neglecting unreported income, it may lead to a decrease in government revenue. Presumably, there is a decrease in growth as well, unless the growth-reducing effect is counterbalanced by one in the opposite direction. Following Sanyal, Gang, and Goswami (2000), thus, under certain circumstances, tax evasion and corruption are directly related. In a country-level empirical comparison, less corrupt countries exhibit higher tax compliance (LA PORTA et al., 1999).

On the subject of tax evasion, Lorenz (2019) distinguishes illegal tax evasion from legal tax avoidance practiced by taxpayers who search for “loopholes" in complicated tax codes. He develops a model where taxpayers may incur costs, related to tax planning, in order to optimize the amount paid of taxes, and uses a replicator dynamics to show that there is a Nash equilibrium in which a share of taxpayers are optimizers and a share is not. In an extension to his model, he allows for taxpayers to play a third strategy, corresponding to illegal tax evasion, and shows that non-optimization is a strictly dominated strategy, thus becoming extinct over time (LORENZ, 2019).

Parallel to the incentives of engaging in corruption, lies the expected punishment faced by corruptible individuals. Naturally, it is a substantial determinant of an agent's behavior and, accordingly, of the aggregate level of corruption in an economy. Jain (2001) provides an extensive account on the subject, and Collier (2002), Bardhan (1997) and Dimant and Schulte (2016) expose the matter in a fashion that reinforces the approach adopted in this thesis. Usually, the expected punishment faced by an individual who engages in corrupt activity is a combination of the probability of being caught and the incurred financial penalty. Evidently, we can expect that the higher either of these elements are the less an individual will be willing to engage in corruption. Were an individual certain to be caught, it would not be rational to act illicitly, unless she has a chance of escaping punishment.

However, sometimes it is difficult (or costly) for the state to detect all corrupt

[6] In their model, the government's monitoring effort is endogenous and directly related to the tax rate.

activity so that it can guarantee the certainty of punishment. Basu, Basu, and Cordella (2016) suggest that asymmetric punishments can help to solve this problem. They develop a model where public officials demand bribes from entrepreneurs in exchange for delivering licenses[7], and introduce the possibility of whistle-blowing by the entrepreneur. It means that the entrepreneur can incur a cost to raise the probability of the public official being detected. Since monitoring is costly to the state, it would benefit from the denouncing of an illegal deal by one of the parts involved. The entrepreneur will denounce the official whenever the expected benefits of obtaining a license without paying a bribe are higher than the expected cost of paying a fine if detected and of reporting the deal. As a result, the authors show that charging a higher penalty from the official than from the entrepreneur (what they call as asymmetric punishment) can eliminate bribery when whistle-blowing is allowed for, provided that the cost of doing so is low enough and the entrepreneur's valuation of the license is not so high that it would pay for her to pay a bribe even if the probability of detection is high.

Similar reasoning is applied by Dufwenberg and Spagnolo (2015), who present a model where officials and entrepreneurs may demand/offer bribes for issuing/obtaining a license and entrepreneurs may costlessly report bribe-takers. They conclude that a radically asymmetric punishment (doubling the baseline fine for the bribe-taker and charging no fine at all from the bribe-giver) yields thriving results when players interact continuously. In one-sided repeated games where one official interacts with different entrepreneurs, reporting corruption is a dominant strategy for the latter. The former, thus, anticipates this behavior and issues the license without demanding a bribe, resulting in a first-best solution.

This outcome is sustained even when the authors extend their model to consider positive costs to the entrepreneur for reporting corruption, provided that these costs are lower than the bribes demanded. That is why the authors suggest that an asymmetric punishment policy such as the one proposed is more fruitful in contexts of large-scale corruption, when the size of the bribes are remarkably high, since it would more than offset the reporting costs and provide a stronger incentive for the entrepreneur to denounce the official (DUFWENBERG; SPAGNOLO, 2015).

Particularly, Dufwenberg and Spagnolo (2015) relate the costs the entrepreneur incurs for reporting corruption to the prevailing institutional set - they may be associated to "[. . .] time lost denouncing/testifying, marking banknotes or wiretapping the exchange" (p. 842). Therefore, law enforcement must be efficient in order to guarantee the benefits from an asymmetric punishment (DUFWENBERG; SPAGNOLO, 2015). Well-defined, solid institutions are imperative to keep the reporting costs low enough and strengthen anti-corruption measurements based on asymmetric punishment.

[7] The size of the bribe is set by a bargaining problem between the two parts, and the demand of bribes by officials requires the existence of a Nash bargaining solution.

Not only the legal penalty is taken into consideration by an agent facing the decision of engaging in corruption, but the social stigma may also play an important role in this choice. One distinguishing feature of the already cited Cerqueti and Coppier's (2011) model of tax evasion is the assumption that the objective value of the penalty faced by an entrepreneur when unreported income is detected is increased by a "shame cost", that is, a subjective value that depends on individual assessments about the public embarrassment of getting caught. Hence, the aggregate level of corruption in society varies according to the distribution of the shame costs throughout the population. Their model is not concerned, however, with the dynamics of corruption. Rather, they consider the level of corruption to be static.

Litina and Palivos (2016) develop a model where the citizens' tax evasion and the politicians' embezzlement reduce the quantity/quality of a public good depicted as public spending on education which raises labor productivity. The effects of an increase in the tax rate are also ambiguous: on the one hand, it stimulates citizens to evade taxation, which yields them utility by raising their level of consumption; on the other, it raises public spending on education, which also yields citizens utility, this time by increasing the amount of public good provided. However, Litina and Palivos (2016) emphasize that politicians' and citizens' misconducts interact and may be complement to each other. Particularly, the more prone to embezzlement are politicians, the more inclined to tax evasion are citizens. Corruption is contagious because "[...] the corrupt behavior of one group may become a strategic complement for another" (LITINA; PALIVOS, 2016, p. 165). According to the authors, this relationship should be tackled when thinking of policies that strive to eradicate corruption. The usual penalties, such as fines, are not successful, because "whenever agents expect other agents to be corrupt, they always find it optimal to be corrupt as well" (LITINA; PALIVOS, 2016, p. 165). This explains the persistence of corruption despite anti-corruption measures adopted by governments all over the world. In fact, the most effective policies should be those that address agents' subjective assessments and eliminate the reinforcement between different agents' deviant behaviors.

In an extension to their model, they include an individual cost they classify as social stigma, equivalent to a moral cost (or shame cost[8]) - the disutility an agent attains when being exposed to have broken the law. They find that when the social stigma is strong enough, the misconduct of one group ceases to be complementary to the other. Instead, they become substitutes: politicians respond to citizens' tax evasion by choosing to embezzle less, fearful of social reprehension. Individuals, in turn, are prompted by peer pressure to abide by the law. The social legitimization of corruption ceases to exist, and the sigmatization of the deviant behavior succeeds in coordinating expectations in the economy. Therefore, the most appropriate anti-corruption policies

8 Following the nomenclature used by Cerqueti and Coppier (2011).

should focus on increasing the moral cost inflicted upon dishonest individuals and highlighting compliance as a praiseworthy behavior (LITINA; PALIVOS, 2016).

Other ways to mitigate corruption have been advocated, like fostering competition among corrupt officials in the provision of the same service, as proposed by Shleifer and Vishny (1993, p. 607): “Because collusion between several agents is difficult, bribe competition between the providers will drive the level of bribes down to zero". This idea has been reiterated by Bardhan (2006, p. 345): “Quite often corruption is there because bureaucrats have a monopoly power [. . .]" over the provision of a public good or service.

Higher wages for bureaucrats have also been put forward as a means to avoid them to indulge in corruption (SVENSSON, 2005). This is the idea behind an efficiency wage policy in the public sector. If public officials are paid wages that are higher than the market-clearing level, they are less tempted to demand for/accept bribes or to embezzle public funds. Acemoglu and Verdier (1998), in a model designed to study the impact of corruption on investment and the allocation of talent, find that there is a trade-off between these two variables, since highly-skilled entrepreneurs may opt not to invest due to the wages practiced in the public sector, above market-clearing level. In spite of that, under certain circumstances, there may be a case of “free-lunch", where an increase in the public sector wage induces better enforcement of property rights, which makes the private sector more profitable, and there is less misallocation of talent.

In view of what has been argued, it is clear that the traditional decision-making theory cannot be discarded when trying to identify the causes for individuals to engage in corruption. Individuals compare the expected benefits against the expected costs of their actions and adopt the behavior that yields them the greatest utility.

Nevertheless, differently from the early purely economic analyses of corruption, individuals’ subjective assessments are equally important. A comprehensive analysis has to ponder the moral costs inflicted in individuals who adopt deviant behaviors. Society can ostracize those who do not fit in the conventional behavior pattern, and this may represent a harmful intrinsic punishment for those individuals. Therefore, in addition to the usual costs and benefits customary to the economic analysis, the peer pressure plays a role in reaching an aggregate outcome of corruption.

Formal and informal institutions are essential in this context because they define not only the legal penalties but also the intrinsic costs associated to drifting from socially tolerated behavior. An attempt to study corruption from this perspective has to retain the individual choice theoretical structure in line with the social background, where interactions take place following socially established norms. This is what we aim to do with the aid of Evolutionary Game Theory.

2.3 CORRUPTION AS A SOCIAL OUTCOME

A country's aggregate level of corruption emerges from each individual's decision. Corruption as a social outcome impacts a nation's economic and political environment. Much effort has been directed to studying the causes for the emergence, persistence and consequences of corruption based on country-level differentials. In the aforementioned Acemoglu and Verdier's (1998) model, for instance, corruption is put forward as an individual-driven action which, collectively, leads to the undermining of institutions, their consequent failure to protect property rights, and a loss of efficiency in the economy.

Considering corruption at a macroeconomic level, scholars have studied the relationship between corruption and politics. Using Acemoglu and Robinson's (2012) nomenclature, corruption belongs to the realm of extractive political institutions. Democracy, in turn, is on the opposite side. Empirical results suggest that more democratic countries present lower levels of corruption (GOEL; NELSON, 2010). Moreover, Treisman (2000) argues that it does not matter whether the country is a democracy today, but for how long it has uninterruptedly been so: out of a sample of 85 countries, using the 1998 Corruption Perception Index, he finds that only countries which have been democracies for at least 40 consecutive years enjoyed a significant albeit small benefit in its perceived corruption. Treisman (2000) associates it to the risk a politician faces of not being fairly elected. In a broader sense, it is related to a public official's degree of accountability towards its actions.

According to Przeworski (2018, p. 98), voting is "[. . .] a mechanism of control over public bureaucracies" because it holds incumbent officials accountable for their actions. An elected government should fear not being reelected if caught engaging in corrupt practices. Empirical evidence is provided by Ferraz and Finan (2011). Using data from audit reports for Brazilian municipalities, the authors find that mayors with reelection incentives misappropriate 27% fewer resources than those without such incentives, suggesting that an electoral process that accomplishes increasing officials' accountability is a compelling reason for public bureaucracy to obey citizens' bidding.

Supporting this idea, the empirical results presented by Lederman, Loayza, and Soares (2005) suggest that transferring resources from central to local governments reduces the incidence of corruption, due to the greater accountability held by local spheres, from being closer to citizens. Lederman, Loayza and Soares's (2005) results also indicate that a greater size of the state increases the incidence of corruption, which is endorsed by the works of Goel and Nelson (2010), who argue that a greater presence of the state, specifically in the regulatory area, is associated to greater opportunities for rent-seeking behavior to arise, hence to more corruption.

It should be evident by now that political institutions contribute to determining the incidence of corruption in a society, but the media sector plays a crucial role as well. In order to steer clear of corruption, it is imperative that any misdeeds carried out by public officials come up. While democratic institutions guarantee fair open elections, which reduce the chances of the population voting for an exposed corrupt politician, an impartial press free of government pressure is necessary so that society is perfectly informed (or as much as it can be) about misdeeds practiced by legislators, rulers, officials and other public authorities. In Ferraz and Finan's (2011) study, greater access to information is related to greater political accountability and less corruption.

This idea is complemented by Kalenborn and Lessmann (2013), who study the interaction between democracy and press freedom and conclude that, concerning their effects on reducing corruption, both variables are conditional on each other. Only being able to identify a corrupt politician does not necessarily reduce corruption, since the population must rely on democratic institutions to vote the politician out of office. Once again, this emphasizes public vote as the ultimate mechanism imposing constraints on public officials' actions. On the other hand, not counting on a free press does not reduce the information asymmetry between voters and candidates, so the corruption level may be persistently high even in a democratic regime. In Kalenborn and Lessmann's (2013) study, surprisingly, the corruption level may increase if measures aimed towards higher democratization are adopted in countries where the media is not free enough, pointing to a potentially harmful effect of democracy in the fight against corruption. That is why the authors suggest that a media liberalization must come before democratic reforms as an instrument in controlling corruption.

Relating to this subject, we must accredit the study of Iwasaki and Suzuki (2012) for gathering the issues of democratization, liberalization and decentralization in an attempt to comprehend why former socialist countries exhibit substantially greater levels of corruption than the world trend. Using panel data for 32 former socialist countries, the authors find that the promotion of "marketization", rule of law, and democratization, which are central aspects to the capitalist system, helps to reduce corrupt activity in transition economies. "Marketization" unavoidably consists of a higher degree of trade openness and of economic freedom, reducing the size of the state, while the rule of law limits the arbitrary abuse of power, enhances the credibility of punishment, and ensures property rights. Democratization, in turn, guarantees fair open elections.

Corruption, in the communist regime, was perceived as a "necessary evil", required to overcome supply shortages and excessive bureaucracy (IWASAKI; SUZUKI, 2012). The passage to capitalist economies, therefore, demands more than political measures and public policies. It includes an essential change in the way of thinking of society, a change in the minds of the citizens. This is related to the authors' evidence for a historical path-dependency: the longer has been a country's exposure to the communist regime, the more pervasive is current corruption, thus the harder it is to fight it (IWASAKI; SUZUKI, 2012). Once it has already been established as a common practice, only a long process of cultural adjustment can overturn the situation, which endorses the idea that democracy reduces corruption at a slow pace (TREISMAN, 2000).

Democracy, economic and political liberalization, government decentralization, and press freedom are some elements that undermine the foundations of corruption. The public bureaucracy which is willing to misuse its authority in favor of its own private gains should struggle with such mechanisms that increase political accountability. That is why, following Acemoglu and Robinson's (2012) reasoning, corrupt governments form extractive political institutions, which tend to create extractive economic institutions. As a matter of fact, corruption and economic growth are, indeed, connected. We devote the next section to this issue, which is the subject of the second essay presented in this thesis.

2.4 CORRUPTION AND ECONOMIC GROWTH

The research on the relationship between corruption and economic growth goes way back. It has been studied for at least 20 years, since Mauro's (1995) pioneer empirical inquiry on the impact of bureaucratic efficiency and political stability on per capita GDP for 67 countries. He finds that corruption negatively affects investment and growth, based on the view that an efficient bureaucracy (political stability, strong legal system, absence of red tape) is necessary to secure private investment. Corruption rooted in red tape (excessive bureaucracy), for instance, would promote delays in granting permits or delivering licenses. It would reduce the marginal product of capital and thus the investment rate, which would dampen economic growth.

Some while before Mauro's (1995) publication, much controversy had emerged from the paper presented by Leff (1964), who argued that, in theory, corruption might positively affect growth due to the rigid laws and cumbersome procedures that curb bureaucracy. Corruption would "get things done" in an economy governed by a lagging public sector overwhelmed with red tape. This idea was endorsed by Lui's (1985) queuing model, in which customers are allowed to pay bribes to public officials in order to get better positions in a queue. In a framework where each customer chooses a strategy according to each one's value of time, whereas officials choose the optimal speed of service aiming at maximizing bribe revenue, Lui (1985) shows that bribery may reduce the time spent in queues. This is because receiving a bribe may encourage a bureaucrat to speed up the process of providing a public service, thus corruption would function as "grease in the wheels" of the economy. Corruption would compensate for the distortions caused by the poor institutional framework.

Notwithstanding, empirical attempts have failed to corroborate this hypothesis. As already mentioned, in a seminal paper, Mauro (1995) empirically studies the relationship between corruption and growth using cross-section data for 67 countries, and finds that corruption negatively affects growth by reducing private investment, due to poor enforcement of property rights. Later on, Mo (2001) reinforced this hypothesis using panel data for 46 countries from 1970 to 1985, and showed that a 1% increase in the corruption level reduces the growth rate by 0.72%, mainly through political instability, although human capital and private investment are also relevant channels[9].

The human capital channel is explained by a decrease in the rate of return of productive activities (that increase human capital) faster than that of rent-seeking activities; corruption diverges resources from the productive to the unproductive sector. The political instability channel, in turn, is explained by the relationship between corruption and income inequality: since corruption tends to maintain wealth in the hands of few, the lower classes, forsaken from the distribution process, react violently, increasing uncertainty in investment and in the power of the state to enforce property rights. According to Mo (2001), this is the most important channel, accounting for 53% of the overall deleterious effect of corruption on growth.

Enthusiasts of the "grease in the wheels" hypothesis have tried to prove its validity under specific circumstances. Swaleheen and Stansel (2007) claimed that corruption is beneficial to economic growth when public officials loosen restrictions on firms' activities, that is, when it improves aggregate efficiency[10]. Likewise, Méon and Weill (2010) argue that "[. . .] corruption is less detrimental in countries where the rest of the institutional framework is weaker" (p. 248). In these countries, corruption would circumvent poor governance and grease the wheels of the economy. However, Méon and Weill's (2010) result also concern the impact of corruption on aggregate efficiency (productivity), and not on income or capital accumulation.

By now, there is a consensus that corruption is inimical to growth, as defended by contemporary researchers (SVENSSON, 2005). Although it may bring positive results in theory, corruption is, as most of the empirical evidence suggest, harmful to capital accumulation and economic growth: it acts as sand rather than grease in the wheels of the economy. Resorting once again to Acemoglu and Robinson (2012), corruption would play the role of an extractive political institution and foster extractive economic institutions, by concentrating power and wealth in the hands of few at the expense of many. Fighting corruption, thus, would breed a less hostile environment for investment. Swaleheen (2012) furthers the discussion and argue that it is not that straightforward: in fact, "growth responds to lower corruption *only* if the fall in corruption is part of a declining trend" (p. 257). Therefore, if the goal is to promote investment and growth, the fight against corruption must be incessant and prolonged.

Moreover, Treisman's (2000) work holds that economic development reduces

[9] In Mo's (2001) study, "The measure of political instability is the average number of assassinations per million population per year and the number of revolutions per year over the period" (p. 70); and human capital is proxied by "schooling years in the total population over age 25" (p. 71).

[10] This seems a little counterintuitive, though, since liberalizing the economy would reduce corruption in the public sector. It seems unlikely that corrupt agents would act in favor of exhausting their source of extra income.

corruption, and Gundlach and Paldam (2009), using instrumental variables based on prehistoric measures of biogeography[11] for countries' income levels, also point that the long-run causality is from income to corruption. We can reckon there is a two-way relationship between the two, which is endorsed by Acemoglu and Robinson (2012) as well: extractive institutions "[...] create a powerful process of negative feedback, with extractive political institutions forging extractive economic institutions, which in turn create the basis for the persistence of extractive political institutions" (ACEMOGLU; ROBINSON, 2012, p. 365). After all, as stated by Jain (2001), most macroeconomic variables are determined simultaneously with corruption. We aim to explore this interaction in our growth model.

An important aspect we should have in mind, thus, is that corruption actively determines a country's growth rate, as well as responds to it. Furthermore, it is persistent. Corruption has become an endemic phenomenon, lingering parallel to capital accumulation and economic development. The investigation of the impacts and the channels through which corruption affects growth when both variables are endogenous is still incipient in the existing literature. Recently, however, researchers have dedicated effort in this direction and important results have been achieved. Next, we outline some of these, in an attempt to acknowledge their merits and for comparison to our work.

Barreto (2000) develops a formal endogenous growth model where the government acts as a monopolist providing public goods and services to be used in the production process. Bureaucrats attempt to extract the rents associated to the public monopoly by choosing to provide a suboptimal level of public good for a given expected punishment, while private agents have to provide the remaining capital stock to private production. This leads to the persistence of corruption in line with economic growth. In his model, corruption has distributional effects, as bureaucrats are able to extract some of the public monopoly's rents to themselves, and, consequently, corruption negatively affects the economy's growth rate.

Blackburn and Forgues-Puccio (2007), in turn, build a framework where high-income households may bribe corruptible bureaucrats, who are responsible for transferring resources from high- to low-income households, through taxes and subsidies, in order to conceal part of their income from the government. Bribery and tax evasion, thus, are both possible deleterious forces to growth and equality. The outcome is that, invariably, corruption increases income inequality as the redistribution policy loses its power: while all low-income households are worse off, only some high-income households are, namely those who are caught acting corruptly. Corruption widens the gap between the poorest and the richest.

[11] These are: "the number of domesticable big mammals in prehistory and the number of domesticable wild grasses in prehistory" (p. 148) as measures of biology; and "climatic conditions favorable for agriculture, latitude, relative East-West orientation, and size of landmass to which a country belongs" (p. 148) as measures of geography.

As to the interaction between corruption and growth, the result presented by Blackburn and Forgues-Puccio (2007) is that the former is damaging to the latter. Their model yields multiple equilibria: there is a certain level of capital below which corruption exists, associated with high inequality and low economic activity, and above which corruption is extinguished, since higher levels of capital correspond to higher wages and, consequently, higher costs for the exposed corrupt bureaucrat up to prohibitive levels. The low-corruption equilibrium is associated with low inequality and high economic activity.

This reiterates the qualitative results found by Blackburn, Bose, and Haque (2006) regarding the two-way negative relationship between corruption and growth in a dynamic neoclassical growth model built under similar conditions. Again, two equilibria are identifiable, namely one with high development and low corruption, where high levels of aggregate income indicate that agents have more to lose if they are caught engaging in corrupt practices; and another with low development and high corruption, where potentially productive resources are diverted for the costly concealment of bribery by bureaucrats. The incidence and persistence of corruption in some economies, according to the authors, is due to “the deep parameters describing preferences and technologies, together with the initial conditions" (p. 2451-2). Therefore, countries that reach the latter equilibrium might find themselves trapped in a situation of high incidence of corruption feeding back low growth rates.

An overlapping generations’ structure similar to Blackburn and Forgues-Puccio’s (2007) is used by Lin and Zhang (2009), in a model where corrupt public officials illicitly earn some additional income from part of individuals’ and firms’ taxes. Different types of corruption are analysed in three different channels through which it affects capital accumulation.

Specifically, they model corruption in the labor market, as workers pay bribes to public officials, which play the role of an entrance fee to the labor market in their first period of life. Corruption in the capital market takes place as former workers are retired and must pay bribes to public officials in order to convert their savings into productive capital. Finally, public officials may as well embezzle directly from public funds financed by taxes collected from the private sector workers and used for spending on infrastructure. Analysing corruption on each market separately, Lin and Zhang (2009) come to the conclusion that an increase in corruption in infrastructure development decreases the rate of return on capital, hence the capital-labor ratio and the wage rate as well. If the resulting decrease in workers’ savings is sufficiently large, then capital accumulation will be reduced. Despite corruption both in the capital and labor markets having come from ordinary workers’ labor income, the channels through which they affect capital accumulation are quite unalike: whereas the former’s consequence is an increase in the interest rate, the latter’s depends on the elasticity of labor supply. Either way, both cases lead to a reduction in capital accumulation.

A Ramsey-type model of growth is developed by Ellis and Fender (2006), where they put forward the provision of a public good by the government as a means for tackling a market failure as well as an opportunity for bureaucrats to divert resources for their own private gain. They assume a time lag in public capital production such that it is not known until later periods whether the government has invested tax revenues or has merely consumed them. It is taken to be the degree of transparency in the fiscal system, or the quality of institutions. Differently from the other papers already mentioned, they focus on the share of corruption in total output, in collected taxes and in total consumption in the steady state. This way, they provide a measure of how much of the economy's total production is devoted to corruption, how much is stolen from the government's revenue, and how much of the embezzled resources is converted into consumption, respectively. All of these measures are decreasing in the level of transparency/quality of institutions in the economy.

