Is Abatement Effective in the Presence of Corruption? A Theoretical Exploration[*]

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Abstract

The paper introduces an additional channel via which corruption may adversely affect environmental quality. It is argued that, in the presence of corruption, politicians may allocate a large fraction of public funds to environmental projects aiming not at improving environmental quality, but rather at increasing their ability to extract rents. This type of behavior has a direct and an indirect effect on environmental quality. First, due to extensive rent-seeking, the effectiveness of environmental projects is disproportional to the amount of public funds allocated to them. Second, citizens who observe the poor outcome of environmental projects, increase tax evasion thus reducing public funds. A vicious circle of extensive tax evasion and rent seeking activities emerges, that has a detrimental effect on environmental quality. Anecdotal evidence from a number of countries that experience

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high levels of corruption, shows little or no improvements in environmental quality despite the implementation of environmental projects. In line with our theoretical findings, this ineffectiveness of the environmental policy is present even when the technology involved is advanced.
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1 Introduction

Corruption in its various forms and expressions is a long-lasting phenomenon prevalent, albeit in a varying degree of intensity, in both developed and developing countries. Its detrimental effects on a wide range of social and economic aspects have been extensively analyzed, including the effect of corruption on economic growth, education and the effectiveness of foreign aid. It is only recently that the effect of corruption on the design and effectiveness of environmental policy has been explored, focusing mainly on the role of lobbying groups in affecting the stringency of environmental policies and thus, environmental quality.

The present paper explores a different channel via which corruption can affect environmental quality. In particular, we argue that in countries experiencing high level of corruption, politicians may allocate a large fraction of public funds to technologically advanced environmental projects aiming however, at increasing their ability to extract high rents rather than improving environmental quality. The behavior of these selfishly motivated politicians has two consequences: i) decreases the policy's effectiveness due to extensive rent-seeking, and ii) reduces tax revenues as citizens, who observe the policy's poor outcome, increase their tax evasion. Thus, the presence of widespread embezzlement leads to a vicious circle of extensive tax evasion and rent seeking, with detrimental effects on environmental quality. Anecdotal evidence from a number of countries with high level of corruption shows that large investments in technologically advanced environmental projects do not yield improvements in environmental quality, thus lending credence to our theoretical hypothesis.

There are two important assumptions embedded in our model that allow us to explore the effect of corruption on environmental quality. First, we emphasize the importance of the interaction between politicians and citizens. We assume that both groups' choices are driven by two, conflicting, types of incentives: first, an altruistic incentive, that is to transfer good quality public goods to their offsprings and second, a selfish incentive, which is to maximize their own consumption by engaging in corrupt activities. In particular, taxpayers have the option to evade taxes, while politicians have the option to embezzle part of the tax revenue.[1] We show that the two groups' common interest in

[1] In this framework we will adopt the term corruption both for rent-seeking activities and for tax evasion. Whereas there is a broad consensus as to the fact that embezzlement of public funds is a corrupt activity, this is not the case for tax evasion. There is an ongoing debate as to whether tax evasion can be classified as corruption according to the term employed by the World Bank (*the abuse of public office for private gain*). For the shake of brevity we will abstract from this debate and we will adopt the term corruption interchangeably for both activities.

their offsprings' wellbeing results in the interaction between their decisions to engage in corrupt activities.

Second, following the literature, we assume that politicians' ability to extract rents is directly related to the level of technology employed in each type of public spending. The intuition is that more advanced technology involves less transparent expenditure allowing the extraction of higher rents. Empirical evidence also confirms this argument, showing that public spending on more technologically advanced sectors, such as the military and the energy sector, suffer from more widespread corruption relatively to more labour intensive sectors such as education.[2] In order to simplify the analysis, we assume that politicians allocate the total tax revenue between environmental improving projects (hereafter also called abatement activities) and education. Abatement activities, which can include investment on renewables and carbon capture and storage projects, is the technology intensive activity involving less transparent expenditure, while education, associated mainly with teachers' wages, is the more transparent activity.[3] To further simplify the analysis we assume that the rates of rent seeking associated with each of the two activities are fixed and exogenously given.