Another distinguishing feature in Ellis and Fender's (2006) approach is the possibility of corruption draining out the total amount of tax revenues up until being detected: due to the time lag in public capital production, "[. . .] a government may, for example, steal everything for two years before being overthrown in some manner, or, it may make smaller payments over the infinite horizon and remain in power" (p. 117). This yields the existence of "an irreducible level of corruption", which fosters competition between potential governments in the offer of different time paths of consumption and utility to private agents.

Finally, Wagner (2017) must be mentioned as the inspirational cornerstone of this work. She inserts an evolutionary dynamics of corruption into a Solow-Swan model of growth with productive public expenditure. In her framework, corrupt and non-corrupt individuals continuously interact amid themselves and change their behavior whenever the alternative strategy's payoff is higher than their current payoff. This leads to multiple equilibria as well, where the economy's growth rate is inversely related to the level of corruption prevailing in society.

An extensive body of research has already been developed in the literature, yet the theoretical investigation as to the consequences of corruption to economic growth when both variables are simultaneously and endogenously determined has not been widely explored so far. That is our goal with the second essay presented in this thesis. We develop a model to study some macroeconomic consequences of corruption, most notably its impact to capital accumulation and to the economy's growth rate, considering the feedback effect between corruption and the macroeconomic variables.

2.5 CONTRIBUTION TO THE LITERATURE

When studying corruption, we have to keep in mind that additional income is the essential incentive an individual has to act corruptly. Nevertheless, the prevalence and persistence of corruption in a society is highly contingent on cultural and moral values. Therefore, an adequate framework for studying corruption should preferably link the incentives at the individual level to the institutional constraints.

Institutions play an important role in properly punishing deviant behavior and preventing it to happen, through pecuniary means or through the shame effect inflicted in a corrupt individual by peer pressure. The fight against corruption involves the greater liberalization and decentralization of the economy, as well as an increasingly free press and an uninterrupted democratic regime. Most importantly, it relies on institutional reforms that aim to the enforcement of property rights and the consequent stimulus to investment. Corruption may be persistent precisely due to inefficient institutions, up to the point where it becomes a social norm instead of a deviant behavior. Social interaction may be regarded as the channel that disseminates cultural and moral values throughout society and coordinate people's behavior.

The first essay is drawn upon a framework where corruption is modeled as an evolutionary process which is able to produce a situation of multiple equilibria as in Mishra (2006) and Accinelli and Carrera (2012). In our first essay's context, equilibrium selection depends on how individuals perceive the prevalence of corruption in society: the more they see it as widespread, the greater are the chances that they will effectively engage in corrupt activity, because they believe they will not deviate from conventional behavior. As in Wagner (2017), the dynamics presented here is based on interactions between boundedly rational individuals. Nonetheless, in contrast to Mishra's (2006), Accinelli and Carrera's (2012) and Wagner's (2017) frameworks, in ours the interaction takes place between individuals belonging to two different populations, each facing different incentives and costs on their decisions. By differing the population of private producers from that of public officials, we expect to achieve our goal of showing that public sector corruption may benefit some private producers and shed light on the relation between bribery and tax evasion.

Last but not least, corruption is understood to be negatively related to economic growth in a two-way causal relationship. Attempts to study the interaction of both variables must take into account that they are endogenous and simultaneously determined. This is a distinguishing feature of our work. In our second essay, corruption and capital accumulation co-evolve, so that reciprocal feedbacks between these two variables are taken into account. This has already been done by Wagner (2017), however in a different framework. Our work is based upon a microfounded growth model, which is more consistent with an evolutionary dynamics of corruption based on a satisficing choice protocol, as is the case.

We believe our work contributes to the literature by showing that a simple structure that takes into account reciprocal feedbacks between corruption and capital accumulation may reproduce the empirical evidence provided by Mauro (1995), Treisman (2000), Mo (2001) and Svensson (2005). Comparing our paper to other theoretical works, Lin and Zhang (2009) treat corruption as a variable exogenous to their model, and though Barreto (2000) and Ellis and Fender (2006) consider both corruption and the growth rate as endogenous, these are not simultaneously determined, preventing a feedback from the former to the latter variable. Both Blackburn, Bose, and Haque (2006) and Blackburn and Forgues-Puccio (2007) miss the possible effects of social interaction and of an individual's potential change of strategy: a bureaucrat who is once corrupt will always be so. In contrast, we do not consider individuals as intrinsically corrupt or honest. Instead, they act as agents with bounded rationality, who may opt for the alternative strategy whenever its expected gain offsets its expected loss.

3 IT TAKES TWO TO TANGO: THE EVOLUTIONARY PERSISTENCE OF CORRUPTION

In order to study the dynamics of corruption in a society, we use an approach based on Evolutionary Games to develop a dynamic model of corruption that aims to depict its persistence in the long run. We expect to show that the interaction between a population of private agents and one of public officials, both made of potentially corruptible individuals, allows for the enduring condition of corruption, implying that public sector corruption thrives in the long run because it hinges on the acceptance, or at least tolerance, of a part of society towards it: the part of private producers who benefit from public corruption.

In this context, the gains and costs of corruption are endogenous to the proportion of corruptible agents in society, thus the choice of an individual to engage in corrupt activities depends on how prevalent they are. Strategic interaction between the agents determines an individual's choice. This justifies our approach based on Evolutionary Games, in which individuals select strategies according to their success in the corresponding population. In our model, social interaction determines the path corruption will follow in the long run.

The main concern of this essay has already been addressed by Wagner (2017), who developed an evolutionary dynamics for a population of corrupt individuals that led to a stable polymorphic equilibrium. Accinelli and Carrera (2012) have proposed an evolutionary-game model as well, where individuals choose to be corrupt or not by rationally imitating others. Specifically, every individual in the society reviews her strategy at a given rate and change it whenever it is rational to do so, that is, whenever the alternative's strategy payoff is higher than the current one's. In addition, in their framework, an individual may also change her strategy because she does not know the alternative expected payoff, but she is dissatisfied with her current payoff. As a result, corruption is extinguished only when non-corrupt individuals do not change their strategy, a state which the authors associate to the effectiveness of institutions in detecting and punishing corrupt activity. In contrast, Bicchieri and Rovelli (1995) argue that a corrupt equilibrium is evolutionarily unstable given the presence of irreducibly honest individuals along with cumulative social costs. Persistent corruption also appears in Mishra's (2006) model, where a low punishment for non-compliant behavior leads to a self-fulfilling belief that everybody engages in non-compliant behavior, so that corruption becomes the social norm and the only surviving strategy in the long run.

The model presented in this essay is also based on individuals choosing their strategies according to the incentives and punishments they face, which are determined by society's institutional set. The incidence of corruption depends on the success of this strategy, so that institutional corruption may arise once it is not regarded as the deviant behavior, such as in Accinelli and Carrera (2012).

However, we present two significant novelties: we do not view individuals as corrupt or not, as if it were an intrinsic characteristic to them. Instead, we believe all individuals are potentially subject to adopt a corrupt behavior in a given situation. At a given period, each individual adopts an abiding or a non-abiding behavior according to a boundedly rational decision, which is reassessed in the next period, and so on.

As reminded by Jain (2001), for corruption to come about, there has to exist the presence of a discretionary power, with economic rents associated to it, and a relatively weak legal or judicial system, such that the odds of detection of a corrupt activity are uncertain. In our model, public officials exert discretionary power by auditing private producers. Public sector corruption is the subject of this thesis, hence the decision to explicitly introduce a population that represents the public sector. Corruption comes about only when private agents willing to adopt a non-abiding behavior interact with public ones who are prone to adopt the same type of behavior.

In spite of some limitations, we believe our model provides valuable insights that contribute to the literature that studies the evolution and persistence of corruption in society, and to its determent instruments. We show there exists a unique long-run equilibrium where a fraction of society that adopts a non-abiding behavior coexists with a fraction that adopts an abiding behavior. This equilibrium, however, is evolutionarily unstable, and equilibrium selection depends on the expected punishments to each population.

Apart from this brief introduction, this essay contains four other sections. The first presents the model's structure in the short run; while the second derives an evolutionary dynamics; the third studies properties of the equilibria found; and the last concludes.

3.1 THE MODEL'S STRUCTURE IN THE SHORT RUN

We assume there are $n \in \mathbb{N}$ individuals in the economy that behave as producers, maximizing gross profit as in a Cournot oligopoly. They behave homogeneously in all respects except as far as trying to evade taxation, as will be explained. In the short run, quantities and prices adjust to reach the market equilibrium according to producers' decision. Producers face an inverse linear market demand of the form

$$p(Q) = a - bQ, \tag{3.1}$$

where a and b are strictly positive parametric constants, $p(Q)$ is the market price, assumed to be strictly positive, $Q = \sum_{i=1}^{n} q_i$, and q_i is producer i's demanded quantity.

We assume the absence of fixed costs of production, but that each producer incurs a linear variable cost proportional to the quantity produced. Therefore, producer i faces a total cost function given by:

$$C(q_i) = cq_i, \tag{3.2}$$

where $c \in (0, a) \subset \mathbb{R}$ is the producer i's constant marginal cost.

From (3.1) and (3.2), the i-th producer's objective function is given by:

$$\pi_i = (a - bQ - c)q_i. \tag{3.3}$$

Each period, the representative producer i maximizes gross profit choosing the quantity produced while considering the expectation on other producers' decision on quantities. Therefore, given (3.3), producer i's best-response function is

$$q_i^* = \frac{a - bQ_{-i} - c}{2b}, \tag{3.4}$$

where Q_{-i} is the sum of all producers' quantities except from producer i.

Given that $q_i^* = q_j^*$ in the symmetric equilibrium, we can obtain the quantity each producer supplies in equilibrium from (3.4) as follows:

$$q^* = \frac{a - c}{b(n+1)}. \tag{3.5}$$

Normalizing n to one, we can rewrite (3.5) as follows:

$$q^* = \frac{a - c}{2b}, \tag{3.6}$$

which is identical to the total quantity produced in the short-run Cournot equilibrium:

$$Q = nq^* = q^*. \tag{3.7}$$

Substituting (3.6) into (3.1) yields the following gross profit function:

$$\pi^* = \frac{(a - c)^2}{4b}, \tag{3.8}$$

which is the same for all producers in the economy. Even though we have assumed that producers engage in a Cournot oligopoly game, the remaining of the exposition does not need to be based on this structure. It suffices that each producer earns a strictly positive gross profit, which we may assume to be exogenously determined.

We assume taxes are collected from reported gross profits. Since all producers face the same demand and total cost functions, they expect the same behavior from their rivals with respect to production decisions (price and quantity). Nonetheless, payoff differentials among producers may arise due to the heterogeneity in abidance behavior: some producers may try to evade part of the taxes owed by underreporting taxable gross profit, and may end up earning higher net profits than those who fully abide by the law.

The government, thus, faces a monitoring problem with respect to the private sector. It observes only the amount of taxes collected, but not each individual's reported income. Due to the willingness of some individuals to adopt a non-abiding behavior, effective tax revenue may be lower than the expected value, so the government instates a bureaucracy responsible for, each period, curbing tax evasion. The designated bureaucrats work as tax auditors, who are required to investigate which producers are trying to evade taxation and, if that is the case, punish them. This occurs, each period, before taxes are collected, which means that, if effective tax revenue is indeed lower than expected, there are tax auditors who are not fulfilling their duties. We assume one bureaucrat audits only one producer, and one producer is audited by only one bureaucrat. An auditor does not know which strategy was adopted by each producer until she audits them. An auditor who meets a tax evader may herself be prone to adopt a non-abiding behavior. If she does so, she looks the other way and does not report the evasion, in exchange for accepting a bribe from the evader.

In our model, the abidance decision occurs subsequent to the production decision. Hence, possible payoff differentials among producers are not inconsistent with the assumption that producers behave alike in the short-run Cournot oligopoly game, facing identical best-response functions, supplying the same quantity at the same price, and earning similar gross profit.

3.1.1 Producers' payoffs

Let us recall that taxes are levied on producers' gross profit, which is shown in expression (3.8). Producers willing to abide by the law are those that adopt an abiding behavior toward their fiscal duties and play the non-corrupt strategy. Using (3.8), the payoff of this type of producer, identified by the subscript *np*, is expressed as follows:

$$\pi_{np} = (1-\tau)\pi^*, \tag{3.9}$$

where $\tau \in (0,1) \subset \mathbb{R}$ is the exogenously given tax rate.

However, a producer may opt not to abide by the law and not report part of the profit earned. Producers who are willing to adopt a non-abiding behavior are those that play the corrupt strategy. The net profit for this type of producer can be expressed as:

$$(1-\tau\alpha)\pi^*, \tag{3.10}$$

where $\alpha \in (0,1) \subset \mathbb{R}$ is the fraction of the producer's gross profit that is reported as taxable, assumed to be exogenously determined. Notice, from (3.10), that a producer who adopts a non-abiding behavior never decides to evade the whole amount of due taxes, even though there is always a fraction that is underreported.

When the government detects the occurrence of corruption, it instates auditors to audit all producers in the economy. We assume that at a given period, each producer is audited only once (and this is known by the whole population of producers), by an auditor who may or may not accept a bribe. The producer, thus, faces a lottery in which, on the one hand, she may duly abide by the law and not evade taxation; on the other, she may engage in tax evasion and hope to be audited by an auditor who is prone to accepting bribes.

Let $y \in [0,1] \subset \mathbb{R}$ the proportion of those who are prone to accepting bribes and thus choose the corrupt strategy, and $1-y$ the proportion of those auditors disinclined to accepting bribes and thus choose the non-corrupt strategy.

A producer willing to adopt the non-abiding behavior, thus, faces a probability y of being audited by an auditor who is also willing not to comply with the law, and a probability $1-y$ otherwise. If the former situation takes place, then the producer observes the auditor's type and will bribe the auditor for not denouncing the evaded taxes. We assume both agents collude and equally split the embezzled share of the producer's net profit[1]. Each one of them, hence, earns the same amount from the evaded taxes, given by $\frac{(1-\alpha)\tau\pi^*}{2}$. In other words, the auditor and the producer split the part of the unreported profit that belongs to the government. Conversely, if the producer who adopts the non-abiding behavior is audited by a law-abiding auditor, then the former is punished with certainty, paying $\delta\pi^*$, where $\delta \in (0,1] \subset \mathbb{R}$ represents the fine which the producer incurs if caught trying to evade taxation by an auditor who adopts an abiding behavior. Therefore, the expected payoff of the producer who plays the corrupt strategy, identified by the subscript *cp*, can be expressed as:

$$\pi_{cp} = y\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^* + (1-y)(1-\delta)\pi^*, \tag{3.11}$$

Suppose that no auditor is willing to accept a bribe, $y=0$, so that the producer who adopts a non-abiding behavior is punished with certainty. From (3.11), notice that, if $\delta = 1$, then this producer's expected payoff is null, because the whole gross profit earned in one period is forfeited as penalty. Hence δ can be an instrument used by the government to deter tax evasion.

Suppose, now, that corruption is widespread in the public sector, $y=1$, such that every auditor accepts a bribe offered by a producer who engages in tax evasion. Notice, from (3.11), that evading taxes will always pay for the producer, because the corrupt strategy's payoff is higher than that of the non-corrupt, since $\alpha \in (0,1) \subset \mathbb{R}$. Therefore, if the producer believes she is audited by an auditor who is certainly willing to adopt a non-abiding behavior, the former will always not report part of its profit, despite having to split its net income with the latter.

Expressions (3.10) and (3.11) represent the payoffs for each of the producers' behavioral strategy, which are crucial to their decision in the lottery concerning law-abidance. They will be recaptured later, but for now we must analyze the auditors' relevant strategies.

[1] It could also be the case that the agents ensue a Nash bargaining process, as in Basu, Basu, and Cordella (2016). For convenience, we steer clear of modeling such bargaining.

3.1.2 Tax auditors' payoffs

The government faces a monitoring problem with respect to the private sector, so it instates a bureaucracy responsible for curbing tax evasion, at the only cost of the wage of its employees. We assume all auditors receive the same strictly positive real wage, $w \in \mathbb{R}_{++}$, which is the sole earning of an auditor who is not willing to accept bribes from producers and thus adopts an abiding behavior. The payoff for this auditor, who plays the non-corrupt strategy, identified by the subscript *na*, is given by:

$$\pi_{na} = w. \tag{3.12}$$

When an auditor prone to adopt the abiding behavior audits a producer who engages in tax evasion, the latter is charged with the corresponding fine. Nonetheless, an auditor who is willing to accept a bribe from the evader may earn, in addition to her wage, half of the producer's evaded taxes[2].

Let $x \in [0,1] \subset \mathbb{R}$ be the proportion of producers in the corresponding population who are willing to engage in tax evasion in a given moment and thus adopt the corrupt strategy. The number of producers who are willing to pay the amount due of taxes and thus adopt the non-corrupt strategy, in turn, is given by $1-x$. In this way, x represents the probability with which an auditor audits a producer who adopts a non-abiding behavior.

Since the government knows how much tax revenue is supposed to be collected in the absence of corruption, any deficit of this amount indicates that producers and auditors have colluded to conceal income from the government, so that corruption is occurring. Therefore, the government monitors and investigates its employees in order to prevent any illicit deals. Corruption effectively takes place when there is a match between a producer and an auditor who are both willing to adopt non-abiding behaviors, which happens with probability xy. Let the probability of an auditor who adopts a non-abiding behavior being detected be given by:

$$\rho(x,y) = \varepsilon + (1-\varepsilon)xy, \tag{3.13}$$

where $\varepsilon \in [0,1] \subset \mathbb{R}$.

Notice, from (3.13), that the probability of detection of an auditor who is willing to adopt a non-abiding behavior has an autonomous component, ε, and another that depends on the quantity of illicit deals that take place in the economy. If corruption is widespread both in the public and the private sector, such that $xy = 1$, then $\rho(x,y) = 1$, so that an auditor who is prone to accepting bribes is certainly detected. Alternatively, as xy approaches zero, there are fewer matches between two agents who adopt non-abiding behaviors because either there are few producers willing to evade taxation, or there are few auditors prone to accepting bribes, or both. In the extreme case of $xy = 0$,

[2] In our framework, only producers offer bribes to auditors. Private agents are active and tax auditors are passive as far as tax evasion is concerned.

then $\rho(x,y)=\varepsilon$, which denotes the exogenously given detection probability of an auditor who is prone to accepting bribes, independent of the frequency of corruption in the society. We assume this is related to the government's monitoring effort.

Moreover, notice, from (3.13), that

$$\frac{\partial\rho(x,y)}{\partial x}=(1-\varepsilon)y\geq 0, \tag{3.14}$$

and

$$\frac{\partial\rho(x,y)}{\partial y}=(1-\varepsilon)x\geq 0. \tag{3.15}$$

This means that the probability of detection of an auditor who is prone to adopt a non-abiding behavior is increasing in both the fraction of producers and of auditors who are also willing to adopt non-abiding behaviors in the economy. In other words, the more likely is a match between agents who adopt non-abiding behaviors, the higher is the probability of the auditor being detected.

It should be mentioned that it is convenient for the government to disclose the information of illicit deals detected each period in order to inhibit non-abiding behavior in the future. Expression (3.13) is the relevant probability the auditor considers when choosing her strategy.

Auditors, thus, very much like producers, play a lottery in which, on the one hand, they can behave according to the law, earning their wage and punishing tax evaders; on the other hand, they may accept bribes offered by producers who play the corrupt strategy and, hence, have their expected incomes increased, for a given expected punishment. In the former case, the auditor is willing to adopt an abiding behavior and plays the non-corrupt strategy, which yields her a payoff represented by expression (3.12). In the latter case, the auditor is willing to adopt a non-abiding behavior and plays the corrupt strategy. If the deal is not detected, which happens with probability $1-\rho(x,y)$, the auditor earns her wage and her share of the evaded taxes, that is, $w+x\frac{(1-\alpha)\tau\pi^*}{2}$, where the second term in the expression represents the expected total amount earned from evaded taxes for a single corruptible auditor, since x represents the probability with which an auditor audits a producer who adopts a non-abiding behavior. However, if the deal is detected, which happens with probability given by (3.13), the auditor has to pay $\gamma\left[w+x\frac{(1-\alpha)\tau\pi^*}{2}\right]$, where $\gamma\in(0,1]\subset\mathbb{R}$ is the cost on total income (wage and illegal evaded taxes) incurred by the auditor. In view of that, the expected payoff of the auditor who plays the corrupt strategy, identified by the subscript *ca*, can be expressed as:

$$\begin{aligned}\pi_{ca}&=[1-\rho(x,y)]\left[w+x\frac{(1-\alpha)\tau\pi^*}{2}\right]+\rho(x,y)(1-\gamma)\left[w+x\frac{(1-\alpha)\tau\pi^*}{2}\right]\\&=[1-\gamma\rho(x,y)]\left[w+x\frac{(1-\alpha)\tau\pi^*}{2}\right].\end{aligned} \tag{3.16}$$

Notice, from (3.16), that if $\gamma\in(0,1)\subset\mathbb{R}$, then the cost incurred by the detected auditor is not enough to deplete her legal income increased by the bribes received.

Intuitively, this can be thought of as there being an investigation on this auditor and her incurring monetary costs for hiring attorneys, collecting proofs for defense, or even the opportunity cost of being temporarily suspended from office. We assume that, since the auditor is employed in the public sector, the chances of dismissal are minimal. In this case, even if the auditor has indeed embezzled public resources, she is judged as not guilty, so she keeps some income after prosecution. If $\gamma = 1$, then the cost incurred by the detected auditor is exactly equal to her total income. This situation can be interpreted as the auditor having to pay back to the government the amount embezzled and the wage she legally earned in one period as a penalty. Hence γ, much like δ, can serve as an instrument used by the government to deter corruption in the public sector.

We do not intend to convey a general equilibrium model of the economy yet. Our purpose so far is simply to develop an evolutionary dynamics that accounts for the interaction of private and public agents who may adopt abiding or non-abiding behaviors. Still, we make an assumption concerning public budget. Each period the government earns revenue from taxes duly paid by producers who adopt an abiding behavior; taxes partly paid by producers who adopt a non-abiding behavior and are audited by auditors who also adopt a non-abiding behavior, which occurs with probability xy; fines paid by producers who adopt a non-abiding behavior and are audited by auditors who adopt an abiding behavior, which occurs with probability $x(1-y)$; and fines paid by auditors who adopt a non-abiding behavior and are detected, which occurs with probability $\rho(x,y)$. We assume each period the government earns enough revenue to pay auditors' wages. This constraint is represented by the following expression:

$$w \le (1-x)\tau\pi^* + xy\alpha\tau\pi^* + x(1-y)\delta\pi^* + \gamma\rho(x,y)y\left[w + x\frac{(1-\alpha)\tau\pi^*}{2}\right], \tag{3.17}$$

where the left- and right-hand sides of (3.17) are the government's average expense with auditors' salaries and the government's average revenue (from taxes duly collected and fines paid by caught auditors), respectively.

It is important to mention that we are not concerned with the method employed by the government to monitor its employees[3]. We simply assume that an auditor is detected with the probability specified by (3.13). When this happens, the auditor is punished, but not the producer who was part of the transactions with this auditor. This is so because tracing back the origins of the illegal transactions may be costly for the government, so that only one part of the transaction is punished: the one that is the most at hand. This assumption leads to important results that are discussed in section 4. At the end of the day, either the producer or the auditor (or both) who play a corrupt

[3] It could be the case that another department is responsible for monitoring the auditors, or that auditors themselves were responsible for monitoring their colleagues, or even that producers denounced public officers who take bribes. For simplicity, we maintain the assumption of an exogenous probability of detection. For works on probability of detection related to whistle-blowing from other agents, the reader is referred to Dufwenberg and Spagnolo (2015) and Basu, Basu, and Cordella (2016).

strategy embezzles a certain amount of public resources. For the government, the final outcome is a decrease in effectively collected tax revenue.

Expressions (3.12)-(3.16) represent the payoffs for each of the auditors' behavioral strategy, which are crucial to their decision in the lottery concerning law-abidance. Notice, from (3.16), that the expected payoff of an auditor who plays the corrupt strategy depends on the proportion of producers who also play the corrupt strategy. The decision of a given population's agent relies on the interaction between the two populations, implying that in the dance of corruption, it takes two to tango. In the next section, we propose an evolutionary dynamics that illustrates the transition from short-run individual decisions to a long-run equilibrium for both producers and auditors.

3.2 A SATISFICING EVOLUTIONARY DYNAMICS OF CORRUPTION

Following the arguments put forward by Wagner (2017), because corrupt activities are usually intended to be concealed, an offender's payoff, either working in the private or the public sector, is unknown to other agents. Therefore, our argument is based on satisficing evolutionary mechanism[4]. Following Vega-Redondo (1996, p. 91), we assume satisficing behavior is only a trigger that transforms an agent into a potential corrupt. The probability of an effective change of strategy relies on the relative frequency of such a strategy in the population. We dub this process as a contagion effect, which can be associated with the idea of conventional behavior in the present context of decision making under uncertainty.

In line with the satisficing principle, we assume producer i, of type $k = cp, np$, has a threshold payoff μ_i she considers to be the minimum acceptable, such that whenever her current payoff π_k falls short of μ_i, she changes her strategy, hoping to obtain a higher payoff. Suppose that adopting an abiding behavior yields producer i a payoff that is below her threshold μ_i. She believes, then, it is worth to risk adopting a non-abiding behavior and evade taxation so that she may end up with a payoff that is higher than her threshold μ_i. Instead of continuing to play the non-corrupt strategy as she did in previous periods, she plays the corrupt strategy, even though she does not know with certainty the corresponding payoff. Conversely, suppose that adopting an abiding behavior yields producer i a payoff that exceeds her threshold μ_i. In this case, there is no reason for her to change her strategy, since she is not dissatisfied with her current payoff.

We assume that the threshold payoffs are randomly and independently distributed across the population of producers, and that it can be represented as a random variable that follows a continuously differentiable and strictly increasing cumulative dis-

4 For more details about types of learning and their modeling as an evolutionary dynamics, see Ponti (2000).

tribution function given by $F : \mathbb{R} \to [0,1] \subset \mathbb{R}$. Thus producer i is dissatisfied with her current strategy with probability $P(\pi_k < \mu_i) = 1 - P(\mu_i \leq \pi_k) = 1 - F(\pi_k)$.

A producer who adopts an abiding behavior and is dissatisfied with the non-corrupt strategy's payoff decides to evade taxation with probability $1 - F\left(\pi_{np}\right)$. She effectively changes her strategy if she believes she will not be ostracized by adopting a non-abiding behavior. Despite not knowing the exact payoff yielded by playing the corrupt strategy, she changes her strategy because she is dissatisfied with her current payoff and perceives corruption as socially acceptable. Therefore, the greater is the proportion of producers adopting a non-abiding behavior, the greater are the chances of a dissatisfied law-abiding producer effectively changing her strategy. As in Vega-Redondo (1996, p. 91), we assume the alternative strategy is chosen with probability given by its relative frequency in the corresponding population, x, that is, the proportion of tax evaders in society measures the success of the corrupt strategy in the producers' population, and it indicates the probability of an effective change in an agent's strategy.

Assuming statistical independence between these events, the inflow to the subpopulation of producers who play the corrupt strategy is equal to the dissatisfied law-abiding producers who actually become tax evaders:

$$(1-x)\left[1-F\left(\pi_{np}\right)\right]x. \tag{3.18}$$

Analogously, the outflow from the subpopulation of producers who play the corrupt strategy is equivalent to the inflow to its counterpart who plays the non-corrupt strategy, which is as follows:

$$x\left[1-F\left(\pi_{cp}\right)\right](1-x). \tag{3.19}$$

Subtracting (3.19) from (3.18), we get the following satisficing evolutionary dynamics for tax evaders:

$$\dot{x} = x(1-x)f(y), \tag{3.20}$$

where

$$f(y) = F\left(\pi_{cp}\right) - F\left(\pi_{np}\right). \tag{3.21}$$

We now turn to the population of public officials. We assume auditor j, of type $h = ca, na$, has a threshold payoff ν_j she considers to be the minimum acceptable. If her current payoff π_h is below ν_j, she goes for the alternative strategy. Suppose that auditor j, who adopts an abiding behavior, is dissatisfied with her current payoff because it is below her threshold ν_j. She reckons it is worth adopting a non-abiding behavior and accept bribes from evaders, since it may increase her expected payoff to a level higher than ν_j. Thus she changes her strategy from the non-corrupt to the corrupt one. Alternatively, suppose that adopting an abiding behavior yields auditor j a payoff that exceeds her threshold ν_j. She does not change her strategy because she is not dissatisfied with her current payoff.

Likewise, we assume that the auditors' threshold payoff is randomly and independently determined across the population of auditors, and that it can be represented as a random variable that follows a continuously differentiable and strictly increasing cumulative distribution function given by $G : \mathbb{R} \to [0,1] \subset \mathbb{R}$. Hence, auditor j is dissatisfied with her current strategy with probability $P\left(\pi_h < \nu_j\right) = 1 - P\left(\nu_j \leq \pi_h\right) = 1 - G(\pi_h)$.

An auditor who adopts an abiding behavior and is dissatisfied with the non-corrupt strategy's payoff decides to accept bribes from evaders with probability $1 - G(\pi_{na})$. Similarly to the private agents' rationale, the auditors' alternative strategy is chosen with probability given by its relative frequency in the corresponding population, y. Therefore, the inflow to the subpopulation of auditors who play the corrupt strategy can be expressed as:

$$(1-y)\,[1-G(\pi_{na})]\,y. \tag{3.22}$$

The outflow from the subpopulation of auditors who play the corrupt strategy, in turn, is given by:

$$y\,[1-G(\pi_{ca})]\,(1-y). \tag{3.23}$$

Subtracting (3.23) from (3.22) yields the following satisficing evolutionary dynamics for corruption in the public sector:

$$\dot{y} = y(1-y)g(x,y), \tag{3.24}$$

where

$$g(x,y) = G(\pi_{ca}) - G(\pi_{na}). \tag{3.25}$$

Expressions (3.20) and (3.24) give us a system whose space state is defined by $\Theta \equiv \left\{(x,y) \in \mathbb{R}^2 : 0 \leq x \leq 1, 0 \leq y \leq 1\right\}$, and which describes the evolution of the two populations based on an appropriate satisficing criterion.

The thresholds μ_i and ν_j determine which producers and which auditors, respectively, take the risk of getting in the lottery of adopting a non-abiding behavior, despite the possibility of getting caught and punished. These thresholds may be related to agents' risk aversion, moral values, or other idiosyncratic characteristics. Producers or auditors who are more risk-averse than others are less likely to get in the lottery of adopting a non-abiding behavior. Therefore, they tend to have higher threshold payoffs than their peers. The same is true for agents who have moral standards higher than others: degree of honesty, intrinsic moral costs, shame cost and social stigma are features that are often used to explain heterogeneity in agents' abidance behavior in corruption models[5]. Agents who are more sensitive to social stigma, for instance, will have a higher threshold payoff, due to the fear of being identified by their peers as individuals who don't abide by the law. The intrinsic thresholds may also be related

[5] These appear in Lui (1986), Andvig and Moene (1990), Cerqueti and Coppier (2011) and Litina and Palivos (2016).

to agents' intertemporal discount rate: the more an agent prefers current rather than future consumption, the less she will be affected by a penalty incurred on her future income and the more willing to adopt a non-abiding behavior she will be.

This means that agents adjust their behavior according to intrinsic conditions and to the relative performance of each strategy in the relevant population. The system, thus, reflects the transition from individual short-run decisions to the social outcome in the long run.

Notice, from (3.20) and (3.24), that in both the producers' and the auditors' populations, when the payoff of the corrupt strategy is greater (less) than that of the non-corrupt, then the proportion of individuals who adopt a non-abiding behavior in the corresponding population increases (decreases).

3.3 EVOLUTIONARY EQUILIBRIA

An equilibrium is reached when the proportion of both producers and auditors who play the corrupt strategies are unchanging in time, that is, when $\dot{x} = \dot{y} = 0$. Equilibria may assume monomorphic (pure-strategy) forms, when only one of the strategies survive in the long run in each population; or fully polymorphic (mixed-strategy) forms, when, in each population, there are agents who play the corrupt strategy coexisting with agents who play the non-corrupt one. We will show that the model has one fully fully polymorphic equilibrium under certain conditions.

Suppose that $x \in (0,1) \subset \mathbb{R}$ and $y \in (0,1) \subset \mathbb{R}$. From (3.20) and (3.24), an equilibrium is only possible if $f(y) = 0$ and $g(x,y) = 0$, which, from (3.21) and (3.28), implies that $\pi_{cp} = \pi_{np}$ and $\pi_{ca} = \pi_{na}$.

Considering the payoffs given by (3.9) and (3.11), we know that $\pi_{cp} = \pi_{np}$ yields:

$$y\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^* + (1-y)(1-\delta)\pi^* = (1-\tau)\pi^*. \tag{3.26}$$

From (3.26), we obtain the fraction of auditors who adopt a non-abiding behavior in the fully polymorphic equilibrium, which is given by:

$$y^* = \frac{2(\delta-\tau)}{2\delta-(\alpha+1)\tau}. \tag{3.27}$$

Let us assume that $2\delta-(\alpha+1)\tau \neq 0$. Then, we have that either $2\delta-(\alpha+1)\tau < 0$ or $2\delta-(\alpha+1)\tau > 0$. If the former case is true, we have that $y^* > 0$ if $\delta < \tau$, and that $y^* < 1$ if $\alpha > 1$, which is impossible. Therefore, for the existence of the fully polymorphic equilibrium, it must be true that $2\delta-(\alpha+1)\tau > 0$. Under such assumption, we have that $y^* > 0$ if

$$\delta > \tau, \tag{3.28}$$

and that $y^* < 1$ if $\alpha < 1$, which is straightforward from (3.10).

Now, considering the payoffs given by (3.12) and (3.16), we know that $\pi_{ca} = \pi_{na}$ yields:

$$[1-\gamma\rho(x^*,y^*)]\left[w + x^* \frac{(1-\alpha)\tau\pi^*}{2}\right] = w. \tag{3.29}$$

The fraction of producers who adopt a non-abiding behavior in the fully polymorphic equilibrium is implicitly determined by (3.29). Since the right-hand side and the second term in brackets of the left-hand side of (3.29) are strictly positive, it follows that

$$\gamma\rho(x^*,y^*) < 1 \tag{3.30}$$

is a necessary condition for the existence of the fully polymorphic equilibrium.

Let

$$h(x,y) \equiv [1-\gamma\rho(x,y)]\left[w + x\frac{(1-\alpha)\tau\pi^*}{2}\right] - w. \tag{3.31}$$

Condition (3.29) is satisfied if, and only if, $h(x,y) = 0$. Using (3.13) and (3.31), we know that $h(0,y) = -\gamma\varepsilon w < 0$, and that $\lim_{x\to 1} h(x,y) = [1-\gamma\rho(1,y)]\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] - w > 0$ if

$$\gamma\rho(1,y)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] < \frac{(1-\alpha)\tau\pi^*}{2}, \tag{3.32}$$

showing that, as x gets sufficiently close to 1, that is, when corruption starts to spread in the private sector, if an auditor's expected punishment for accepting bribes (left-hand side of (3.32)) is lower than the expected gain from an illegal deal (right-hand side of (3.32)), then the difference between payoffs of the corrupt and non-corrupt strategy for the auditor increases, and so does the proportion of auditors adopting a non-abiding behavior. For some $y^* \in (0,1) \subset \mathbb{R}$, the proportion of producers who adopt a non-abiding behavior in the fully polymorphic equilibrium, x^*, such that $h(x^*,y^*) = 0$, is reached if conditions (3.30) and (3.32) are satisfied.

Take $y = y^*$, as specified by (3.27). We are now going to show that, for a given y^*, there is only one $x^* \in (0,1) \subset \mathbb{R}$ such that $h(x^*,y^*) = 0$, by showing that $h(x,y^*)$ is a strictly increasing function in x. From (3.31), we know that

$$\frac{\partial h((x,y^*)}{\partial x} = -\gamma\frac{\partial\rho(x,y^*)}{\partial x}\left[w + x\frac{(1-\alpha)\tau\pi^*}{2}\right] + [1-\gamma\rho(x,y^*)]\frac{(1-\alpha)\tau\pi^*}{2}. \tag{3.33}$$

Substituting (3.14) into (3.33) and rearranging, we get that $\frac{\partial h}{\partial x}(x,y^*) > 0$ if

$$\gamma(1-\varepsilon)y^*\left[w + x\frac{(1-\alpha)\tau\pi^*}{2}\right] < [1-\gamma\rho(x,y^*)]\frac{(1-\alpha)\tau\pi^*}{2}. \tag{3.34}$$

Notice that the left-hand side and the right-hand side of (3.34) are lower than the left-hand side and the right-hand side of (3.32), respectively. Therefore, if a fully polymorphic equilibrium (x^*,y^*) exists, it is unique if the left-hand side of (3.32) is lower than the right-hand side of (3.34), that is, if

$$\gamma\rho(1,y^*)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] < [1-\gamma\rho(x,y^*)]\frac{(1-\alpha)\tau\pi^*}{2}. \tag{3.35}$$

This means that the fully polymorphic equilibrium is unique if the expected losses for the auditor who adopts a non-abiding behavior when corruption is widespread in the private sector are lower than the expected gains of corruption for the auditors, that is, only then auditors will be willing to take the risk of adopting a non-abiding behavior.

At last, we are going to show that an extreme situation of absence of corruption or absolute corruption is not possible in one population unless it happens in the other as well. We start by analyzing the auditors' population, in order to show that whenever $y = 0$ or $y = 1$, an equilibrium such that $x \in (0,1) \subset \mathbb{R}$ cannot occur. Suppose that $y = 0$ and $x \in (0,1) \subset \mathbb{R}$. Considering (3.24), it follows that $\dot{y} = 0$, and considering (3.21) and the payoffs given by (3.9) and (3.11), it follows that $f(0)$ is a well-defined value such that $f(0) \neq 0$ if $\delta \neq \tau$, which is satisfied by (3.28). In this case, from (3.20), $\dot{x} = 0$ if, and only if, $x = 0$ or $x = 1$. Now, suppose that $y = 1$ and $x \in (0,1) \subset \mathbb{R}$. Considering (3.24), it follows that $\dot{y} = 0$. Considering, once again, (3.21) and the payoffs given by (3.9) and (3.11), it follows that $f(1)$ is also a well-defined value, and that $f(1) \neq 0$ if $\alpha \neq 1$, which is straightforward from (3.10).

Analogously, we turn to the producers' population to show that, whenever $x = 0$ or $x = 1$, an equilibrium such that $y \in (0,1) \subset \mathbb{R}$ cannot occur. Suppose that $x = 0$ and $y \in (0,1) \subset \mathbb{R}$. Considering (3.20), it follows that $\dot{x} = 0$, and considering (3.25) and the payoffs given by (3.12) and (3.16), it follows that $g(0,y)$ is a well-defined value such that $g(0,y) \neq 0$ if $\gamma\rho(0,y) \neq 1$, which is implied by (3.30). In this case, from (3.24), $\dot{y} = 0$ if, and only if, $y = 0$ or $y = 1$. Now, suppose that $x = 1$ and $y \in (0,1) \subset \mathbb{R}$. Considering (3.20), it follows that $\dot{x} = 0$. Considering, once again, (3.25) and the payoffs given by (3.12) and (3.16), it follows that $g(1,y)$ is also a well-defined value, and that $g(1,y) \neq 0$ if $\gamma\rho(1,y)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] \neq \frac{(1-\alpha)\tau\pi^*}{2}$, which is satisfied by (3.32).

Therefore, a polymorphic equilibrium only exists when, in each population, there are agents who play the corrupt strategy coexisting with agents who play the non-corrupt one. Such an equilibrium (x^*, y^*) exists if conditions (3.28)-(3.32) are satisfied. In this case, y^* is given by (3.27) and x^* is implicitly determined by (3.29). This equilibrium is unique under condition (3.35). Aside from the fully polymorphic equilibrium, the dynamical system formed by (3.20) and (3.24) has four monomorphic equilibria, given by $(0,0)$, $(0,1)$, $(1,0)$ and $(1,1)$.

3.3.1 Analysis of local stability

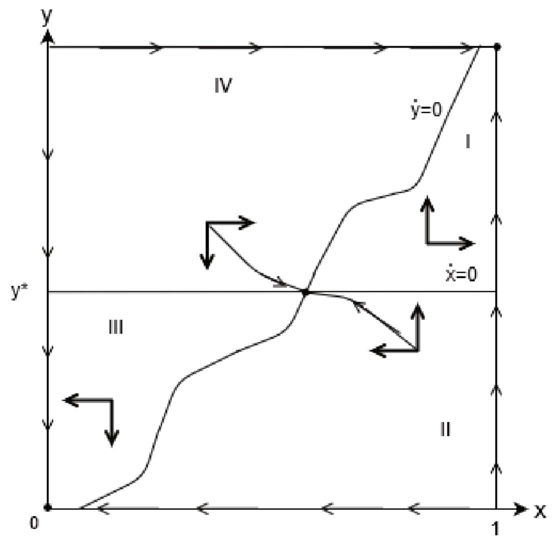
We now study the local stability properties of the fully polymorphic equilibrium. We know, from (3.20), there are three isoclines $\dot{x} = 0$, namely $\{(x,y) \in \Theta : x = 0\}$, $\{(x,y) \in \Theta : x = 1\}$ and $\{(x,y) \in \Theta : f(y) = 0\}$. Since $f(y) = 0$ implies (3.27), the latter can be represented as $\{(x,y) \in \Theta : y = y^*\}$. We can draw each of them in Figure 3.1. Considering (3.21), when $0 < y < y^*$, it follows that $\pi_{cp} < \pi_{np}$, as the chances of a producer being audited by an auditor who adopts an abiding behavior are higher than the one prevailing at the fully polymorphic equilibrium. Thus the proportion of producers willing to evade taxation declines, so $\dot{x} < 0$. This movement is represented by the arrows pointing left in regions II and III in Figure 3.1. Analogously, when $y^* < y < 1$, it follows that $\pi_{cp} > \pi_{np}$, since there are more auditors prone to accept bribes from evaders. Consequently, the proportion of producers willing to evade taxation increases, so $\dot{x} > 0$. This movement is represented by the arrows pointing right in regions I and IV in Figure 3.1.

We can also identify in Figure 3.1 three isoclines $\dot{y} = 0$, namely $\{(x, y) \in \Theta : y = 0\}$, $\{(x, y) \in \Theta : y = 1\}$ and $\{(x, y) \in \Theta : g(x, y) = 0\}$. The first two are easily drawn in Figure 3.1. From (3.29) and (3.31), the third one can be represented as $\{(x, y) \in \Theta : h(x, y) = 0\}$. Making use of the implicit-function rule, we know that the slope of this curve in the xy-plane is given by:

$$\left.\frac{dy}{dx}\right|_{\dot{y}=0} = -\frac{\frac{\partial h}{\partial x}}{\frac{\partial h}{\partial y}} = \frac{\frac{\partial h}{\partial x}}{\gamma(1-\varepsilon)x\left[w + x\frac{(1-\alpha)\tau\pi^*}{2}\right]} > 0, \tag{3.36}$$

since the numerator of (3.36) is strictly positive, from (3.33). Thus the isocline defined by the locus $\{(x, y) \in \Theta : h(x, y) = 0\}$ is strictly increasing around the fully polymorphic equilibrium. Moreover, we know, from (3.31), that this isocline intercepts the y-axis at point $\left(\frac{\gamma\varepsilon}{1-\gamma\varepsilon}\frac{2w}{(1-\alpha)\tau\pi^*}, 0\right)$. Notice that this abscissa is strictly positive and strictly lower than one, from (3.35). We also know from (3.31) that when $x = 1$, it follows that $y = \frac{(1-\alpha)\tau\pi^* - \gamma\varepsilon[2w+(1-\alpha)\tau\pi^*]}{\gamma(1-\varepsilon)[2w+(1-\alpha)\tau\pi^*]}$, which is strictly greater than one, because of (3.32). This allows us to draw the isocline $\dot{y} = 0$ defined by $\{(x, y) \in \Theta : h(x, y) = 0\}$ in Figure 3.1.

Figure 3.1 – Phase diagram when $\delta > \tau$ and $\gamma\rho(x, y) < 1$.



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Considering (3.25), when $0 < x < x^*$, it follows that $\pi_{ca} < \pi_{na}$ because there are less producers willing to evade taxation, so there are less resources for evaded taxes.

Thus the proportion of auditors willing to adopt a non-abiding behavior declines, so $\dot{y} < 0$. This movement is represented by the arrows pointing down in regions III and IV in Figure 3.1. Analogously, when $x^* < x < 1$, it follows that $\pi_{ca} > \pi_{na}$, due to the higher amount of producers willing to evade taxation. Consequently, the proportion of auditors prone to accepting bribes increases, so $\dot{y} > 0$. This movement is represented by the arrows pointing up in regions I and II in Figure 3.1.

In Figure 3.1, the monomorphic equilibria $(0,0)$ and $(1,1)$ are local attractors, while the monomorphic equilibria $(1,0)$ and $(0,1)$ are local repellers. The fully polymorphic equilibrium (x^*, y^*) is a saddle point, so the economy presents trajectories that approach the equilibrium, but eventually move away from it, without reaching it. Eventually, the economy moves to a situation of widespread corruption or absence of corruption. The stable arm of (x^*, y^*) is the only path that moves the system towards the fully polymorphic equilibrium. It is the boundary line between the basins of attraction of the monomorphic equilibria given by $(0,0)$ and $(1,1)$. The proofs for each equilibrium's local stability are demonstrated in Appendices A and B.

Let us now suppose that the government increases the expected punishment for auditors who adopt a non-abiding behavior, while maintaining the penalty for producers constant. From (3.16), we know that

$$\frac{\partial \pi_{ca}}{\partial \gamma} = -\rho(x,y)\left[w + x\frac{(1-\alpha)\tau\pi^*}{2}\right] < 0 \tag{3.37}$$

and

$$\frac{\partial \pi_{ca}}{\partial \varepsilon} = -\gamma(1-xy)\left[w + x\frac{(1-\alpha)\tau\pi^*}{2}\right] < 0, \tag{3.38}$$

using the fact that $\frac{\partial \rho(x,y)}{\varepsilon} = (1-xy)$. Thus as the expected punishment for auditors who adopt a non-abiding behavior increases, due to either a higher penalty or a more efficient government monitoring, the corrupt strategy's payoff for the auditor decreases, while the non-corrupt strategy's, given by (3.12), is unchanged. We know, from (3.24) and (3.25), that $\pi_{ca} < \pi_{na}$ implies that $\dot{y} < 0$. When the auditor's expected punishment increases such that condition (3.30) is no longer satisfied, then $\gamma\rho(x,y) = 1$, the fully polymorphic equilibrium ceases to exist, and the isocline $\dot{y} = 0$ expressed as $\{(x,y) \in \Theta : h(x,y) = 0\}$ moves to the right, increasing the basin of attraction of the monomorphic equilibrium $(0,0)$ and widening regions III and IV in the phase diagram. This situation is pictured in Figure 3.2.