The above framework allow us to focus on the strategic interactions between citizens who pay taxes and politicians who allocate public funds between the two types of activities. Whenever taxpayers observe politicians directing disproportionately higher level of public funds to the high rent seeking activity, they react by increasing the rate of their tax evasion. On the contrary, whenever they observe politicians directing more resources to the less rent seeking activity, they respond by increasing their compliance. Crucially, the type of interaction between the two groups (i.e., strategic complementarity or strategic substitutability) as well as the emerging equilibria depend primarily on the level of technology used in each sector and the associated rent seeking rates. Therefore, environmental quality at the equilibrium critically depends on the interaction between abatement technology and rent seeking opportunities.

In order to derive analytical results, we develop a highly stylized model. However, a more elaborate model relaxing the main assumptions, yields qualitatively similar results. The augmented version of the model is not fully tractable analytically and thus, we resort to numerical simulations. For presentation purposes, we relegate the presentation of this model to an appendix.

[2] See for example Gupta et al.(2000), Delavallade (2006) and Mauro (1998).

[3] See Tanzi and Davoodi (1997) and (2000) and Hessami (2010).

Our results have two important policy implications with respect to the effectiveness of environmental public projects. First, the effectiveness of publicly funded environmental projects does not depend only on the level of spending, but also on the level of corruption. The reason is that in the presence of rent-seeking by politicians that leads to improper implementation of environmental projects, citizens increase tax evasion. As a result, the total amount of public funds are reduced with detrimental effects on environmental quality. Second, the promotion of technologically advanced environmental projects does not guarantee improvements in environmental quality in the presence of corruption. This is so, because advanced technologies are associated with higher embezzlement of public funds. Therefore, strengthening the institutional system by improving transparency and reducing corruption is crucial for increasing tax revenues and allocating them efficiently among different activities.

The present paper relates to two strands in the literature. The first, explores the effect of corruption on environmental quality. The majority of contributions uses a political economy approach and explores the effect of bureaucracy and lobbying groups on the stringency of environmental policy. Pashigian (1985) explains how locational competition among regions with different growth rates affects the stringency of regulations in these regions. Cropper et al. (1992) and Helland (1998) report the effect of environmental interests on political and budget considerations on the US Environmental Protection Agency (US EPA) regulations. Lopez and Mitra (2000) examine the effect of corruption and rent seeking on the relationship between pollution and growth and on the shape of the environmental Kuznets curve, while Fredriksson and Millimet (2000) and Fredriksson et al. (2003) examine the effect of corruption and rent seeking on US FDI, on the stringency of environmental policy and the pollution haven hypothesis. Fredriksson et al. (2010) argue that in the presence of majoritarian systems the majority party may impose sub-optimally high or low pollution taxes due to a majority bias. Fredriksson and Wollscheid (2014) argue that the effects of party discipline and party strength on environmental policy are conditional on the degree of political stability. In our paper, we focus on a different channel through which the effect of corruption on environmental quality may take place, i.e., via rent-seeking opportunities associated with investment in environmental projects.

Second, we build upon the literature exploring the interactions among different societal groups, including the government. We argue that politicians' corrupt behavior may trigger non-compliance on behalf of citizens, leading to the reduction of total public revenues. This suggests that corruption seems to be contagious, or as Andvig and Moene (1990) put it "corruption may corrupt". Tanzi and Davoodi (2000) investigate the relationship between levels of corruption (measured by corruption perception indices) and GDP in a sample of 97 countries and find that higher corruption is consistent with lower revenues of all types of taxes, especially income taxes. Whenever taxpayers feel that politicians are corrupt or that their burden is not fair compared to others they choose to become more corrupt as well. Litina and Palivos (2013) associate the current economic crisis in Greece with corrupt activities of different societal groups and their interaction.

Section 2 of the paper provides some anecdotal evidence that motivates our analysis. Section 3 introduces the benchmark model. We resort to a simple framework that allows us to obtain analytical results and to account for the fact that more funds on abatement may lead to lower environmental quality. Section 4 concludes the paper. The appendix establishes the robustness of our theoretical results via employing a set of more realistic assumptions. As these assumptions increase the complexity of the model we solve it numerically and show that it can yield qualitatively similar predictions.

2 Anecdotal Evidence

One of the major problems associated with tracing corrupt activities is driven by the fact that they take place secretly and come to the surface only if/when revealed and investigated. This is particularly true for the case of environmental policy and illegal activities associated with it. Two main reasons can account for this fact. First, it is only in the last few decades, that large environmental projects have been undertaken and thus corruption activities associated with them are also a relatively new phenomenon. Second, the technology associated with these projects is rather advanced and therefore it is even more difficult to identify the instances of corruption since they involve less transparent activities.

Two examples are cited in this section: i) The Lesotho Highlands Water Project (LHWP); and ii) The SISTRI Project. Moreover in Section 2.3 we present some simple correlations indicating the negative effect of corruption on environmental quality and suggesting an interaction between the stage of technology and the level of corruption.

2.1 Lesotho Highlands Water Project

The Lesotho Highlands Water Project (LHWP) was initiated in 1986 by an agreement between the governments of Lesotho and South Africa, and it was, at the time, the most extensive international water transfer project globally. Its aim was to provide water resources to Johannesburg by diverting it from the Orange to the Vaal river. Moreover it was supposed to generate royalties from water sales and hydroelectric power for Lesotho. The agreement dedicated resources to the development of the rural areas of Lesotho, the compensation for those who have been displaced and amendments to the areas affected by the project.

The implementation of the project required the development of a number of dams and tunnels and the estimated cost of the project was more than $8 billion. As the project expanded across a large area, the benefits associated with it came with substantial environmental costs to nearby communities. A significant part of the project's cost was related to the development of a social fund aimed at mitigating the environmental consequences. During the first phase of the project 4 dams and 110km of tunnels were constructed. Nevertheless, the project remains largely unfinished, the expected benefits have not been realized, while extensive environmental degradation has occurred. The delay is due to a number of corruption scandals related to the project. In 1999 a corruption scandal burst out, involving 12 companies and the Chief executive of the Lesotho Highlands Development Agency. In particular, the companies were accused of offering huge bribes to win various contracts. These actions resulted in the inefficient management of the project's funds, inflating the financial cost and increasing the environmental burden. After the Agency's Chief executive himself was found guilty, three major European firms were also found guilty and charged, and one Canadian firm has been debarred at the World Bank. This situation defamed the project, delaying its second phase which was initiated only very recently (March 2014) amidst concerns about the likelihood of corruption in tender processes.

2.2 The SISTRI Project

In 2009 the Italian Ministry of Environment launched an information system, SISTRI, aimed at unifying the waste management services at the national level and improving the urban waste management at the Campania region. The implementation of the system was expected to yield substantial environmental improvements through the deterrence of illegal waste dumping and significant cost reductions. The estimated cost of the project was about 400 million euros and it involved highly sophisticated technology that would ensure the achievement of the ambitious goals. Nevertheless, a large part of the funds were collected by the companies via non-transparent procedures without any advancement of the project. A large scandal emerged involving bribes, embezzlement of the funds and a number of other illegal activities. The project's launch date was postponed twice before being abolished in August 2011. A number of people have been persecuted, among them government officials and a member of the parliament. More recently (March 2014), two former managers of Finmeccanica SpA, Italy's state-controlled defense and industrial group, have also been arrested over allegations of international corruption in relation to the SISTRI project.

2.3 Empirical Evidence

To further motivate the analysis and support the hypothesis advanced in this paper, we show correlations between proxies of environmental policies, corruption and environmental quality. The analysis of this section is only illustrative and is not aspiring to provide an empirical argument. Nevertheless is it quite useful in quantifying the paper's arguments and illustrating the interaction between corruption and environmental quality. Overall, the theoretical hypothesis advanced in the paper is that the effectiveness of environmental policy depends on the extend of corruption which is positively associated with the level of technology used. We employ a sample of 132 countries, drawing data from the World Bank for the period 1996-2010 for which the data is available.