In this setting, the fraction of auditors who adopt a non-abiding behavior decreases independently of the frequency of corruption in the population of producers, because the expected punishment for public officials is set to its maximum level. As the incidence of corruption in the public sector decreases, so does the payoff of the corrupt strategy for the producer, since there are fewer auditors prone to accepting bribes. As a result, the proportion of producers adopting a non-abiding behavior falls. In the extreme case of absence of corruption in the population of auditors ($y = 0$), the fraction of producers who adopt a non-abiding behavior decreases due to the certainty of being penalized. In Figure 3.2, the monomorphic equilibrium $(0,0)$ is a local attractor, whereas equilibrium $(0,1)$ is a local repeller, and equilibria $(1,0)$ and $(1,1)$ are saddle points. The economy eventually reaches the monomorphic equilibrium $(0,0)$. The proofs for each equilibrium's local stability are demonstrated in Appendix C.

Let us consider now the effect of an increase in the tax rate to the model's equilibria. Let us start by analyzing the situation in which the auditor's expected punishment does not change, it remains such that $\gamma\rho(x,y) < 1$. From the payoffs given by (3.9)-(3.16), it follows that

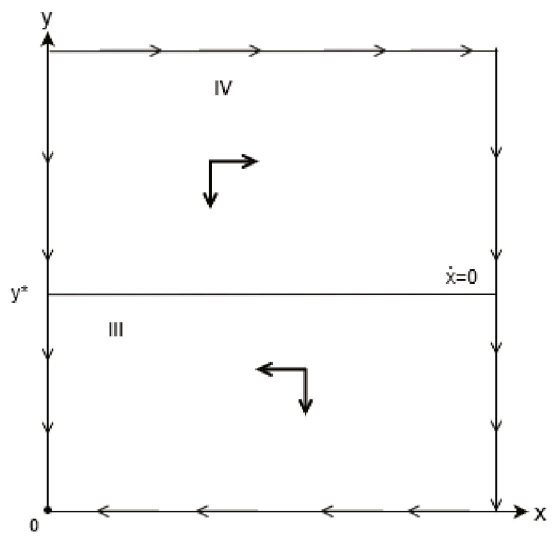
$$\frac{\partial \pi_{np}}{\partial \tau} = -\pi^* < -y\left(\frac{\alpha+1}{2}\right)\pi^* = \frac{\partial_{cp}}{\partial \tau} \tag{3.39}$$

and

$$\frac{\partial \pi_{ca}}{\partial \tau} = [1-\gamma\rho(x,y)]x\frac{(1-\alpha)\pi^*}{2} > 0. \tag{3.40}$$

We can see that as the tax rate increases, the payoff of both strategies for the producers' population decreases, but the decrease in the non-corrupt strategy's payoff is higher than that in the corrupt one. From (3.20) and (3.21), when $\pi_{cp} > \pi_{np}$, we know that $\dot{x} > 0$. When the tax rate increases such that condition (3.28) no longer holds, the fully polymorphic equilibrium ceases to exist, and the isocline $\dot{x} = 0$ expressed as $\{(x,y) \in \Theta : y = y^*\}$ moves downwards. The basin of attraction of the monomorphic equilibrium $(1,1)$ increases, widening regions I and IV in the phase diagram. This situation is pictured in Figure 3.3.

Figure 3.2 – Phase diagram when $\delta > \tau$ and $\gamma\rho(x,y) = 1$.



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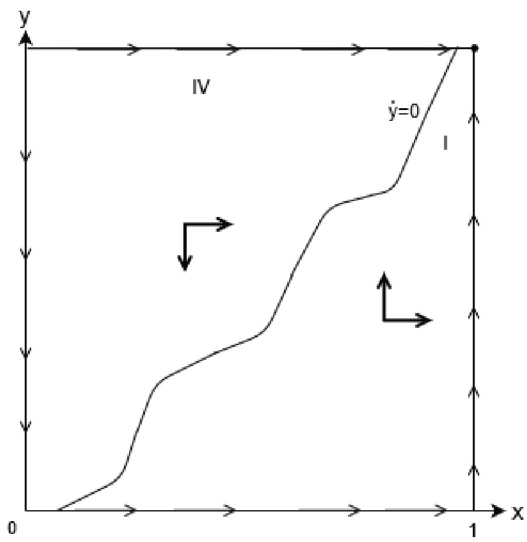
Now, the tax rate increase led to relatively low punishments for both populations. If the economy starts in a situation where corruption is absent in the population of producers, the fraction of auditors who play the corrupt strategy declines, since they find no producers willing to evade taxation, but still face an autonomous probability of being investigated. However, the proportion of producers who adopt a non-abiding behavior increases regardless of the frequency of corruption in the population of auditors, since, even if producers are caught, the cost which they incur is lower than the tax rate. As the proportion of producers willing to evade taxation increase, so does the payoff of the corrupt strategy for auditors, which leads to an increase in the fraction of auditors willing to adopt a non-abiding behavior, because their expected punishment is not high enough to deter them from playing the corrupt strategy. The economy eventually reaches an equilibrium characterized by widespread corruption in both populations. In Figure 3.3, the monomorphic equilibria $(0,0)$ and $(1,0)$ are saddle points, equilibrium $(0,1)$ is a local repeller, and equilibrium $(1,1)$ is a local attractor. The proofs for each equilibrium's local stability are demonstrated in Appendix D. Notice that the same outcome would arise if, instead of raising the tax rate, the government reduced the penalty for the producer who is caught evading taxes such that $\delta < \tau$. In this case, the payoff of the corrupt strategy for the producer is always higher than that of the non-corrupt.

At last, let us consider the case of an increase in the tax rate (or, likewise, a decline in producers' penalty) such that $\delta < \tau$ while the auditors' penalty is raised such that $\gamma\rho(x,y) = 1$. We know, from (3.39) that an increase in the tax rate leads to a decrease in the non-corrupt strategy's payoff for the producer higher than that

Figure 3.3 – Phase diagram when $\delta < \tau$ and $\gamma\rho(x,y) < 1$.



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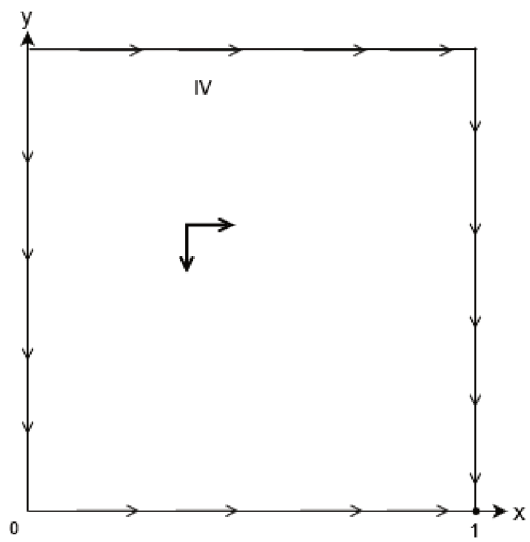
in the corrupt one, which moves the isocline $\dot{x} = 0$ expressed as $\{(x, y) \in \Theta : y = y^*\}$ downwards. On the other hand, now that $\gamma\rho(x, y) = 1$, the corrupt strategy's payoff is null, but the non-corrupt one is strictly positive. It does not pay for the auditors not to abide by the law because the expected punishment for the auditor who is caught accepting bribes is relatively high. This moves the isocline $\dot{y} = 0$ defined as the locus $\{(x, y) \in \Theta : h(x, y) = 0\}$ to the right, expanding region IV in the phase diagram and turning the monomorphic equilibrium (1,0) stable. Despite a high penalty for the auditors who are caught accepting bribes, this equilibrium is stable because the producers still have an incentive to evade taxation, since they effortlessly get away with adopting a non-abiding behavior. This situation is pictured in Figure 3.4.

Figure 3.4 – Phase diagram when $\delta < \tau$ and $\gamma\rho(x, y) = 1$.



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In diagram Figure 3.4, the monomorphic equilibria (0,0) and (1,1) are saddle points, equilibrium (0,1) is a local repeller, and equilibrium (1,0) is a local attractor. The proofs for each equilibrium's local stability are demonstrated in Appendix E.

3.4 FINAL REMARKS

We have developed a simple model where a population of potentially corruptible private agents interact with another of potentially corruptible public officials. While producers may engage in tax evasion, auditors may accept bribes to turn a blind eye on the evaded taxes and not denounce producers who adopt a non-abiding behavior, in exchange for half of the unreported amount of taxes.

In our model, individuals are not intrinsically corrupt or honest. Instead, they act as agents with bounded rationality, weighing the gains and losses of adopting a non-abiding behavior towards the law. What is inherent to each individual is the threshold payoff below which each agent decides to take the risk of disobeying the law. This threshold may be related to agents' risk aversion, intertemporal discount rate, moral values, or other idiosyncratic characteristics. Following Vega-Redondo (1996, p. 91), we assume satisficing behavior is a trigger that transforms an agent into a potential corrupt. The probability of an effective change of strategy relies on the relative frequency of such a strategy in the population. This contagion effect can be associated with the idea of conventional behavior in the present context of decision making under uncertainty.

The results presented in section 3.3.1 indicate that corruption in the public sector may be pervasive precisely due to the interaction between self-interested auditors and private producers who aim to achieve personal gains at the expense of public services. Notice that the collusion between private agents and public officials may lead to an outcome of widespread corruption in society (in both populations).

Our results suggest that the thriving of public sector corruption demands the acceptance of private agents, implying that in the dance of corruption, it takes two to tango. In other words, corruption arises from the strategic interaction between public and private agents. Even for a relatively high punishment for the producers who adopt a non-abiding behavior, if the expected punishment for the auditors who adopt a non-abiding behavior is not similarly relatively high, the economy may reach the monomorphic equilibrium $(1,1)$, of absolute corruption, widespread in society and regarded as the social norm rather than the deviant behavior, as in Mishra (2006) and Accinelli and Carrera (2012). When corruption is absent in one of the populations, one group will not be able to find a partner to dance the tango of corruption.

This result may as well reflect some limitations in our framework. More specifically, in our model, public officials cannot actively propose illegal deals. They act as mere profiteers of an already tainted situation. Another improvement in our model could be to consider the possibility of producers and auditors engaging in a bargain in order to split the gains of tax evasion. We leave it to future research.

Despite the instability of the fully polymorphic equilibrium (x^*, y^*), our model demonstrates that curbing corruption in the public sector alone is not enough to eradicate it from society. Only if the expected punishments for both private producers and auditors are high that the monomorphic equilibrium $(0,0)$ becomes the only stable one, or else the existence of the fully polymorphic equilibrium leads to a situation similar to that presented by Andvig and Moene (1990), where the economy eventually reaches either the equilibrium of absence of corruption or that of widespread corruption. Again, this suggests that corruption can only be suppressed if the government tackles the collusion that may occur between private agents and public officials, as Litina and Palivos (2016) argue. Otherwise, corruption may become a deep-rooted phenomenon in society, one which lingers through long periods of time.

4 PERSISTENT CORRUPTION AND MACROECONOMIC CONSEQUENCES

Corruption comes in all shapes and sizes. It may take the form of bribes paid by citizens to public officials in exchange for services to which they are entitled, illegal contributions to party campaigns, or the diversion of public resources to private gains. The definition of corruption is contingent on specific rules that vary with different legal systems, and even within a country's legislation it may be difficult to find an exact definition[1]. What is increasingly acknowledged by scholars, nonetheless, is that corruption negatively affects economic growth. Mauro (1995), Mo (2001) and Svensson (2005) provide empirical evidence that corruption is harmful to a country's income level and growth rate, while Treisman's (2000) results show that economic development reduces corruption.

The goal of this essay is to study the impact of persistent corruption on capital accumulation in a context where the two variables co-evolve. According to Jain (2001), most macroeconomic variables are determined simultaneously with corruption, thus reciprocal feedbacks should be taken into account, which is an important contribution of our work. We develop a dynamic growth model with productive public spending where corruption and capital accumulation are both endogenous and simultaneously determined variables. In particular, we treat corruption as the tax evasion practiced by individuals who expect to have an increase in income, and model it as an evolutionary process that accounts for its persistence based on social interaction. In terms of government revenue, tax evasion represents a leak on public budget, such that tax revenue (and public spending) may be lower than expected because corruption diverts resources from the production process to the consumption of individuals. We show that under certain conditions, the economy may reach an equilibrium where individuals who play the corrupt strategy coexist with individuals who play the non-corrupt one. In a framework where the two variables co-evolve, corruption does not cease to exist in the long run, rather it becomes an endemic phenomenon, lingering parallel to capital accumulation.

The relation between corruption and economic growth has been explored in the literature, notably by Lin and Zhang (2009), Barreto (2000), Ellis and Fender (2006), Blackburn, Bose, and Haque (2006) and Blackburn and Forgues-Puccio (2007), as already mentioned in chapter 2. The work of Wagner (2017), which provided the cornerstone for this thesis, models corruption as an evolutionary process and inserts it in a Solow-Swan model of growth with productive public expenditure, in which the economy's growth rate is inversely related to the level of corruption.

With respect to these papers, we put forward some novelties which bring about different qualitative results that may contribute to the literature. While Lin and Zhang

[1] On an extensive account of the definition and different types of corruption, see Jain (2001) and Svensson (2005).

(2009) treat corruption as exogenous, Barreto (2000) considers both corruption level and growth rate as endogenous, though not simultaneously determined. Because the former is determined first, this prevents a feedback from corruption to the growth rate. The same drawback appears in Ellis and Fender's (2006) model, where corruption does not affect either the level or rate of growth of output in the economy. Blackburn and Forgues-Puccio (2007) do not allow intermediary levels of corruption in the public sector: corruption is either absent or widespread; either all or none bureaucrats are corrupt. In addition, both Blackburn and Forgues-Puccio (2007) and Blackburn, Bose, and Haque (2006) miss the possible effects of social interaction, and consider that a bureaucrat who is once corrupt will always be so; likewise, an incorruptible bureaucrat will never engage in bribery and tax evasion. Among these, tax evasion is present only in Blackburn and Forgues-Puccio (2007) and Lin and Zhang (2009), nonetheless our framework is more similar to Ellis and Fender's (2006), where corruption is seen as the embezzlement of public resources practiced by bureaucrats, in spite of defining corruption in a different manner.

At last, Wagner (2017) provides an insightful evolutionary dynamics of corruption to be simultaneously determined with growth. However, her results do not point to an equilibrium where corruption is persistent, instead it either is absent in the long run or it becomes widespread and depletes the whole of the economy's resources. We believe that a microfounded growth model, such that the level of corruption in the short run depends on individuals' choices, may aid to tackle this issue.

The remainder of this essay is structured as follows. In the first section, we examine the behavior of individuals in our model economy, describing the young individual's saving decision, which depends on her chosen behavioral strategy. In the second section, we present the firm's decision, and in the third, we analyze the general equilibrium and the dynamics of the capital stock. In the fourth section, we then propose an evolutionary dynamics of corruption based on a satisficing choice protocol. In the fifth section, we derive the equilibrium of the model and discuss the implications of corruption to capital accumulation. The sixth section concludes.

4.1 THE YOUNG INDIVIDUAL'S DECISION

We start our exposition by deriving the young individual's decision in an overlapping generations framework, where finite-horizon individuals live only for two periods. In this way, each period there will always coexist two generations of individuals. At their first period of life, individuals are endowed with one unit of labor, which they supply inelastically to the private sector in exchange for labor income. They consume part of the income received and save the rest for consumption in their second period of life, when they are retired. While young, therefore, individuals must decide how much of their income is going to be saved to finance second-period consumption and generate next period's capital stock. For simplicity, we assume the economy is closed and produces a single good that can be used for consumption and investment purposes, which is supplied by firms in a competitive market, and whose market-clearing price is normalized to one.

4.1.1 Optimal saving rate

All individuals in the economy present the same optimal saving rate, derived from their saving decision while young. Let c_{1t} and c_{2t+1} denote the individual born in period t's consumption when young and old, respectively. In her first period of life, her consumption is given by:

$$c_{1t} = (1 - s_t) y_t^e, \tag{4.1}$$

where $s_t \in [0,1] \subset \mathbb{R}$ is the portion of her income that is saved at period $t \in \mathbb{N}$ and y_t^e is her expected income, which is assumed to be homogeneously formed throughout the population according to the law-abidance decision detailed in subsection 4.1.2.

In period $t+1$ this individual retires and consumes her first-period savings plus the interest earned:

$$c_{2t+1} = (1 + r_{t+1}) s_t y_t^e, \tag{4.2}$$

where r_{t+1} is the exogenously given interest rate at period $t+1$.

Substituting (4.1) into (4.2) yields the intertemporal budget constraint faced by this individual:

$$c_{1t} + \frac{1}{1 + r_{t+1}} c_{2t+1} = y_t^e. \tag{4.3}$$

It is important to note that the individual consumes throughout her life the whole of the income she earns, leaving no bequests for future generations. It is for this reason that all individuals are born without any initial wealth, at any $t \in \mathbb{N}$.

Let $\theta \in (0, \infty) \subset \mathbb{R}$ be the one period's discount factor, which is assumed equal for all individuals and for all generations. Let also $u(\cdot)$ be a continuously differentiable utility function, which is assumed strictly increasing and strictly quasi-concave. The young individual born at period t chooses c_{1t} and c_{2t+1} that maximize her lifetime utility, given by:

$$u_t = u(c_{1t}) + \frac{1}{1 + \theta} u(c_{2t+1}), \tag{4.4}$$

subject to (4.3).

Optimal c_{1t}^* and c_{2t+1}^* are such that

$$u'(c_{1t}^*) - \frac{1 + r_{t+1}}{1 + \theta} u'(c_{2t+1}^*) = 0. \tag{4.5}$$

Equation (4.5), along with equation (4.3), form the individual's problem's first-order conditions, which are also sufficient conditions, given the assumptions on the utility function. For simplicity, we assume a logarithmic utility function, that is, $u(c_{1t}) = \ln c_{1t}$ and $u(c_{2t+1}) = \ln c_{2t+1}$. Based on (4.5), we get

$$\frac{c^*_{2t+1}}{c^*_{1t}} = \frac{1 + r_{t+1}}{1+\theta}. \tag{4.6}$$

Substituting (4.1) and (4.2) in (4.6), we obtain the young individual's optimal saving rate, given by:

$$s^*_t = \frac{1}{2+\theta}. \tag{4.7}$$

Notice, from (4.7), that as θ approaches ∞, the less the individual values future relative to current consumption, so the optimal decision is to allocate most of her expected income to first-period consumption as s^*_t tends to zero. Otherwise, when θ approaches 0, she tends to equally split her expected income between her two periods of life.

4.1.2 Corruption, tax evasion and saving

As argued in chapter 2, the phenomenon of corruption can be traced back to its origins in individual decisions. In the model presented here it is a choice young individuals face concerning tax compliance. Young individuals supply their unit of labor to the private sector and earn a strictly positive real wage $w_t \in \mathbb{R}_{++}$. They must decide whether to abide by the law and pay the due amount of taxes levied on their wage, or not to abide by the law and attempt to evade taxation, taking the risk of being detected and punished.

We assume that, at period $t \in \mathbb{N}$, there are $L_t \in \mathbb{N}$ individuals in the economy, who either adopt an abiding behavior and play the non-corrupt strategy (amounting to $L_{n,t} \in \mathbb{N}$), or take the risk of adopting a non-abiding behavior and play the corrupt strategy (adding up to $L_{c,t} \in \mathbb{N}$). Thus $L_t = L_{n,t} + L_{c,t}$.

The individual who adopts an abiding behavior decides to play the non-corrupt strategy and pay her due amount of taxes. The expected income of an individual born at period $t \in \mathbb{N}$ who plays the non-corrupt strategy (identified by the subscript n) is her wage after taxes:

$$y_{n,t} = (1-\tau)w_t, \tag{4.8}$$

where $\tau \in (0,1) \subset \mathbb{R}$ is the exogenously given tax rate.

Considering (4.7) and (4.8), we know that all individuals who play the non-corrupt strategy expect to earn the same income and have the same optimal saving rate. Given such intragroup homogeneity, the aggregate saving of the non-corrupt subpopulation at period $t \in \mathbb{N}$ can be established as follows:

$$S_{n,t} = s^*_t y_{n,t} L_{n,t} = \frac{1-\tau}{2+\theta} w_t L_{n,t}. \tag{4.9}$$

By adopting a non-abiding behavior, individuals may be audited and punished with a fine proportional to their income, so that they may end up with less than their wage. What triggers each individual to get in this lottery is detailed in section 4.4. However, it is common to all of them the incentives and punishments faced.

The incentive an individual has to get in the lottery of adopting a non-abiding behavior is the potential increase in income obtained from tax evasion. We assume that an individual who attempts to evade taxation decides not to pay any taxes whatsoever. Nonetheless, she faces the risk of being audited, in which case she has to pay γw_t for the government as a punishment, where $\gamma \in (0,1] \subset \mathbb{R}$ is the fine charged on her, expressed as a fraction of her income. We assume she is audited with probability[2] $\varepsilon \in [0,1] \subset \mathbb{R}$, so that the expected income of the corrupt individual born at period $t \in \mathbb{N}$ who plays the corrupt strategy (identified by the subscript c) can be expressed as:

$$\begin{aligned} y_{c,t} &= (1-\varepsilon) w_t + \varepsilon (1-\gamma) w_t \\ &= (1-\rho) w_t, \end{aligned} \tag{4.10}$$

where $\rho \equiv \varepsilon\gamma \in [0,1] \subset \mathbb{R}$ represents the expected punishment of an individual who is willing to take the risk of adopting a non-abiding behavior.

Let us make some remarks about the individual who is caught attempting to evade taxation. The fine this individual incurs must be paid in one installment in her first period of life. As a result, the higher the fine is, the less is the remaining income for the individual's second-period consumption. The value of the fine depends on the economy's institutional framework, and it can be set to any strictly positive real value. Notice, from (4.10), that if $\gamma \in (0,\tau) \subset \mathbb{R}$, then the fine the offender incurs is lower than the tax rate. If she is caught, she keeps part of τw_t, that is, she successfully embezzles a part of government's revenue, even after punishment. This can be associated to a poor institutional framework, with poorly defined property rights and where the feeling of impunity prevails. If $\gamma = \tau$, then the offender has to pay a fine equal to the exact amount embezzled; and if $\gamma \in (\tau, 1] \subset \mathbb{R}$, then she has to forfeit more income than what she would had she adopted an abiding behavior. The fine γ, thus, is an instrument for the government to prevent individuals from adopting a non-abiding behavior. Were it set to its maximum level ($\gamma = 1$) and individuals certain to be caught ($\varepsilon = 1$), the expected income of those who play the corrupt strategy would be null. However, because for any $\rho \in [0,1] \subset \mathbb{R}$ we must have that $\rho = \varepsilon\gamma$, it follows that even if the fine is set to a high level, the probability of detection may be sufficiently low so that the expected punishment (ρ) may be lower than one, and the individual who plays the corrupt strategy earns a positive payoff, as seen in (4.10).

Given the corrupt subpopulation's intragroup homogeneity, analogous to its non-corrupt counterpart, we can use (4.7) and (4.10) to find the aggregate saving of the

[2] For simplicity, we assume that ε is related to the government monitoring efficiency and is exogenously determined. For a different and yet simple approach, see Cerqueti and Coppier (2011).

corrupt subpopulation at period $t \in \mathbb{N}$, which is as follows:

$$S_{c,t} = s_t^* y_{c,t} L_{c,t} = \frac{1-\rho}{2+\theta} w_t L_{c,t}. \tag{4.11}$$

Notice, from (4.8) and (4.10), that the difference between the incomes of individuals who adopt abiding and non-abiding behaviors is the duty on wage faced by each of them. While the former is lowered because of the tax rate, the latter is reduced by the expected punishment of those who are willing to take the risk of adopting a non-abiding behavior. Furthermore, notice, from (4.9) and (4.11) that the tax rate and the expected punishment determine the contribution of each type of individual to each of the subpopulations' aggregate savings. If $\rho < \tau$, for instance, then those who play the corrupt strategy contribute more to the corrupt subpopulation's aggregate saving than those who play the non-corrupt strategy do to the aggregate saving of their corresponding subpopulation.

4.2 THE FIRM'S DECISION

As in Barro (1990), government is introduced in the model as the provider of goods that are used as inputs for private production, such as infrastructure spending or the provision of electricity by the state. We assume that each period the government provides goods in the amount of $G_t \in \mathbb{R}_+$ which are financed by taxes collected on individuals' wages in the amount of $T_t \in \mathbb{R}_+$, running a balanced budget each period, as will be explained in section 4.3.

Each period, firms hire labor from young individuals and combine it with the capital owned by the old and the productive public expenditure, which they take as given, to produce output in the form of the homogeneous good that can be used for consumption and investment (additions to capital stock) purposes. The good and the factors markets are competitive and, as already stated, the good's market-clearing price is normalized to one. All firms operate using the same technology, expressed as the neoclassical production function:

$$Y_t = F\left(K_t^d, G_t, N_t\right), \tag{4.12}$$

where $Y_t \in \mathbb{R}_+$ is aggregate output and $K_t^d \in \mathbb{R}_+$ and $N_t \in \mathbb{R}_+$ are the aggregate quantities of capital and labor demands, respectively, at period $t \in \mathbb{N}$. More precisely, $F\left(K_t^d, G_t, N_t\right)$ is of class C^2, exhibits strictly positive and diminishing marginal products with respect to each input, as well as constant returns to scale, and satisfies the Inada conditions[3].

[3] We consider here $F\left(K_t^d, G_t, N_t\right)$ as an individual production function. Since there are no externalities directly related to production and firms produce a homogeneous good taking its price and the real wage as given, the economy works as if there were a single firm operating a production function which yielded the maximum output obtained from the aggregation of the individual production functions for a given level of aggregate labor. For this reason, the aggregate production function exhibits the same

We assume that (4.12) takes the Cobb-Douglas form, given by:

$$F\left(K_t^d, G_t, N_t\right) = K_t^{d\,\alpha} G_t^{\beta} N_t^{1-(\alpha+\beta)}, \tag{4.13}$$

where $\alpha \in (0,1) \subset \mathbb{R}$ and $\beta \in (0,1) \subset \mathbb{R}$ are parametric constants. In addition, $\alpha + \beta \in (0,1) \subset \mathbb{R}$.

Dividing (4.13) by the number of employed individuals in the economy, we can express (4.13) in its intensive form:

$$y_t = k_t^{d\,\alpha} g_t^{\beta}, \tag{4.14}$$

where $y_t \equiv \frac{Y_t}{N_t}$, $k_t^d \equiv \frac{K_t^d}{N_t}$ and $g_t \equiv \frac{G_t}{N_t}$ are output, capital and government spending intensities, respectively.

Since labor and capital are paid their marginal products, we can use (4.14) and the conditions for profit maximization to find:

$$w_t = F_{N_t} = [1 - (\alpha + \beta)] k_t^{d\,\alpha} g_t^{\beta} \tag{4.15}$$

and

$$r_t = F_{K_t^d} = \alpha k_t^{d\,\alpha - 1} g_t^{\beta}, \tag{4.16}$$

where $F_{N_t} \equiv \frac{\partial F(K_t^d, G_t, N_t)}{\partial N_t}$ and $F_{K_t^d} \equiv \frac{\partial F(K_t^d, G_t, N_t)}{\partial K_t^d}$ denote labor and capital marginal products at period $t \in \mathbb{N}$, respectively.

4.3 GENERAL EQUILIBRIUM AND CAPITAL ACCUMULATION

Recall that government spending is taken as given by firms. The government provides goods to be used in the private production process financed by taxes, which, in the absence of tax evasion, are expected to be collected in period $t \in \mathbb{N}$ in the amount of $T_t^e = \tau w_t L_t$. Due to the willingness of some individuals to adopt a non-abiding behavior, however, effective tax revenue may be lower than its expected level. The effective tax revenue is the amount of taxes collected on the wages of individuals who adopt an abiding behavior, that is, $T_t = \tau w_t L_{n,t}$. Apart from the effective tax revenue, the government also obtains revenue from the fines paid by individuals who play the corrupt strategy and are audited and punished. Considering an individual is audited with probability ε and the government charges a fine γ on tax evasion, the latter earns $\rho w_t L_{c,t}$. This way, government spending is equal to effective tax revenue plus the revenue obtained from fines paid by the corresponding individuals. We assume that, each period, a fraction $x_t = \frac{L_{c,t}}{L_t}$ of the population chooses to play the corrupt strategy,

properties as the individual production function. In equilibrium, capital and labor marginal products are the same for each firm individually and equal to the marginal products of the aggregate production function. For a detailed account, see Simonsen and Cysne (2009).

so that a fraction $1-x_t = \frac{L_{n,t}}{L_t}$ of the population chooses to play the non-corrupt strategy. Government spending per young individual in the economy, thus, is given by:

$$g_t = \frac{T_t + \rho w_t L_{c,t}}{L_t} = [\tau(1-x_t) + \rho x_t] w_t. \tag{4.17}$$

Notice, from (4.17), that an increase in the fraction of individuals who play the corrupt strategy at a given period has, on the one hand, a negative impact on government spending per young individual due to a decrease in effective tax revenue, but, on the other, a positive impact that comes from the potential increase in revenue obtained from fines, because there are more individuals who evade taxation and may get caught. So, the net impact depends on the differential $\rho-\tau$, that is, $\frac{\partial g_t}{\partial x_t} = \rho-\tau$ will be strictly negative, zero or strictly positive, if $\rho<\tau$, $\rho=\tau$ or $\rho>\tau$, respectively.

General equilibrium requires that supply equals demand in the good and labor markets. When dealing with their production decision, firms face a predetermined capital stock, whose source is the previous generation's young individuals' saving. The good market reaches an equilibrium when, at any $t \in \mathbb{N}$, the capital stock demanded by firms equals the capital stock owned by the old individuals, who were responsible, while young, for the previous generation's saving decision. This occurs when:

$$K_t^d = K_t. \tag{4.18}$$

Since labor supply is inelastically provided only by the young individuals in the economy, labor market reaches an equilibrium when the labor demanded by firms equals the labor supplied by young individuals, at any $t \in \mathbb{N}$, regardless their chosen strategy. This is the case when:

$$N_t = L_t.^4 \tag{4.19}$$

Perfect competition in the factors' markets implies that, from (4.15)-(4.19), the wage rate that clears the labor market at period $t \in \mathbb{N}$ is given by:

$$w_t = \{[1-(\alpha+\beta)]\}^{\frac{1}{1-\beta}} [\tau(1-x_t) + \rho x_t]^{\frac{\beta}{1-\beta}} k_t^{\frac{\alpha}{1-\beta}} \equiv w(x_t, k_t). \tag{4.20}$$

Notice, from (4.20), that

$$\frac{\partial w_t}{\partial k_t} = \frac{\alpha}{1-\beta} \{[1-(\alpha+\beta)]\}^{\frac{1}{1-\beta}} [\tau(1-x_t) + \rho x_t]^{\frac{\beta}{1-\beta}} k_t^{-\frac{1-(\alpha+\beta)}{1-\beta}} > 0 \tag{4.21}$$

and

$$\frac{\partial w_t}{\partial x_t} = \frac{\beta}{1-\beta} \{[1-(\alpha+\beta)]\}^{\frac{1}{1-\beta}} [\tau(1-x_t) + \rho x_t]^{\frac{2\beta-1}{1-\beta}} k_t^{\frac{\alpha}{1-\beta}} (\rho-\tau), \tag{4.22}$$

which means that an increase (decrease) in the capital intensity in the economy leads to an increase (decrease) in the wage rate, while the effect of a change in the incidence

4 This condition implies that expressing variables in terms of young individuals is equivalent to expressing their intensity. That is why, for example, $g_t \equiv \frac{G_t}{N_t} = \frac{G_t}{L_t}$.

of corruption in the economy on the wage rate is not straightforward, instead it depends on the relative values of ρ and τ. If $\rho < \tau$, for instance, then an increase in the level of corruption leads to a decrease in the wage rate, since the fines paid by individuals who play the corrupt strategy and are caught are not enough to compensate the decrease in productive public expenditure resulting from less individuals playing the non-corrupt strategy, which induces a damaging effect on the production process. In this case, corruption produces a negative externality on the income of individuals who adopt an abiding behavior, through changes in the wage rate.

In addition, using (4.16)-(4.20), equilibrium in the capital market is reached when the interest rate (or rate of profit) is as follows:

$$r_t = \alpha\{[\tau(1-x_t)+\rho x_t]w\}^{\beta} {k_t}^{\alpha-1}. \tag{4.23}$$

When the incidence of corruption changes, the interest rate accompanies the movement in the wage rate: if $\rho < \tau$, an increase in the level of corruption leads to a decrease in the interest rate because the revenue the government earns with fines cannot offset its losses with tax evasion, which is harmful to the production process. Whenever (4.18) or (4.19) are not satisfied, the wage rate or the interest rate will vary until an equilibrium is once again reached, when all young individuals are employed and all of the predetermined capital stock is used.

These equilibrium conditions, however, are not enough to determine capital accumulation. We still need to understand how the capital stock owned by the old individuals and supplied to the firms is generated. We know that individuals, while young, save part of their income. Following Barro and Sala-i-Martin (2003), equilibrium in the good market requires that aggregate net investment be equal to aggregate net saving. Assuming that capital fully depreciates in one period, it means that:

$$K_{t+1} - K_t = S_{n,t} + S_{c,t} - K_t. \tag{4.24}$$

The left-hand side of (4.24) represents the change in capital stock from period t to $t+1$, that is, aggregate net investment, while the right-hand side shows the saving of the young (abiding and non-abiding) and the dissaving of the old.

We suppose there is a strictly positive initial capital stock, $K_0 \in \mathbb{R}_{++}$, which firms, at period $t = 0$, combine with the exogenously given productive public expenditure and with the labor supplied by the first generation's young population to produce current output. When the first young individuals retire, they are the owners of the capital stock at $t = 1$, originated from their saving the previous period. By the end of their lives, firms will have consumed all of the capital stock they own, and next period's capital stock will stem from the saving of the next generation's young population. The process goes on for all $t \in \mathbb{N}$, hence it is the saving of the young population at period t that generates capital stock at period $t+1$, as shown in (4.24).

For simplicity, we assume that there is no population growth. Thus substituting (4.9) and (4.11) into (4.24) and dividing the resulting expression by the number of individuals in the economy yields: [5]

$$k_{t+1} = h(x_t)w(x_t, k_t), \tag{4.25}$$

where $w(x_t, k_t)$ is given by (4.20) and

$$h(x_t) \equiv \frac{1}{2+\theta}[(1-\rho)x_t + (1-\tau)(1-x_t)]. \tag{4.26}$$

Expression (4.25) is the equation of motion of capital stock per young individual in the economy for a given level of corruption, and expression (4.26) denotes the marginal impact of a change in the wage rate on capital accumulation, stemmed from the economy's aggregate private saving. The first term on the right-hand side of (4.26) is the optimal saving rate, which is assumed to be the same for all individuals, while the second shows each subpopulation's fraction of remaining income after taxation. Notice that the expression inside brackets in (4.26) is a linear combination of $(1-\rho)$ and $(1-\tau)$. Since $\rho \in [0,1] \subset \mathbb{R}$ and $\tau \in (0,1) \subset \mathbb{R}$, we know that $(1-\rho) \in [0,1]$ and that $(1-\tau) \in (0,1) \subset \mathbb{R}$, hence it follows that a linear combination between these two elements is also positive. Thus $h(x)$ is strictly positive for all $x \in [0,1) \subset \mathbb{R}$.

From (4.26), we have that

$$\frac{\partial h}{\partial x_t} = \frac{\tau-\rho}{2+\theta}. \tag{4.27}$$

Comparing expressions (4.22) and (4.27), we can see that an increase in the level of corruption produces two opposing forces on capital accumulation. If the tax rate (which is the duty on the income of the individual who adopts an abiding behavior) is higher than the expected punishment for the individual who is willing to adopt a non-abiding behavior ($\rho < \tau$), then a higher incidence of corruption in the economy affects capital accumulation negatively through the lower wage rate, but, at the same time, positively due to the higher private capital accumulation, as shown in (4.27). This is so because there are more individuals who evade taxation, and those that are not caught[6] allocate their savings in the capital market, contributing to private capital accumulation more than the individuals who suffered the heavy toll of the tax burden on their incomes. Since the model economy is closed, individuals who evade taxation and are not caught can only supply their savings to the domestic private capital market. Were it possible to

[5] We could get to the same result if we considered there was a *continuum* of individuals normalized to 1, so that the aggregate saving of the corrupt and non-corrupt subpopulations would be $S_{c,t} = \int_0^{x_t} s_t y^e_{c,t} dz = s_t y^e_{c,t} x_t = \frac{1-\rho}{2+\theta} w(x_t, k_t) x_t$ and $S_{n,t} = \int_{x_t}^1 s_t y^e_{n,t} dz = \frac{1-\tau}{2+\theta} w(x_t, k_t)(1-x_t)$, respectively. We would substitute these equations in (4.24) and, considering the population is normalized to one, capital intensity at $t+1$ would therefore be the sum of the integrals presented above. We would then obtain (4.25).

[6] It is worth recalling that the probability of detection ε does not depend on the incidence of corruption.

allocate their savings on foreign economies, the positive impact of a higher incidence of corruption on capital accumulation would vanish, or at least be reduced. There would occur capital flight, maybe to tax heavens or even secret accounts abroad.

To achieve our goal of assessing the interaction between corruption and capital accumulation, the level of corruption still needs to be endogenously determined. In order to do so, we now present the evolutionary path the corrupt subpopulation follows, an important feature of our model.

4.4 AN EVOLUTIONARY DYNAMICS OF CORRUPTION

An individual takes the risk of adopting a non-abiding behavior because she expects to have an increase in her income, for a given probability of being caught. The higher is her expected income, the higher can be consumption in both periods of her life and, accordingly, the utility attained. Therefore, an individual's behavior toward corruption plays a crucial role in our model. It is convenient for our analysis, then, to find an expression for an individual's utility in terms of her expected income. We do this by deriving the indirect utility function, that is, the maximum utility that can be attained for a given good price and a given expected income.

4.4.1 Indirect utility functions

Recall that young individuals in the economy, regardless of their abidance behavior, save part of their income and consume the rest. Thus, from (4.1) and (4.7), a type $j = c, n$ individual's optimal first-period consumption is given by:

$$c^*_{j,1t} = \frac{1+\theta}{2+\theta} y_{j,t}. \tag{4.28}$$

When retired, individuals consume their savings plus the interest earned. Hence, from, (4.2) and (4.7), a type $j = c, n$ individual's optimal second-period consumption is

$$c^*_{j,2t+1} = \frac{1+r_{t+1}}{2+\theta} y_{j,t}. \tag{4.29}$$

For analytical purposes, we derive the indirect utility function based on the following positive monotonic transformation of the utility function:

$$\begin{aligned}\tilde{u}_t(c_{j,1t}, c_{j,2t+1}) &= \left[\frac{2+\theta}{1+\theta}\left(\frac{2+\theta}{1+r_{t+1}}\right)^{\frac{1}{1+\theta}} e^{u_t}\right]^{\frac{1+\theta}{2+\theta}} \\ &= \left[\frac{2+\theta}{1+\theta}\left(\frac{2+\theta}{1+r_{t+1}}\right)^{\frac{1}{1+\theta}} e^{\left(\ln c_{1t} + \frac{1}{1+\theta}\ln c_{2t+1}\right)}\right]^{\frac{1+\theta}{2+\theta}}. \end{aligned} \tag{4.30}$$

Notice that the first-order conditions obtained from the maximization of (4.30) subject to (4.3) satisfy (4.6), that is, both utility functions (4.4) and (4.30) represent the same preference relation.

Substituting (4.28) and (4.29) into (4.30) leads us to the type $j = c, n$ individual's indirect utility function, given by:

$$\tilde{u}_t(c^*_{j,1t}, c^*_{j,2t+1}) = y_{j,t}. \tag{4.31}$$

As we can see from (4.31), an individual's utility ultimately depends on her expected income. That is what she takes into account when choosing her strategy. Therefore, the utility attained by individuals who are willing to take the risk of adopting a non-abiding behavior may differ substantially from the one attained by those who choose to fully abide by the law. This is a relevant feature of the satisficing dynamics according to which the level of corruption will evolve.

4.4.2 A satisficing dynamics

We now describe an evolutionary dynamics through which corruption evolves, grounded on individual decision making based on a satisficing evolutionary mechanism[7]. Following the arguments put forward by Wagner (2017), because corrupt activities are usually intended to be concealed, an offender's payoff is unknown to the rest of the population. In our framework, there are two channels through which an individual may acquire information about a given strategy's payoff. Suppose that individual i belongs to the generation born in $t+1$. She may either get in touch with an individual born in t who has played the corrupt strategy and learn what has been its payoff the previous period, or she may not have contact with an individual of such type and learn what has been the non-corrupt strategy's payoff the previous period, which we assume is publicly known. The distribution of strategies throughout the population determines not only the payoff values, but also the access to information about them.

Let us first consider the case where individual i, born in $t+1$, does not get in touch with a corrupt individual born in t. We assume the relative frequency of corruption in the population, given by x_t, measures the strategy's popularity and influences the decisions made by individuals born in $t+1$. The more prevalent is corruption in society, the greater are the chances of an individual born in $t+1$ being influenced by an individual who has taken the risk of adopting a non-abiding behavior in t. This way, the relative frequency of the corrupt strategy in one period serves as a proxy for the contagion of corruption in the subsequent period. This means that, of all individuals born in $t+1$, a fraction $x_t L_{t+1}$ of them is marred by corruption.

Having had contact with an individual who had played the corrupt strategy the previous period, individual i acquires information about the corrupt strategy's payoff, $y_{c,t}$. Whether she will effectively engage in corruption depends on a satisficing choice protocol. We assume individual i has a threshold payoff μ_i she considers to be the

[7] For more details about types of learning and their modeling as an evolutionary dynamics, see Ponti (2000).

minimum acceptable, such that whenever the payoff yielded by the corrupt strategy exceeds μ_i, she is willing to take the risk and get in the lottery of adopting a non-abiding behavior. We will dub this process as “induced corruption". We also assume that the threshold payoff is randomly and independently determined across individuals born in the same generation and across different generations. It can be represented as a random variable that follows a continuously differentiable and strictly increasing cumulative distribution function given by $P : \mathbb{R} \to [0,1] \subset \mathbb{R}$. Thus the probability with which individual i, influenced by a corrupt individual born in t, adopts a non-abiding behavior in $t+1$ is given by:

$$Prob\left(\mu_i < y_{c,t}\right) = P\left(y_{c,t}\right). \tag{4.32}$$

Therefore, assuming that the random variables related to the satisficing and to the corruption's pervasiveness effects are independent from each other, the number of individuals born in $t+1$ who are marred by corruption and cannot resist but indulge in it is given by:

$$x_t L_{t+1} P\left(y_{c,t}\right). \tag{4.33}$$

However, individual i may be willing to take the risk of adopting a non-abiding behavior simply because the non-corrupt strategy's payoff is lower than her threshold μ_i, regardless of induced corruption. As aforementioned, individual i may not have contact with an individual who has played the corrupt strategy the previous period and learn the non-corrupt strategy's payoff, $y_{n,t}$. In this case, she effectively goes for the corrupt strategy if the payoff yielded by the non-corrupt strategy is lower than that which she considers to be the minimum acceptable. We will dub this as “autonomous corruption". The probability with which individual i, who was born in $t+1$ and was not influenced by a corrupt individual born in t, adopts a non-abiding behavior can be expressed as:

$$Prob\left(\mu_i > y_{n,t}\right) = 1 - Prob\left(\mu_i \leq y_{n,t}\right) = 1 - P\left(y_{n,t}\right). \tag{4.34}$$

Considering that a fraction $(1-x_t)L_{t+1}$ of individuals born in $t+1$ do not get in touch with an individual who has played the corrupt strategy the previous period, and, again, assuming that the random variables related to the satisficing and to the corruption's pervasiveness effects are independent from each other, the number of individuals who engage in autonomous corruption is given by:

$$(1-x_t)L_{t+1}\left[1 - P\left(y_{n,t}\right)\right]. \tag{4.35}$$

In the present context of decision making under uncertainty, the process of obtaining information depends on the distribution of strategies throughout the population (social influence), but the effective decision of engaging in corruption relies on individuals' satisficing behavior.

Notice that the greater is μ_i, the more resistant is the individual born in t with respect to induced corruption, but at the same time, the more inclined she is to engage in autonomous corruption, in view of the macroeconomic circumstances (namely, wage and tax rates). The threshold payoff μ_i, hence, may be related to each individual's moral values. Individuals with a high threshold payoff, for instance, are less affected by peer pressure, but more likely to engage in corruption by their own. On the other hand, individuals with a low threshold payoff tend to be more vulnerable to their peers' influence, but less likely to engage in autonomous corruption.

Aggregating (4.34) and (4.35) yields the total number of individuals who are willing to take the risk of adopting a non-abiding behavior in $t+1$:

$$L_{c,t+1} = x_t L_{t+1} P\left(y_{c,t}\right) + (1-x) L_{t+1}\left[1 - P\left(y_{n,t}\right)\right]. \tag{4.36}$$

Dividing both sides of (4.36) by the number of young individuals born in $t+1$ leads us to the following satisficing evolutionary dynamics:

$$x_{t+1} = x_t P\left(y_{c,t}\right) + (1-x_t)\left[1 - P\left(y_{n,t}\right)\right]. \tag{4.37}$$

The evolutionarily satisficing dynamics expressed by (4.37) states that corruption increases as the corrupt (non-corrupt) strategy's payoff is higher (lower), because of the stronger incentive individuals have to play the corrupt strategy.

4.5 PERSISTENT CORRUPTION AND MACROECONOMIC CONSEQUENCES

For analytical purposes, we assume the threshold payoff follows an exponential distribution, that is, $P(y_{j,t}) = 1 - \mathrm{e}^{-\lambda y_{j,t}}$, for an individual of type $j = c, n$, where $\lambda > 0$ is the distribution's rate parameter. The exponential distribution's mean is given by the inverse of the rate parameter, hence $\frac{1}{\lambda}$ is the mean of the threshold payoffs of individuals born in t. The rate parameter λ, thus, can be thought of as society's average moral standard, or degree of honesty. We should expect that societies with high moral standards tend to present a high value of λ, implying that individuals are less likely to engage in autonomous corruption, yet more likely to give way to induced corruption.

Having obtained the equations that describe the evolution of capital stock and of corruption, we can analyze the economy's dynamics. Taking $P(y_{j,t}) = 1 - \mathrm{e}^{-\lambda y_{j,t}}$ and substituting (4.8), (4.10) and (4.20) in the two difference equations (4.25) and (4.37), we can write the dynamical system that represents the state transition of the economy as follows:

$$\begin{cases} x_{t+1} = x_t\left[1 - \mathrm{e}^{-\lambda(1-\rho)w_t}\right] + (1-x_t)\mathrm{e}^{-\lambda(1-\tau)w_t}, \\ k_{t+1} = h(x_t)w(x_t, k_t), \end{cases} \tag{4.38}$$

whose state space is given by $\Theta \equiv \left\{(x,k) \in \mathbb{R}^2 : 0 \le x \le 1, k > 0\right\}$.

In the steady state, both capital intensity and the level of corruption are unchanging in time. The equilibrium must satisfy $k_{t+1} = k_t = k^*$ and $x_{t+1} = x_t = x^*$, for all $t \in \mathbb{N}$, where k^* and x^* denote the steady state level of each variable. We are going to show that a polymorphic (mixed-strategy) equilibrium such that $x^* \in (0,1) \subset \mathbb{R}$, where both corrupt and non-corrupt strategies survive in the long run, exists and is unique.

Using (4.20) and the second equation in (4.38), we can express capital intensity in the equilibrium as a function of the proportion of individuals who play the corrupt strategy in that equilibrium:

$$k^* = [1-(\alpha+\beta)]^{\frac{1}{1-(\alpha+\beta)}} h(x^*)^{\frac{1-\beta}{1-(\alpha+\beta)}} [\tau(1-x^*)+\rho x^*]^{\frac{\beta}{1-(\alpha+\beta)}} \equiv k(x^*). \tag{4.39}$$

First, we are going to show that a monomorphic equilibrium, where only of the strategies survive in the long run, is not possible. Notice, from the first equation in (4.38), that if $x_t = 0$, then $x_{t+1} = \mathrm{e}^{\lambda(1-\tau)w(0,k(0))} > 0$. Thus $(0,k(0))$ is not an equilibrium. Analogously, if $x_t = 1$, then $x_{t+1} = 1-\mathrm{e}^{-\lambda(1-\rho)w(1,k(1))} < 1$. Thus $(1,k(1))$ is not an equilibrium either.

In fact, we are going to show that a polymorphic equilibrium, such that $x^* \in (0,1) \subset \mathbb{R}$, is the only evolutionarily possible outcome. Let

$$\varphi(x_t,k(x_t)) \equiv x_{t+1}-x_t = -x_t\mathrm{e}^{-\lambda(1-\rho)w_t} + (1-x_t)\mathrm{e}^{-\lambda(1-\tau)w_t}. \tag{4.40}$$

Considering the first equation in (4.38), we know that $x_{t+1} = x_t = x^*$ if, and only if, $\varphi(x^*,k(x^*)) = 0$. Let us show that there is a unique $x^* \in (0,1) \subset \mathbb{R}$ such that $\varphi(x^*,k(x^*)) = 0$. Notice, from (4.40), that

$$\varphi(0,k(0)) = \mathrm{e}^{-\lambda(1-\tau)w(0,k(0))} > 0 \tag{4.41}$$

and that

$$\varphi(1,k(1)) = -\mathrm{e}^{-\lambda(1-\rho)w(1,k(1))} < 0. \tag{4.42}$$

Therefore, we can apply the intermediate value theorem to readily conclude that there exists some $x^* \in (0,1) \subset \mathbb{R}$ such that $(x^*,k(x^*))$ is an evolutionary equilibrium.

Moreover, notice, from (4.40), that

$$\frac{\partial\varphi}{\partial x_t} = -\mathrm{e}^{-\lambda(1-\rho)w_t} - \mathrm{e}^{-\lambda(1-\tau)w_t} - \lambda\left[(1-x_t)(1-\tau)\mathrm{e}^{-\lambda(1-\tau)w_t} - x_t(1-\rho)\mathrm{e}^{-\lambda(1-\rho)w_t}\right]\left(\frac{\partial w_t}{\partial x_t} + \frac{\partial w_t}{\partial k_t}\frac{\partial k_t}{\partial x_t}\right). \tag{4.43}$$

We know that in the equilibrium $\varphi(x^*,k(x^*)) = 0$. From (4.40), it follows that

$$x^*\mathrm{e}^{-\lambda(1-\rho)w^*} = (1-x^*)\mathrm{e}^{-\lambda(1-\tau)w^*}, \tag{4.44}$$

where $w^* \equiv w(x^*,k^*)$. Substituting (4.44) into (4.43) yields

$$\frac{\partial\varphi(x^*,k^*)}{\partial x_t} = \Phi(x^*,k^*) - x^*\mathrm{e}^{-\lambda(1-\rho)w^*}\lambda\left[(\rho-\tau)\left(\frac{\partial w_t}{\partial x_t} + \frac{\partial w_t}{\partial k_t}\frac{\partial k_t}{\partial x_t}\right)\right], \tag{4.45}$$

where $\Phi(x^*, k^*) \equiv -e^{-\lambda(1-\rho)w^*} - e^{-\lambda(1-\tau)w^*} < 0$. We can simplify the expression in brackets in (4.45) and rewrite it as

$$(1-\beta)\left\{\beta - \alpha\left[\frac{+\tau(1-x^*)+\rho x^*}{(1-\rho)x^* + (1-\tau)(1-x^*)}\right]\right\}. \tag{4.46}$$

Expression (4.46) is strictly positive if the following sufficient condition is satisfied:

$$\frac{\beta}{\alpha+\beta} > \tau(1-x^*) + \rho x^*. \tag{4.47}$$

Assuming (4.47) is satisfied and recalling that $\Phi(x^*, k^*) < 0$, it follows, from (4.45), that $\varphi(x_t, k_t)$ is strictly decreasing around the equilibrium $(x^*, k(x^*))$. Considering (4.41), (4.42) and (4.45), we can conclude that there exists only one $x^* \in (0,1) \subset \mathbb{R}$ such that $\varphi(x^*, k(x^*)) = 0$. Furthermore, notice, from (4.47), that as α approaches zero, the left-hand side of (4.47) approaches one, so that the sufficient condition (4.47) is always satisfied, implying that a low level of capital productivity leads to the emergence of corruption.

Local stability analysis through the system's linearization does not yield tractable analytical results. The nonlinearities present in the dynamical system require a numerical investigation of the model's long-run global dynamical behavior. As suggested by Medio and Lines (2001, p. 105), it can be done "[...] by studying the asymptotic behaviour of orbits and concentrating the analysis on regions of the state space which are *persistent* in the weak sense that orbits never leave them [...]".

In order to do so, we assume the model's parameters take values commonly adopted in the literature. Based on Leeper, Walker, and Yang (2010), capital's output share is calibrated to $\alpha = 0.36$, the share of productive public expenditure to $\beta = 0.1$, labor income tax rate to $\tau = 0.214$, and the discount factor to $\theta = 0.99$. We set the initial level of corruption to $x = 0.1$ and the initial capital intensity to $k = 0.03$. In order to satisfy condition (4.47), we set the expected punishment to $\rho = 0.1$. As for the rate parameter for the exponential distribution, we assume as benchmark that $\lambda = 0.5$, though we will show what are the implications for the system's stability when λ varies. The numerical simulations and their graphical representations presented in this section were obtained with the open-source software iDMC, version 2.0.10.[8]

[8] This version of the software is available at https://code.google.com/archive/p/idmc/.

Figure 4.1 – Lyapunov characteristic exponents.

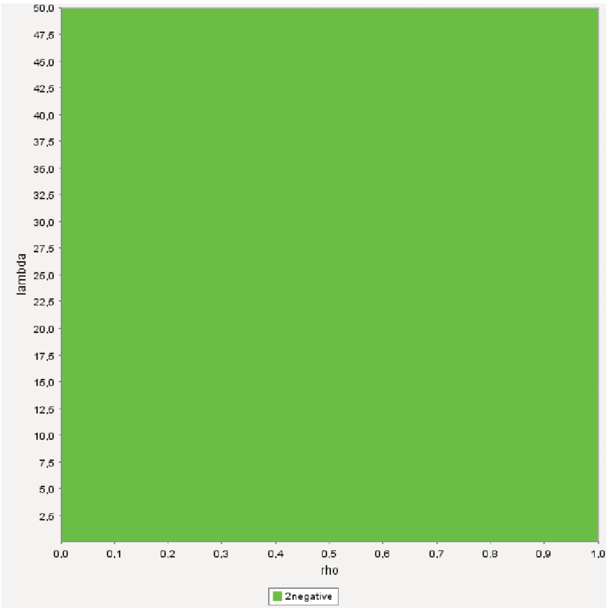

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Figure 4.1 presents the combination of values of the pair of parameters given by (ρ,λ) for which the Lyapunov characteristic exponents (LCE) are strictly negative[9], with $\rho \in (0,1) \subset \mathbb{R}$ and $\lambda \in (0,50) \subset \mathbb{R}$. Following Medio and Lines (2001, p. 193), the Lyapunov characteristic exponents (LCE) are the average, asymptotic, exponential rates of divergence of nearby orbits. Therefore, our model has 2 LCEs measuring the divergence of nearby orbits, one for each dimension. In the green region in Figure 4.1, both of the system's LCEs are negative, meaning that orbits in the basin of attraction of the economy's steady state converge to it, as the distance between them decreases (MEDIO; LINES, 2001, p. 197). Notice that the system is asymptotically stable for every combination of values of ρ and λ considered.

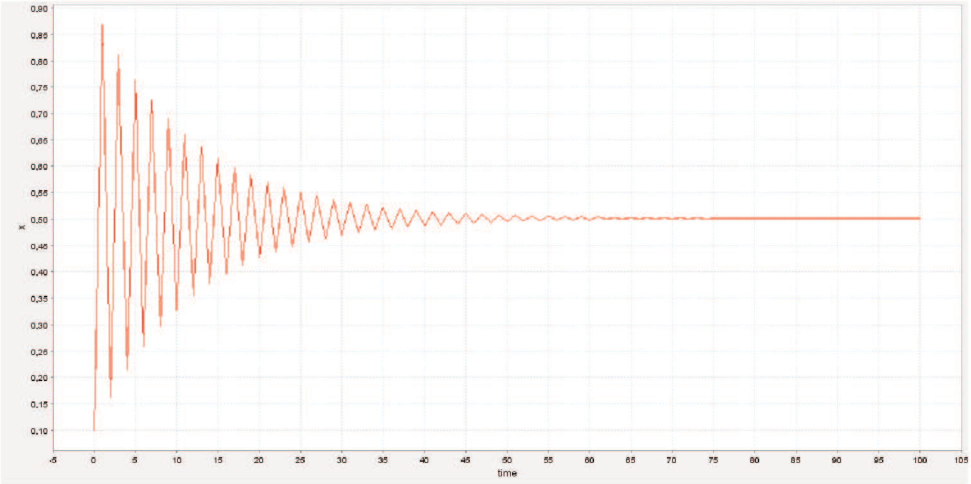
Figure 4.2 pictures the trajectories[10] for the level of corruption (panel (a)), capital intensity (panel (b)) and the wage rate (panel (c)) according to the parameter values and initial conditions specified above. Notice, from panels (b) and (c), that the evolution of the wage rate qualitatively accompanies that of capital intensity, as shown in expression (4.21).

[9] We set the precision parameter (smaller value corresponding to greater precision) to 0.01, with 5000 iterations. As recommended by Lines (2007), this is an appropriate value for looking for positive exponents.

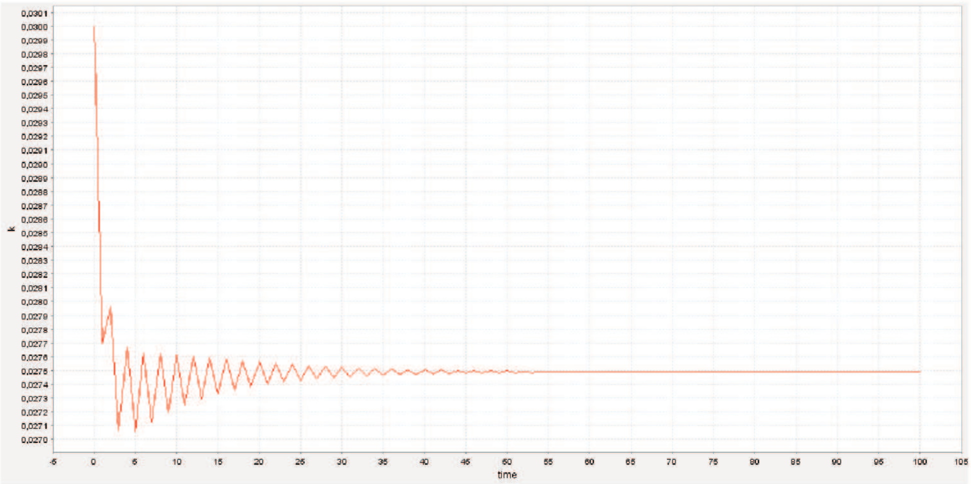
[10] For a clearer visualization of the system's dynamics, we set 100 iterations and no transient iterations. For this routine, the algorithm required, apart from the already specified parameters, an initial value for the wage rate. We set it to $w = 0.103$, which is the value obtained when we substitute the parameters and initial conditions specified above into expression (4.20).

Figure 4.2 – Trajectories for x, k and w when $\rho < \tau$.

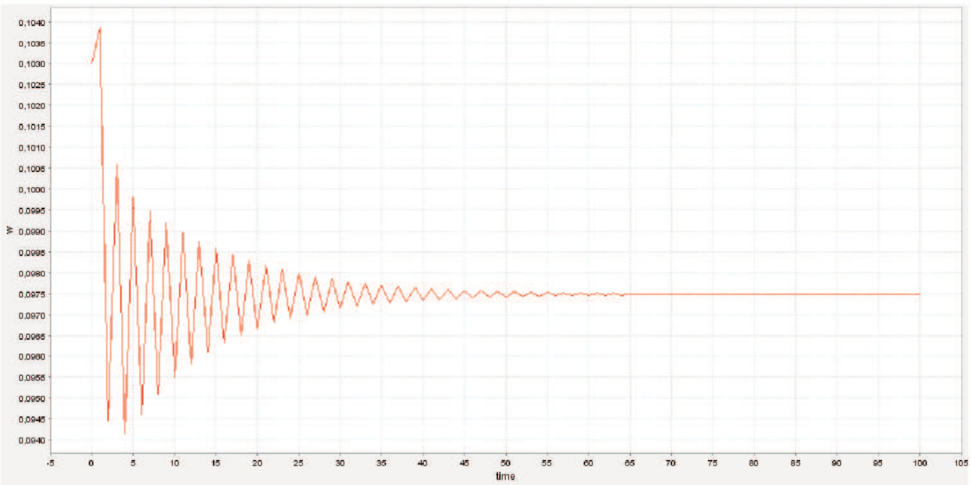
(a) Trajectory for x.



(b) Trajectory for k.



(c) Trajectory for w.



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The economy's dynamics can be illustrated as follows. Given the initial conditions, the economy is in a situation where $0 < x < x^*$. Since $\rho < \tau$, we know, from (4.8) and (4.10), that individuals have an incentive to take the risk of adopting a non-abiding behavior. Thus the fraction of individuals who play the corrupt strategy increases. As this change takes place, capital intensity declines, because the increase in corruption diverts resources from productive activities to less productive ones. Consequently, the wage rate falls, because of (4.21) and (4.22). This impact on the wage rate is more strongly felt by an individual who plays the corrupt strategy, since $\rho < \tau$. Individuals, now, have an incentive to adopt an abiding rather than a non-abiding behavior. Thus the fraction of individuals who play the corrupt strategy decreases. Because capital intensity increases as a consequence of lower incidence of corruption, so does the wage rate, which encourages individuals to play the corrupt strategy.

This mechanism goes on until the economy reaches its steady state with higher incidence of corruption, lower capital intensity and lower wage rate. Notice, in panel (c) in Figure 4.2, that the wage rate slightly rises before a sharp fall. This happens because prior to the reaction of the wage rate to the decline in capital intensity, private contribution to capital accumulation increases, due to the increased tax evasion. The increase in private saving raises the wage rate, but this effect is soon overwhelmed because of the lower productive public expenditure.

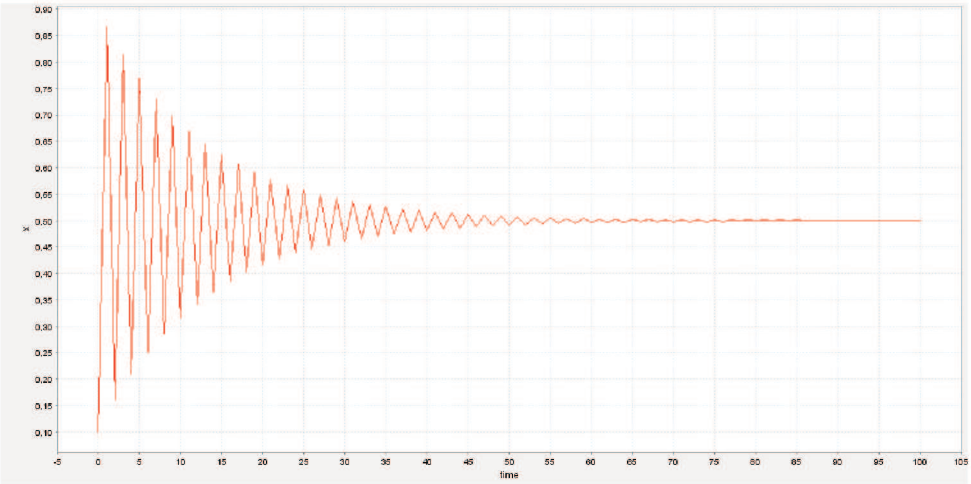
As we know from Figure 4.1, the system is asymptotically stable for every combination of $\rho \in (0,1) \subset \mathbb{R}$ and $\lambda \in (0,50) \subset \mathbb{R}$. Suppose, then, that the expected punishment is set to a level such that $\rho > \tau$. Figure 4.3 shows the trajectories for x (panel (a)), k (panel (b)) and w (panel (c)) when $\rho = 0.247$[11] and the other parameters and initial conditions remain the same (recall that $\tau = 0.214$).

In Figure 4.3, the numerical simulation's results do not present significant qualitative changes from Figure 4.2. The steady state levels of corruption, capital intensity and wage rate, in this case, are lower, but the behavior of the variables is quite similar. The economy begins at a point where $0 < x < x^*$. There is an initial increase in the level of corruption because, regardless of the value ρ assumes, some individuals will have a threshold payoff so low that they consider the tax rate a duty too costly on their income, thus they engage in autonomous corruption. That is all it takes to kickstart the chain reaction of increasing corruption and decreasing capital intensity. It is worth noticing, also, that when $\rho > \tau$, reactions of the capital intensity and wage rate to changes in the level of corruption are less pronounced, compared to when $\rho < \tau$. This is so because the revenue obtained from fines by the government is not so different than the one it would obtain were all individuals to play the non-corrupt strategy. This prevents capital intensity and the wage rate from varying so much every time the level of corruption changes.

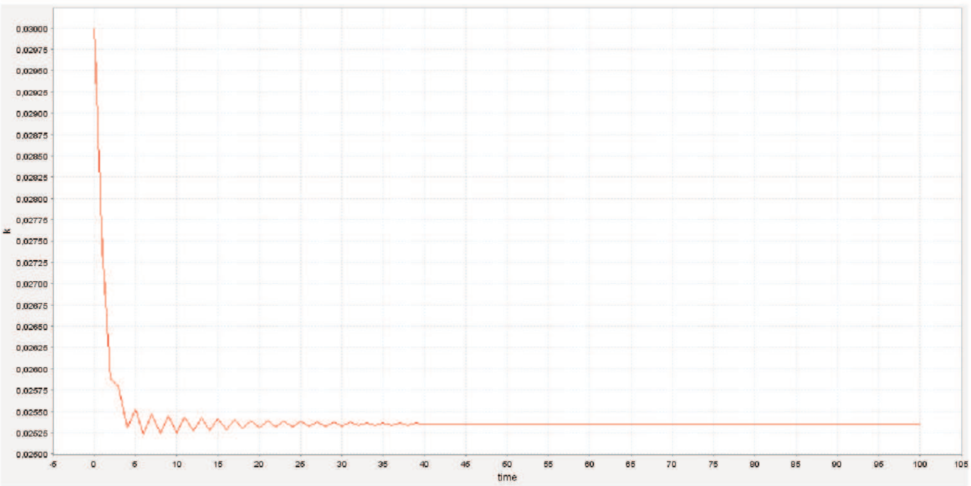
[11] This is the maximum value of ρ for which condition (4.47) is satisfied.

Figure 4.3 – Trajectories for x, k and w when $\rho > \tau$.

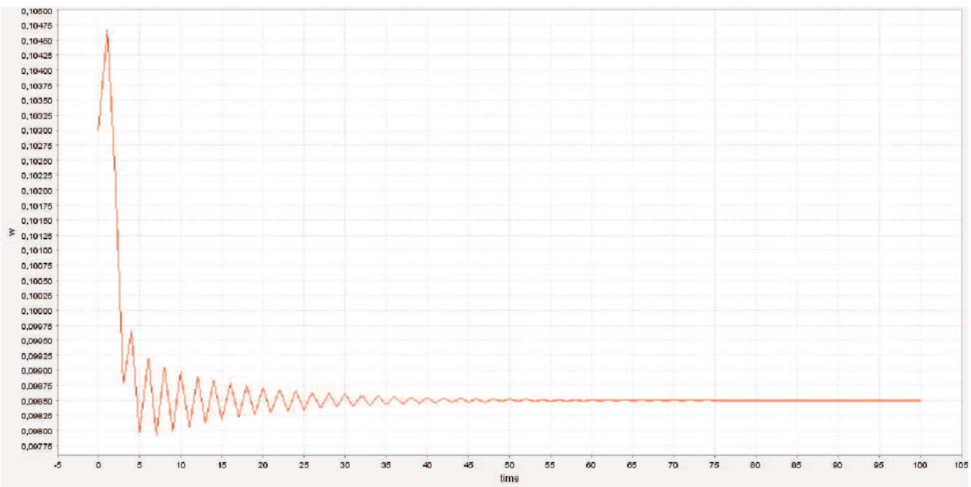
(a) Trajectory for x.



(b) Trajectory for k.



(c) Trajectory for w.



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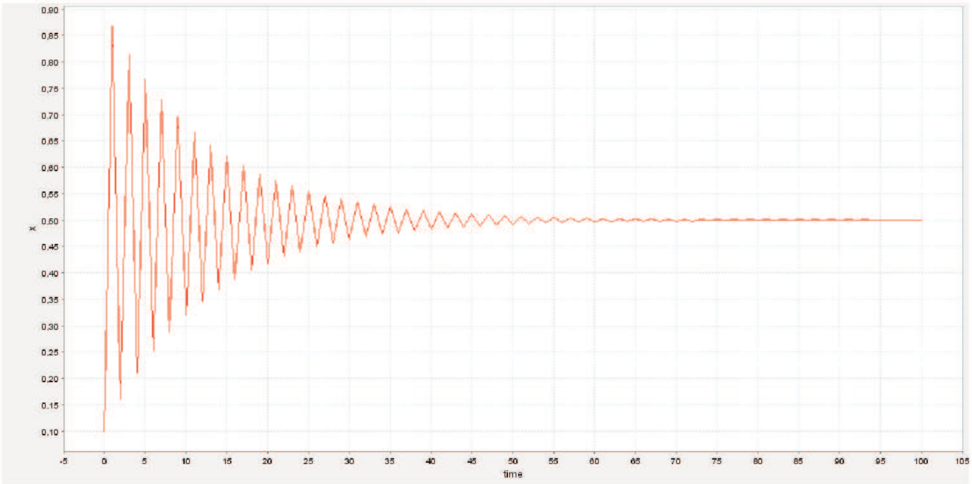
At last, suppose that the economy's institutional set is such that $\rho = \tau$. Trajectories for *x* (panel (a)), *k* (panel (b)) and *w* (panel (c)) when this is the case are presented in Figure 4.4. In Figure 4.4, the expected punishment is set to $\rho = 0.214$, while all other numerical specifications remain unaltered. Once again, the pervasiveness of corruption leads to its persistence, along with lower levels of capital intensity and wage rate. In this case, when the level of corruption changes, the ensuing capital intensity and wage rate movements are practically absent, since $\rho = \tau$.

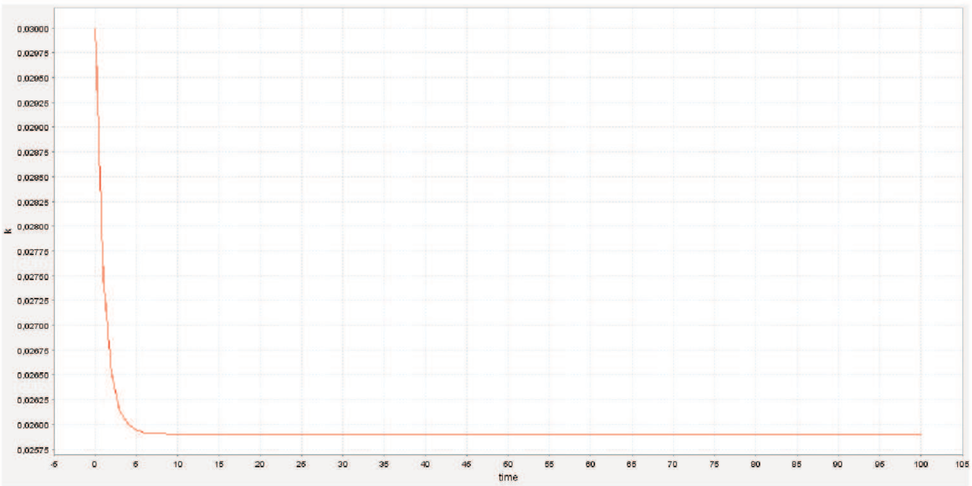
It is clear from these illustrations that the interaction between corruption and capital accumulation engenders a vicious circle of corruption dampening economic growth, which goes on until corruption reaches its steady state level and capital intensity is at a level lower than its initial one. Overall, the gain in private saving resulting from more individuals evading taxation is overwhelmed by the loss in effective tax revenue and the consequent lower productive public expenditure. The consequence of persistent corruption with regard to the growth of the economy is that capital accumulation in the steady state is lower than in the case where corruption is absent.

Figure 4.4 – Trajectories for x, k and w when $\rho = \tau$.

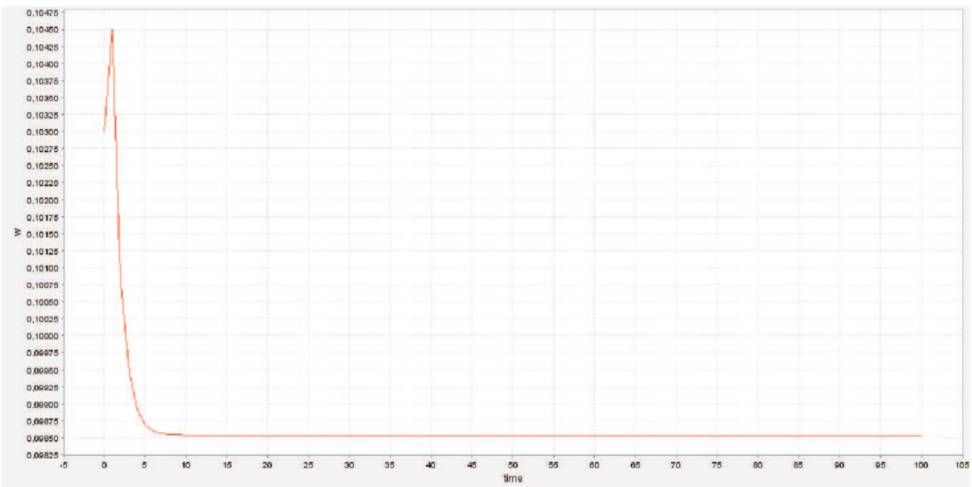
(a) Trajectory for x.



(b) Trajectory for k.



(c) Trajectory for w.



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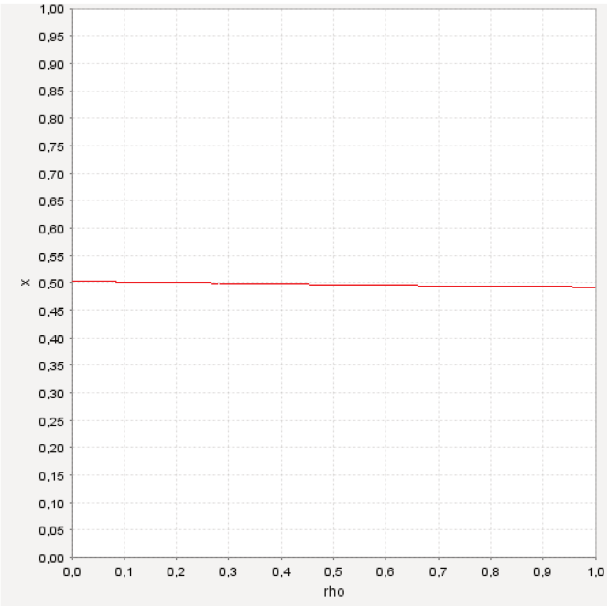
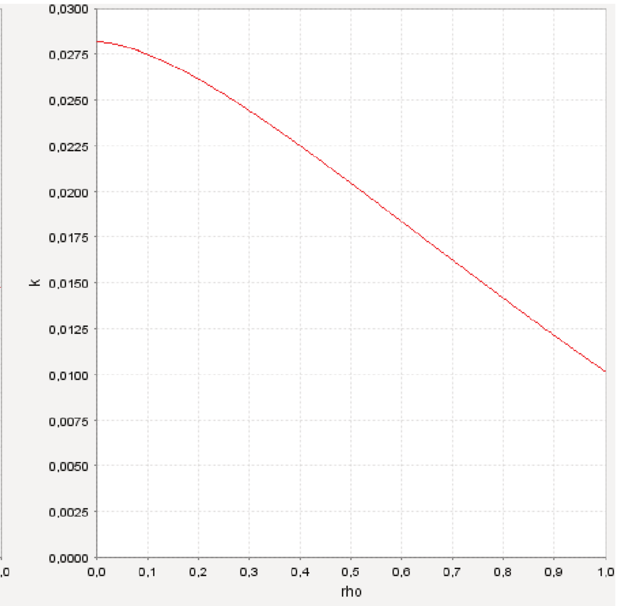
In order to better understand the long-run global dynamics of the system, Figure 4.5 pictures one-parameter bifurcation diagrams describing the long-run behavior of the levels of corruption and capital intensity as functions of ρ and τ. The expected punishment faced by individuals who play the corrupt strategy, ρ, and the tax rate, τ, are the instruments that the government has to fight corruption. On the one hand, a low tax rate may be used as a disincentive for individuals to take the risk of adopting a non-abiding behavior. On the other, the government may try to raise the value of ρ by improving its monitoring efficiency (and thus the probability of detection of corruption), or by raising the fine imposed on individuals who play the corrupt strategy and are caught. These parameters are ultimately related to the economy's institutional set.

Figure 4.5 – Long-run impacts of ρ and τ.

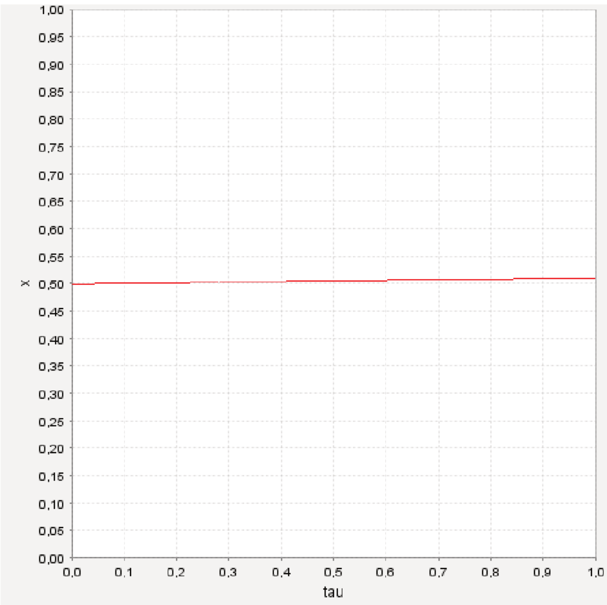
(a) Impact of ρ on x^*.



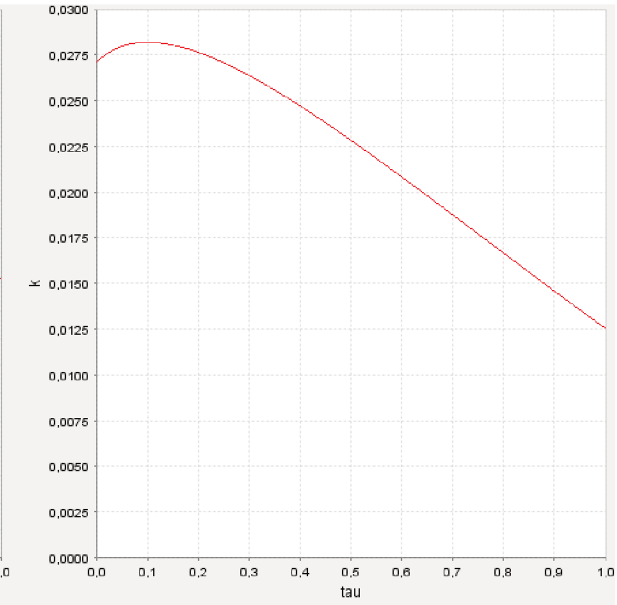
(b) Impact of ρ on k^*.



(c) Impact of τ on x^*.



(d) Impact of τ on k^*.



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In Figure 4.5, the required numerical specifications are as in Figures 4.1 and 4.2. We set 5000 iterations, of which 1000 are designated as transient (i.e. the number of initial iterations that have been ignored by the algorithm before computing the equilibrium values). In panels (a) and (d), the long-run impact of the expected punishment (ρ) and the tax rate (τ), respectively, on the equilibrium level of corruption is portrayed, with $\rho \in (0,1) \subset \mathbb{R}$ and $\tau \in (0,1) \subset \mathbb{R}$.

An increase in ρ leads to a slight decrease in x^*, which can be explained by the higher duty on the income of those individuals who play the corrupt strategy. An increase in τ, as expected, leads to a slight increase in x^*, since a higher tax rate encourages individual who are willing to take the risk of adopting a non-abiding behavior to play the corrupt strategy. Panels (b) and (c), in turn, portray the long-run impact of the expected punishment and the tax rate, respectively, on the equilibrium level of capital intensity. As ρ increases, capital intensity decreases, suggesting that the gain in revenue obtained from fines by the government is not enough to compensate the loss in effective tax revenue due to tax evasion. This is because, even when ρ increases, corruption persists in the long-run. As τ increases, on the other hand, capital intensity increases at first, because of higher effective tax revenue, but soon starts to fall, as the fraction of individuals who take the risk of adopting a non-abiding behavior rises, and the vicious circle of higher corruption and lower capital intensity takes place.

4.6 FINAL REMARKS

We have developed a dynamic model of growth to study the impact of corruption to capital accumulation in an economy where both variables are endogenous and simultaneously determined. In our framework, capital accumulation stems from individuals' saving decisions. Firms hire labor from young individuals and combine it with the capital owned by the old and the productive public expenditure to produce output in the form of an homogeneous consumption good.

The government provides goods to be used in the private production process financed by taxes. Due to the willingness of some individuals to take the risk of adopting a non-abiding behavior, however, effective tax revenue may be lower than its expected level, so the government audits individuals in order to deter tax evasion. We assume an exogenously given probability of detection, but a natural extension to the model would be to propose a function where the probability of detection is related to the incidence of corruption in the economy, as suggested by the literature.

Even though the model could have yielded a positive impact of corruption on capital accumulation because individuals who evade taxation and are not caught can only supply their savings to the domestic private capital market, the results presented in section 4.5 illustrated the opposite effect. For reasonable parameter values, numerical simulations showed, overall, the gain in private saving resulting from more individuals evading taxation is overwhelmed by the loss in effective tax revenue and the consequent lower productive public expenditure. The consequence of persistent corruption with regard to the growth of the economy is that capital accumulation in the steady state is lower than in the case where corruption is absent.

If the expected punishment for misconduct is not sufficiently high, corruption lingers parallel to capital accumulation. Moreover, if the expected punishment for an individual who is willing to take the risk of adopting a non-abiding behavior is lower than the tax rate, then individuals have an incentive to play the corrupt strategy up until the point where the economy reaches the polymorphic equilibrium $(x^*(k^*), k^*(x^*))$. This is so because the tax rate is the duty on income faced by individuals who adopt an abiding behavior. The absence of monomorphic equilibria can be related to an irreducible level of corruption, as suggested by Ellis and Fender (2006): since some individuals will always consider the tax rate a duty too costly on their income, there will always be individuals who are willing to take the risk of adopting a non-abiding behavior.

We have modeled the dynamics of corruption as an evolutionary process based on the satisficing principle. In the present context of decision making under uncertainty, the process of obtaining information depends on social influence, but the effective decision of engaging in corruption relies on individuals' satisficing behavior. The decision of individuals to take the risk of adopting a non-abiding behavior lies ultimately on their moral values. This aids to understand the persistence of corruption in the economy. In societies with high moral standards, we should expect to find fewer individuals inclined to engage in autonomous corruption. We have showed that an equilibrium where a fraction of the population who plays the corrupt strategy coexists with the remaining fraction who plays the non-corrupt strategy is the only evolutionarily stable outcome. This result suggests that corruption is not a phenomenon that naturally disappears in the long run, instead it lingers parallel to capital accumulation, despite its harmful effects to economic growth the associated moral cost.

In our model, the incidence of corruption in the economy decreases capital accumulation, so the steady state level of the latter is lower when compared to the case of absence of corruption. The growth of output per worker temporarily oscillates during the short-run transitional dynamics until the economy reaches its new steady state. Sustained growth, nonetheless, is only possible through technological progress, which is not considered here. It is, thus, a model of exogenous growth. A possible extension of considering technological progress is left for future research.

5 CONCLUSION

Corruption has become an endemic phenomenon, lingering parallel to capital accumulation and economic development, and it does not give evidence of self-correction in the long run. This thesis presented two essays concerning the investigation on the persistence of corruption from an evolutionary approach and its impact to economic growth, apart from a broad review on the subject (chapter 2).

The third chapter presented the thesis's the first essay, in which we proposed an evolutionary approach to the dynamics of corruption in a society, based on pairwise interactions among boundedly rational agents, in order to capture the influence of society's aggregate behavior as perceived by individuals on their decision-making process. In our model, individuals are not intrinsically corrupt or honest. Instead, they act as agents with bounded rationality, weighing the gains and losses of adopting a non-abiding behavior towards the law. What is inherent to each individual is the threshold payoff below which each agent decides to take the risk of disobeying the law. This threshold may be related to agents' risk aversion, intertemporal discount rate, moral values, or other idiosyncratic characteristics.

Our results suggest that the thriving of public sector corruption demands the acceptance of private agents, implying that in the dance of corruption, it takes two to tango. A polymorphic equilibrium, where both strategies survive in the long run is evolutionarily unstable. Even if the economy starts on the saddle path, a small disturbance leads it to an equilibrium of absence of corruption, or of institutionalized corruption, widespread in both populations and regarded as the social norm, according to the expected punishments faced by each population. This idea corroborates the literature, namely Andvig and Moene (1990), Mishra (2006) and Accinelli and Carrera (2012). As argued by Litina and Palivos (2016), corruption can only be suppressed if the government tackles the strategic interaction between private agents and public officials. Otherwise, corruption may become a deep-rooted phenomenon in society, one which lingers through long periods of time.

Chapter 4 of this thesis presented the essay that explored the impacts and the channels through which corruption affects growth when both variables are endogenous and simultaneously determined, which is still incipient in the existing literature. In this second essay, we developed a dynamic growth model with productive public expenditure to study some macroeconomic consequences of corruption, most specifically its impact to capital accumulation, considering the feedback effect between corruption and the macroeconomic variables. In particular, we propose an evolutionary dynamics of corruption that accounts for its persistence based on individuals' satisficing behavior. The harmful effects of corruption to growth have been empirically verified by Mauro (1995), Mo (2001) and Svensson (2005). This is reiterated in our model: the consequence of persistent corruption with regard to the growth of the economy is that capital accumulation in the steady state is lower than in the case where corruption is absent.

In the first essay, we achieved our goal of modeling corruption as an evolutionary process in a context where its persistence may be due not to historical circumstances, but to the fact that it has costs and gains on which individuals base their decisions, contingent to the economy's institutional set. In the second essay, we showed that persistent corruption has adverse effects to capital accumulation in the long run, since it transfers resources from public productive activities to less productive ones, despite being viewed as immoral. Using the framework of the first essay in the growth model of second essay can yield interesting results. We leave it for further research. Another interesting research would be to investigate the impact of corruption on the distribution of wealth and on social welfare, in light of the growth model proposed in the second essay.

Finally, it should also be stressed that the satisficing choice protocol is one of the many possible mechanisms of individual strategy selection. Our choice to model the dynamics of corruption following such a behavior was based on the need for secrecy of corruption activities, which makes the information concerning strategy's payoffs unavailable to the whole population, and on the easy intuitive interpretation to the models. A particularity of our argument is that every individual may potentially indulge in corruption, according to her intrinsic threshold payoff. Some may see it as a shortcoming, since there may be incorruptible individuals in the society. Nonetheless, these may also be viewed as individuals who have an extremely high threshold. Assuming a fraction of individuals to be inherently incorruptible no matter what could alter the stability of the models' equilibria. We leave it for further research as well.

REFERENCES

ACCINELLI, E.; CARRERA, E. J. S. Corruption driven by imitative behavior. **Economics Letters**, Elsevier, v. 117, n. 1, p. 84–87, 2012.

ACEMOGLU, D.; ROBINSON, J. A. **Why Nations Fail**: The Origins of Power, Prosperity and Poverty. 1st. New York: Crown, 2012. P. 529.

ACEMOGLU, D.; VERDIER, T. Property rights, corruption and the allocation of talent: a general equilibrium approach. **The Economic Journal**, Blackwell Publishers, v. 108, p. 1381–1403, Sept. 1998.

ANDVIG, J. C.; MOENE, K. O. How corruption may corrupt. **Journal of Economic Behavior & Organization**, Elsevier, v. 13, n. 1, p. 63–76, 1990.

BARDHAN, P. Corruption and development: a review of issues. **Journal of Economic Literature**, American Economic Association, v. 35, n. 3, p. 1320–1346, 1997.

BARDHAN, P. The economist's approach to the problem of corruption. **World Development**, Elsevier, v. 34, n. 2, p. 341–348, 2006.

BARRETO, R. A. Endogenous corruption in a neoclassical growth model. **European Economic Review**, Elsevier, v. 44, n. 1, p. 35–60, 2000.

BARRO, R. J. Government spending in a simple model of endogeneous growth. **Journal of Political Economy**, The University of Chicago Press, v. 98, 5, Part 2, s103–s125, 1990.

BARRO, R. J.; SALA-I-MARTIN, X. **Economic Growth**. 2nd. Cambridge: The MIT Press, 2003. P. 673.

BASU, K.; BASU, K.; CORDELLA, T. Asymmetric punishment as an instrument of corruption control. **Journal of Public Economic Theory**, Wiley Online Library, v. 18, n. 6, p. 831–856, 2016.

BICCHIERI, C.; ROVELLI, C. Evolution and revolution: the dynamics of corruption. **Rationality and Society**, SAGE Publishing, v. 7, n. 2, p. 201–224, 1995.

BLACKBURN, K.; BOSE, N.; HAQUE, M. E. The incidence and persistence of corruption in economic development. **Journal of Economic Dynamics and Control**, Elsevier, v. 30, n. 12, p. 2447–2467, 2006.

BLACKBURN, K.; FORGUES-PUCCIO, G. Distribution and development in a model of misgovernance. **European Economic Review**, Elsevier, v. 51, n. 6, p. 1534–1563, Aug. 2007.

CERQUETI, R.; COPPIER, R. Economic growth, corruption and tax evasion. **Economic Modelling**, Elsevier, v. 28, n. 1-2, p. 489–500, Jan. 2011.

COLLIER, M. Explaining corruption: an institutional choice approach. **Crime, Law and Social Change**, Springer, v. 38, p. 1–32, July 2002.

DIMANT, E.; SCHULTE, T. **The Nature of Corruption**: an interdisciplinary perspective. Jan. 2016. MPRA Paper – University Library of Munich.

DUFWENBERG, M.; SPAGNOLO, G. Legalizing bribe giving. **Economic Inquiry**, Wiley Online Library, v. 53, n. 2, p. 836–853, 2015.

ELLIS, C.; FENDER, J. Corruption and transparency in a growth model. **International Tax and Public Finance**, Springer, v. 13, p. 115–149, Jan. 2006.

FERRAZ, C.; FINAN, F. Electoral accountability and corruption: evidence from the audits of local governments. **American Economic Review**, American Economic Association, v. 101, n. 4, p. 1274–1311, 2011.

GOEL, R.; NELSON, M. Causes of corruption: history, geography and government. **Journal of Policy Modeling**, v. 32, n. 4, p. 433–447, 2010.

GUNDLACH, E.; PALDAM, M. The transition of corruption: from poverty to honesty. **Economics Letters**, Elsevier, v. 103, n. 3, p. 146–148, 2009.

HELLMANN, O. The historical origins of corruption in the developing world: a comparative analysis of East Asia. **Crime, Law and Social Change**, Springer, v. 68, p. 145–165, 2017.

IWASAKI, I.; SUZUKI, T. The determinants of corruption in transition economies. **Economics Letters**, v. 114, n. 1, p. 54–60, 2012.

JAIN, A. K. Corruption: a review. **Journal of Economic Surveys**, Wiley Online Library, v. 15, n. 1, p. 71–121, 2001.

KALENBORN, C.; LESSMANN, C. The impact of democracy and press freedom on corruption: conditionality matters. **Journal of Policy Modeling**, v. 35, n. 6, p. 857–886, 2013.

LA PORTA, R. et al. The quality of government. **Journal of Law, Economics and Organization**, Oxford University Press, v. 15, n. 1, p. 222–279, 1999.

LEDERMAN, D.; LOAYZA, N. V.; SOARES, R. R. Accountability and corruption: political institutions matter. **Economics & Politics**, v. 17, n. 1, p. 1–35, 2005.

LEEPER, E. M.; WALKER, T. B.; YANG, S. S. Government investment and fiscal stimulus. **Journal of Monetary Economics**, v. 57, n. 8, p. 1000–1012, Nov. 2010.

LEFF, N. H. Economic development through bureaucratic corruption. **American Behavioral Scientist**, SAGE Publishing, v. 8, n. 3, p. 8–14, 1964.

LIN, S.; ZHANG, W. The effect of corruption on capital accumulation. **Journal of Economics**, Springer, v. 97, n. 1, p. 67–93, 2009.

LINES, M. Practical tools for identifying dynamics in discrete systems. **Working Paper 3**, Department of Statistics, University of Udine, 2007.

LITINA, A.; PALIVOS, T. Corruption, tax evasion and social values. **Journal of Economic Behavior & Organization**, Elsevier, v. 124, p. 164–177, 2016.

LORENZ, J. Population dynamics of tax avoidance with crowding effects. **Journal of Evolutionary Economics**, Springer, v. 29, n. 2, p. 581–609, Apr. 2019.

LUI, F. T. A dynamic model of corruption deterrence. **Journal of Public Economics**, Elsevier, v. 31, n. 2, p. 215–236, 1986.

LUI, F. T. An equilibrium queuing model of bribery. **Journal of Political Economy**, The University of Chicago Press, v. 93, n. 4, p. 760–781, 1985.

MANTZAVINOS, C.; NORTH, D. C.; SHARIQ, S. Learning, institutions, and economic performance. **Perspectives on Politics**, Cambridge University Press, v. 2, n. 1, p. 75–84, 2004.

MAURO, P. Corruption and growth. **The Quarterly Journal of Economics**, The MIT Press, v. 110, n. 3, p. 681–712, 1995.

MEDIO, A.; LINES, M. **Nonlinear dynamics**: a primer. 1st. Cambridge: Cambridge University Press, 2001. P. 300.

MÉON, P. G.; WEILL, L. Is corruption an efficient grease? **World Development**, Elsevier, v. 38, n. 3, p. 244–259, 2010.

MISHRA, A. Persistence of corruption: some theoretical perspectives. **World Development**, v. 34, n. 2, p. 349–358, 2006.

MO, P. H. Corruption and economic growth. **Journal of Comparative Economics**, Elsevier, v. 29, n. 1, p. 66–79, 2001.

NORTH, D. C. Institutions. **Journal of Economic Perspectives**, American Economic Association, v. 5, n. 1, p. 97–112, Mar. 1991.

PHILP, M. Defining political corruption. **Political Studies**, SAGE Publishing, v. 45, n. 3, p. 436–462, 1997.

PONTI, G. Continuous-time evolutionary dynamics: theory and practice. **Research in Economics**, Elsevier, v. 54, n. 2, p. 187–214, 2000.

PRZEWORSKI, A. **Why Bother with Elections?** Cambridge: Polity Press, 2018. P. 141.

ROSE-ACKERMAN, S. The economics of corruption. **Journal of Public Economics**, Elsevier, v. 4, n. 2, p. 187–203, Feb. 1975.

SAMUELSON, L. **Evolutionary Games and Equilibrium Selection**. Cambridge: The MIT Press, 1997. P. 309.

SANYAL, A.; GANG, I. N.; GOSWAMI, O. Corruption, tax evasion and the Laffer curve. **Public Choice**, Springer, v. 105, n. 1/2, p. 61–78, 2000.

SHLEIFER, A.; VISHNY, R. W. Corruption. **The Quarterly Journal of Economics**, The MIT Press, v. 108, n. 3, p. 599–617, 1993.

SHONE, R. **Economic Dynamics**. Cambridge: Cambridge University Press, 2002. P. 724.

SIMONSEN, M. H.; CYSNE, R. P. **Macroeconomia**. 4. ed. São Paulo: Atlas, 2009.

SVENSSON, J. Eight questions about corruption. **Journal of Economic Perspectives**, American Economic Association, v. 19, n. 3, p. 19–42, 2005.

SWALEHEEN, M. Curbing corruption for higher growth: the importance of persistence. **Economics Letters**, Elsevier, v. 116, n. 2, p. 255–257, 2012.

SWALEHEEN, M.; STANSEL, D. Economic freedom, corruption, and growth. **Cato J.**, HeinOnline, v. 27, p. 343–358, 2007.

TRANSPARENCY INTERNATIONAL. **25 corruption scandals that shook the world**. [S.l.: s.n.], 2019. Available from: `https://www.transparency.org/news/feature/25_corruption_scandals`. Visited on: 22 Feb. 2020.

TRANSPARENCY INTERNATIONAL. **Corruption Perceptions Index 2018**. [S.l.: s.n.], 2019. Available from: `www.transparency.org/whatwedo/publication/corruption_perceptions_index_2019`. Visited on: 6 Mar. 2019.

TREISMAN, D. The causes of corruption: a cross-national study. **Journal of Public Economics**, Elsevier, v. 76, n. 3, p. 399–457, 2000.

VEGA-REDONDO, F. **Evolution, Games, and Economic Behaviour**. 1st. New York: Oxford University Press, 1996. P. 209.

WAGNER, E. M. **Persistence of corruption and some macroeconomic implications**: an evolutionary game approach. 2017. Dissertação (Mestrado em Economia) – Universidade Federal de Santa Catarina, Centro Sócio-Econômico, Programa de Pós-Graduação em Economia, Florianópolis.

APPENDIX A – LOCAL STABILITY OF THE POLYMORPHIC EQUILIBRIUM

We are going to prove each equilibrium's local stability using the Jacobian matrices in each situation. The demonstrations provided here are based on Shone (2002).

The Jacobian matrix evaluated around the equilibrium $(x^*, y^*) \in \Theta$ is given by:

$$J(x^*,y^*)=\begin{bmatrix} 0 & x^*(1-x^*)F'(\pi_{pc})\left[\frac{2\delta-(\alpha+1)\tau}{2}\right]\pi^* \\ y^*(1-y^*)G'(\pi_{ac})\left\{-\Lambda+[1-\gamma\rho(x^*,y^*)]\frac{(1-\alpha)\tau\pi^*}{2}\right\} & -y^*(1-y^*)G'(\pi_{ac})\Lambda \end{bmatrix}, \quad \text{(A.1)}$$

where $\Lambda = \gamma(1-\varepsilon)y^*\left[w + x^*\frac{(1-\alpha)\tau\pi^*}{2}\right] > 0$.

The polymorphic equilibrium is a saddle point if

$$\left|J(x^*,y^*)\right| = \begin{vmatrix} 0 & a \\ b & c \end{vmatrix} = -ab < 0, \quad \text{(A.2)}$$

where $a \equiv x^*(1-x^*)F'(\pi_{pc})\left[\frac{2\delta-(\alpha+1)\tau}{2}\right]\pi^*$, $b \equiv y^*(1-y^*)G'(\pi_{ac})\left\{-\Lambda+[1-\gamma\rho(x^*,y^*)]\frac{(1-\alpha)\tau\pi^*}{2}\right\}$, and $c \equiv -y^*(1-y^*)G'(\pi_{ac})\Lambda$.

Let us investigate the value of a. From (3.27), we know that $2\delta-(\alpha+1)\tau > 0$, thus $a > 0$. Now, let us check the value of b. From (3.34), we know that $\Lambda < [1-\gamma\rho(x,y^*)]\frac{(1-\alpha)\tau\pi^*}{2}$, which means the expression in braces in b is strictly positive, thus $b > 0$. Therefore, it follows that $\left|J(x^*,y^*)\right| < 0$. This completes the demonstration that the polymorphic equilibrium $(x^*, y^*) \in \Theta$ is a saddle point (as shown in Figure 3.1).

APPENDIX B – LOCAL STABILITY OF THE MONOMORPHIC EQUILIBRIA WHEN THE POLYMORPHIC EQUILIBRIUM EXISTS

The Jacobian matrix evaluated around the monomorphic equilibrium $(0,0) \in \Theta$ is given by:

$$J(0,0) = \begin{bmatrix} F((1-\delta)\pi^*) - F((1-\tau)\pi^*) & 0 \\ 0 & G((1-\gamma\varepsilon)w) - G(w) \end{bmatrix}. \tag{B.1}$$

This monomorphic equilibrium is a local attractor if

$$|J(0,0)| = ab > 0 \tag{B.2}$$

and

$$tr\ J(0,0) = a + b < 0, \tag{B.3}$$

where $a \equiv F((1-\delta)\pi^*) - F((1-\tau)\pi^*)$ and $b \equiv G((1-\gamma\varepsilon)w) - G(w)$.

Let us investigate the value of a. From (3.28), we know that $\delta > \tau$. Since F is a strictly increasing function, $a < 0$. Now, let us check the value of b. It is straightforward that $(1-\gamma\varepsilon)w < w$. Since G is also a strictly increasing function, it follows that $b < 0$. Thus, $|J(0,0)| > 0$ and $tr\ J(0,0) < 0$, which proves that the monomorphic equilibrium $(0,0) \in \Theta$ is a local attractor (Figure 3.1).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,1) \in \Theta$ is given by:

$$J(1,1) = \begin{bmatrix} F((1-\tau)\pi^*) - F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) & 0 \\ 0 & G(w) - G\left((1-\gamma)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) \end{bmatrix}. \tag{B.4}$$

This monomorphic equilibrium is a local attractor if

$$|J(1,1)| = ab > 0 \tag{B.5}$$

and

$$tr\ J(1,1) = a + b < 0, \tag{B.6}$$

where $a \equiv F((1-\tau)\pi^*) - F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right)$ and $b \equiv G(w) - G\left((1-\gamma)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right)$.

Let us check the value of a. Since $\alpha < 1$ and F is a strictly increasing function, it is straightforward that $a < 0$. Now, let us check the value of b. Considering that G is a strictly increasing function, notice that $b < 0$ if $\gamma\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] < \frac{(1-\alpha)\tau\pi^*}{2}$, which follows from (3.32). In this case, it follows that $|J(1,1)| > 0$ and $tr\ J(1,1) < 0$, which proves that the monomorphic equilibrium $(1,1) \in \Theta$ is a local attractor (Figure 3.1).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,0) \in \Theta$ is given by:

$$J(1,0) = \begin{bmatrix} F((1-\tau)\pi^*) - F((1-\delta)\pi^*) & 0 \\ 0 & G\left((1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) - G(w) \end{bmatrix}. \tag{B.7}$$

This monomorphic equilibrium is a local repeller if

$$\left|J(1,0)\right| = ab > 0 \tag{B.8}$$

and

$$tr\ J(1,0) = a + b > 0, \tag{B.9}$$

where $a \equiv F((1-\tau)\pi^*) - F((1-\delta)\pi^*)$ and $b \equiv G\left((1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) - G(w)$.

Let us check the value of a. From (3.28), we know that $\delta > \tau$. Since F is a strictly increasing function, $a > 0$. Now, let us check the value of b.Considering that G is a strictly increasing function, notice that $b > 0$ if $\gamma\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] < \frac{(1-\alpha)\tau\pi^*}{2}$, which follows from (3.32). Therefore, $\left|J(1,0)\right| > 0$ and $tr\ J(1,0) > 0$, which proves that the monomorphic equilibrium $(1,0) \in \Theta$ is a local repeller (Figure 3.1).

At last, the Jacobian matrix evaluated around the monomorphic equilibrium $(0,1) \in \Theta$ is given by:

$$J(0,1) = \begin{bmatrix} F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*) & 0 \\ 0 & G(w) - G((1-\gamma\varepsilon)w) \end{bmatrix}. \tag{B.10}$$

This monomorphic equilibrium is a local repeller if

$$\left|J(0,1)\right| = ab > 0 \tag{B.11}$$

and

$$tr\ J(0,1) = a + b > 0, \tag{B.12}$$

where $a \equiv F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*)$ and $b \equiv G(w) - G((1-\gamma\varepsilon)w)$.

Let us check the value of a. Since $\alpha < 1$ and F is a strictly increasing function, it is straightforward that $a > 0$. Now, let us investigate the value of b. It is straightforward that $(1-\gamma\varepsilon)w < w$. Since G is also a strictly increasing function, it follows that $b > 0$. Thus, $\left|J(0,1)\right| > 0$ and $tr\ J(0,1) > 0$, which proves that the monomorphic equilibrium $(0,1) \in \Theta$ is a local repeller (Figure 3.1).

APPENDIX C – LOCAL STABILITY OF THE MONOMORPHIC EQUILIBRIA WHEN $\delta > \tau$ AND $\gamma\rho(x,y) = 1$

The Jacobian matrix evaluated around the monomorphic equilibrium $(0,0) \in \Theta$ is given by:

$$J(0,0) = \begin{bmatrix} F((1-\delta)\pi^*) - F((1-\tau)\pi^*) & 0 \\ 0 & G((1-\gamma\varepsilon)w) - G(w) \end{bmatrix}. \qquad \text{(C.1)}$$

This monomorphic equilibrium is a local attractor if

$$|J(0,0)| = ab > 0 \qquad \text{(C.2)}$$

and

$$tr\ J(0,0) = a + b < 0, \qquad \text{(C.3)}$$

where $a \equiv F((1-\delta)\pi^*) - F((1-\tau)\pi^*)$ and $b \equiv G((1-\gamma\varepsilon)w) - G(w)$.

Let us investigate the value of a. From (3.28), we know that $\delta > \tau$. Since F is a strictly increasing function, $a < 0$. Now, let us check the value of b. It is straightforward that $(1-\gamma\varepsilon)w < w$. Since G is also a strictly increasing function, it follows that $b < 0$. Thus, $|J(0,0)| > 0$ and $tr\ J(0,0) < 0$, which proves that the monomorphic equilibrium $(0,0) \in \Theta$ is a local attractor (Figure 3.2).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,1) \in \Theta$ is given by:

$$J(1,1) = \begin{bmatrix} F((1-\tau)\pi^*) - F\left([1-(\frac{\alpha+1}{2})\tau]\pi^*\right) & 0 \\ 0 & G(w) - G\left((1-\gamma)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) \end{bmatrix}. \qquad \text{(C.4)}$$

This monomorphic equilibrium is a saddle point if

$$|J(1,1)| = ab < 0, \qquad \text{(C.5)}$$

where $a \equiv F((1-\tau)\pi^*) - F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right)$ and $b \equiv G(w) - G\left((1-\gamma)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right)$.

Let us check the value of a. Since $\alpha < 1$ and F is a strictly increasing function, it is straightforward that $a < 0$. Now, let us check the value of b. Since $\gamma\rho(x,y) = 1$, it follows that $(1-\gamma)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] = 0$. Considering that G is a strictly increasing function, we have that $b > 0$. Therefore, $|J(1,1)| < 0$, which proves that the monomorphic equilibrium $(1,1) \in \Theta$ is a saddle point (Figure 3.2).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,0) \in \Theta$ is given by:

$$J(1,0) = \begin{bmatrix} F((1-\tau)\pi^*) - F((1-\delta)\pi^*) & 0 \\ 0 & G\left((1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) - G(w) \end{bmatrix}. \qquad \text{(C.6)}$$

This monomorphic equilibrium is a saddle point if

$$\left|J(1,0)\right| = ab < 0, \tag{C.7}$$

where $a \equiv F((1-\tau)\pi^*) - F((1-\delta)\pi^*)$ and $b \equiv G\left((1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) - G(w)$.

Let us check the value of a. From (3.28), we know that $\delta > \tau$. Since F is a strictly increasing function, $a > 0$. Now, let us check the value of b. Since $\gamma\rho(x,y) = 1$, it follows that $(1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] = 0$. Considering that G is a strictly increasing function, we have that $b < 0$. Therefore, $\left|J(1,0)\right| < 0$, which proves that the monomorphic equilibrium $(1,0) \in \Theta$ is a saddle point (Figure 3.2).

At last, the Jacobian matrix evaluated around the monomorphic equilibrium $(0,1) \in \Theta$ is given by:

$$J(0,1) = \begin{bmatrix} F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*) & 0 \\ 0 & G(w) - G((1-\gamma\varepsilon)w) \end{bmatrix}. \tag{C.8}$$

This monomorphic equilibrium is a local repeller if

$$\left|J(0,1)\right| = ab > 0 \tag{C.9}$$

and

$$tr\ J(0,1) = a + b > 0, \tag{C.10}$$

where $a \equiv F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*)$ and $b \equiv G(w) - G((1-\gamma\varepsilon)w)$.

Let us check the value of a. Since $\alpha < 1$ and F is a strictly increasing function, it is straightforward that $a > 0$. Now, let us investigate the value of b. It is straightforward that $(1-\gamma\varepsilon)w < w$. Since G is also a strictly increasing function, it follows that $b > 0$. Thus, $\left|J(0,1)\right| > 0$ and $tr\ J(0,1) > 0$, which proves that the monomorphic equilibrium $(0,1) \in \Theta$ is a local repeller (Figure 3.2).

APPENDIX D – LOCAL STABILITY OF THE MONOMORPHIC EQUILIBRIA WHEN $\delta < \tau$ AND $\gamma\rho(x, y) < 1$

The Jacobian matrix evaluated around the monomorphic equilibrium $(0,0) \in \Theta$ is given by:

$$J(0,0) = \begin{bmatrix} F((1-\delta)\pi^*) - F((1-\tau)\pi^*) & 0 \\ 0 & G((1-\gamma\varepsilon)w) - G(w) \end{bmatrix}. \tag{D.1}$$

This monomorphic equilibrium is a saddle point if

$$\left|J(0,0)\right| = ab < 0, \tag{D.2}$$

where $a \equiv F((1-\delta)\pi^*) - F((1-\tau)\pi^*)$ and $b \equiv G((1-\gamma\varepsilon)w) - G(w)$.

Let us investigate the value of a. Since $\delta < \tau$ and F is a strictly increasing function, $a > 0$. Now, let us check the value of b. It is straightforward that $(1-\gamma\varepsilon)w < w$. Since G is also a strictly increasing function, it follows that $b < 0$. Thus, $\left|J(0,0)\right| < 0$, which proves that the monomorphic equilibrium $(0,0) \in \Theta$ is a saddle point (Figure 3.3).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,1) \in \Theta$ is given by:

$$J(1,1) = \begin{bmatrix} F((1-\tau)\pi^*) - F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) & 0 \\ 0 & G(w) - G\left((1-\gamma)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) \end{bmatrix}. \tag{D.3}$$

This monomorphic equilibrium is a local attractor if

$$\left|J(1,1)\right| = ab > 0 \tag{D.4}$$

and

$$tr\ J(1,1) = a + b < 0, \tag{D.5}$$

where $a \equiv F((1-\tau)\pi^*) - F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right)$ and $b \equiv G(w) - G\left((1-\gamma)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right)$.

Let us check the value of a. Since $\alpha < 1$ and F is a strictly increasing function, it is straightforward that $a < 0$. Now, let us check the value of b. Considering that G is a strictly increasing function, notice that $b < 0$ if $\gamma\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] < \frac{(1-\alpha)\tau\pi^*}{2}$, which follows from (3.32). Therefore, $\left|J(1,1)\right| > 0$ and $tr\ J(1,1) < 0$, which proves that the monomorphic equilibrium $(1,1) \in \Theta$ is a local attractor (Figure 3.3).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,0) \in \Theta$ is given by:

$$J(1,0) = \begin{bmatrix} F((1-\tau)\pi^*) - F((1-\delta)\pi^*) & 0 \\ 0 & G\left((1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) - G(w) \end{bmatrix}. \tag{D.6}$$

This monomorphic equilibrium is a saddle point if

$$\left|J(1,0)\right| = ab < 0, \tag{D.7}$$

where $a \equiv F((1-\tau)\pi^*) - F((1-\delta)\pi^*)$ and $b \equiv G\left((1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) - G(w)$.

Let us check the value of *a*. Since $\delta < \tau$ and F is a strictly increasing function, $a < 0$. Now, let us check the value of *b*. Considering that G is a strictly increasing function, notice that $b > 0$ if $\gamma\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right] < \frac{(1-\alpha)\tau\pi^*}{2}$, which follows from (3.32). Therefore, $|J(1,0)| < 0$, which proves that the monomorphic equilibrium $(1,0) \in \Theta$ is a saddle point (Figure 3.3).

At last, the Jacobian matrix evaluated around the monomorphic equilibrium $(0,1) \in \Theta$ is given by:

$$J(0,1) = \begin{bmatrix} F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*) & 0 \\ 0 & G(w) - G((1-\gamma\varepsilon)w) \end{bmatrix}. \tag{D.8}$$

This monomorphic equilibrium is a local repeller if

$$|J(0,1)| = ab > 0 \tag{D.9}$$

and

$$tr\ J(0,1) = a + b > 0, \tag{D.10}$$

where $a \equiv F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*)$ and $b \equiv G(w) - G((1-\gamma\varepsilon)w)$.

Let us check the value of *a*. Since $\alpha < 1$ and F is a strictly increasing function, it is straightforward that $a > 0$. Now, let us investigate the value of *b*. It is straightforward that $(1-\gamma\varepsilon)w < w$. Since G is also a strictly increasing function, it follows that $b > 0$. Thus, $|J(0,1)| > 0$ and $tr\ J(0,1) > 0$, which proves that the monomorphic equilibrium $(0,1) \in \Theta$ is a local repeller (Figure 3.3).

APPENDIX E – LOCAL STABILITY OF THE MONOMORPHIC EQUILIBRIA WHEN $\delta < \tau$ AND $\gamma\rho(x,y)=1$

The Jacobian matrix evaluated around the monomorphic equilibrium $(0,0)\in\Theta$ is given by:

$$J(0,0)=\begin{bmatrix} F((1-\delta)\pi^*)-F((1-\tau)\pi^*) & 0 \\ 0 & G((1-\gamma\varepsilon)w)-G(w) \end{bmatrix}. \quad \text{(E.1)}$$

This monomorphic equilibrium is a saddle point if

$$|J(0,0)| = ab < 0, \quad \text{(E.2)}$$

where $a \equiv F((1-\delta)\pi^*)-F((1-\tau)\pi^*)$ and $b \equiv G((1-\gamma\varepsilon)w)-G(w)$.

Let us investigate the value of a. Since $\delta<\tau$ and F is a strictly increasing function, $a>0$. Now, let us check the value of b. It is straightforward that $(1-\gamma\varepsilon)w<w$. Since G is also a strictly increasing function, it follows that $b<0$. Thus, $|J(0,0)|<0$, which proves that the monomorphic equilibrium $(0,0)\in\Theta$ is a saddle point (Figure 3.4).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,1)\in\Theta$ is given by:

$$J(1,1)=\begin{bmatrix} F((1-\tau)\pi^*)-F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) & 0 \\ 0 & G(w)-G\left((1-\gamma)\left[w+\frac{(1-\alpha)\tau\pi^*}{2}\right]\right) \end{bmatrix}. \quad \text{(E.3)}$$

This monomorphic equilibrium is a saddle point if

$$|J(1,1)| = ab < 0, \quad \text{(E.4)}$$

where $a \equiv F((1-\tau)\pi^*)-F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right)$ and $b \equiv G(w)-G\left((1-\gamma)\left[w+\frac{(1-\alpha)\tau\pi^*}{2}\right]\right)$.

Let us check the value of a. Since $\alpha<1$ and F is a strictly increasing function, it is straightforward that $a<0$. Now, let us check the value of b. Since $\gamma\rho(x,y)=1$ and G is a strictly increasing function, it follows that $b>0$. Therefore, $|J(1,1)|<0$, which proves that the monomorphic equilibrium $(1,1)\in\Theta$ is a saddle point (Figure 3.4).

The Jacobian matrix evaluated around the monomorphic equilibrium $(1,0)\in\Theta$ is given by:

$$J(1,0)=\begin{bmatrix} F((1-\tau)\pi^*)-F((1-\delta)\pi^*) & 0 \\ 0 & G\left((1-\gamma\varepsilon)\left[w+\frac{(1-\alpha)\tau\pi^*}{2}\right]\right)-G(w) \end{bmatrix}. \quad \text{(E.5)}$$

This monomorphic equilibrium is a local attractor if

$$|J(1,0)| = ab > 0 \quad \text{(E.6)}$$

and

$$tr\ J(1,0) = a+b < 0, \quad \text{(E.7)}$$

where $a \equiv F((1-\tau)\pi^*) - F((1-\delta)\pi^*)$ and $b \equiv G\left((1-\gamma\varepsilon)\left[w + \frac{(1-\alpha)\tau\pi^*}{2}\right]\right) - G(w)$.

Let us check the value of *a*. Since $\delta < \tau$ and F is a strictly increasing function, $a < 0$. Now, let us check the value of *b*. Since G is a strictly increasing function and $\gamma\rho(x,y) = 1$, $b < 0$. Therefore, $\left|J(1,0)\right| > 0$ and $tr\ J(1,0) < 0$, which proves that the monomorphic equilibrium $(1,0) \in \Theta$ is a local attractor (Figure 3.4).

At last, the Jacobian matrix evaluated around the monomorphic equilibrium $(0,1) \in \Theta$ is given by:

$$J(0,1) = \begin{bmatrix} F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*) & 0 \\ 0 & G(w) - G((1-\gamma\varepsilon)w) \end{bmatrix}. \tag{E.8}$$

This monomorphic equilibrium is a local repeller if

$$\left|J(0,1)\right| = ab > 0 \tag{E.9}$$

and

$$tr\ J(0,1) = a + b > 0, \tag{E.10}$$

where $a \equiv F\left(\left[1-\left(\frac{\alpha+1}{2}\right)\tau\right]\pi^*\right) - F((1-\tau)\pi^*)$ and $b \equiv G(w) - G((1-\gamma\varepsilon)w)$.

Let us check the value of *a*. Since $\alpha < 1$ and F is a strictly increasing function, it is straightforward that $a > 0$. Now, let us investigate the value of *b*. It is straightforward that $(1-\gamma\varepsilon)w < w$. Since G is also a strictly increasing function, it follows that $b > 0$. Thus, $\left|J(0,1)\right| > 0$ and $tr\ J(0,1) > 0$, which proves that the monomorphic equilibrium $(0,1) \in \Theta$ is a local repeller (Figure 3.4).