Table 1 presents the results of our regression analysis. In column (1), we use a per capita measure of CO_2 emissions measured in metric tons as proxy for environmental quality. As a proxy of environmental policy we use a measure of electricity production from renewable resources as a fraction of the total electricity production (both measured in kWh). In the absence of data on the actual cost of implementing this policy, we make the implicit assumption that this measure proxies both the costs associated with these technologies and the level of the technology employed. As a proxy for the level of corruption in a country we employ the corruption perception index from the Transparency International (CPI index-TI). The measure we use ranges from zero to ten, with ten denoting the most corrupt country.[4]

Interestingly, the correlation coefficients support the theoretical hypothesis advanced in this paper. Note first that the negative coefficient of investment in renewables confirms that higher investment in renewables is associated with lower per capita emissions. Most importantly though, the coefficient of corruption is positive, thereby capturing the adverse effect of corruption on environmental quality. The positive and statistically

[4] It should be noted that we have rescaled the standard CPI measure, to make the interpretation of our results more tractable. Therefore, higher values of our index, indicate more corrupt countries.

significant coefficient of the interactive term captures the partial effect of investment in renewables holding the level of corruption constant, i.e. investment in renewables is less efficient in more corrupt economies.

In column (2) we use an alternative proxy for environmental policy, namely production of electricity from natural gas resources as a percentage of total electricity. Increasing the share of natural gas decreases CO_2 emissions, with the coefficient being smaller than in the case of renewables. The coefficient of corruption is statistically insignificant and the interaction term is positive. Although the promotion of natural gas presents an environmental improvement over coal and oil, it is not as effective as renewables in reducing CO_2 emissions. Furthermore, natural gas is relatively less advanced technologically than renewables and thus, less prone to corruption. The theoretical framework of the paper captures precisely this interaction between environmental technology and the extend of corruption in an economy.

Finally column (3) replicates the analysis in column (1) using an alternative measure of corruption from the World Governance Indicators (WGI). This measure ranges from -2.5 to 2.5 with 2.5 referring to the most corrupt country.[5] The results are similar to those in column (1), with the positive coefficient of corruption suggesting that indeed corruption confers a negative effect on environmental quality. The interactive term is also positive. All three columns introduce time and country fixed effects therefore netting out many sources of unobserved heterogeneity.

We view these results as simple correlations that nevertheless clarify the argument advanced in the paper. A refined empirical work is beyond the scope of our analysis. Overall the aim of this section is to provide evidence that corruption has an adverse effect on environmental quality and to relate the level of corruption to the level of the employed technology.

[5]Similarly to the CPI measure, in the context of our analysis the measure of corruption has been rescaled.

	(1)	(2)	(3)
		Per Cap. CO2 Emissions	
Renewable Resources (RR)	-0.123***		-0.154***
	(0.023)		(0.036)
Natural Gas Resources (NR)		-0.045***	
		(0.006)	
Corruption Perception Index-Rescaled (CPI)	0.112*	-0.091	
	(0.061)	(0.066)	
Control of Corruption-Rescaled (CC)			0.538***
			(0.169)
Interaction	0.016***	0.009***	0.035**
	(0.005)	(0.001)	(0.015)
Time Fixed Effects	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes
Observations	1670	1670	1460
Countries	132	132	134
Years	15	15	11
R-squared	0.039	0.060	0.048

Summary: This table illustrates that the reduction of CO2 emissions via the use of alternative sources of electricity production is less effective in the presence of corruption, while controlling for country and time fixed effects.

Notes: (i) Per capita CO2 Emissions measure is the per capita level of CO2 emissions measured in metric tons; (ii) Nuclear Electricity Production is a measure of electricity production from nuclear sources as a fraction of the total electricity production (both measured in kWh); (iii) CPI is a measure of corruption provided by Transparency International (TI). Countries are scaled from 0-10 with 10 being the least corrupt. In this table the measure of corruption has been rescaled with 10 indicating the most corrupt country; (iv) Control of Corruption is a measure on the control of corruption from the World Governance Indicators (WGI). This measure ranges from -2.5 to 2.5 with the latter referring to the least corrupt country. Similarly, this measure has been rescaled with 2.5 indicating the most corrupt country; (v) Robust standard error estimates are reported in parentheses; (vi) *** denotes statistical significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level, all for two-sided hypothesis tests.

3 The Benchmark Model

Consider a perfectly competitive overlapping generations economy where economic activity extends over infinite discrete time and a single good is being produced in the private sector. Individuals live for two periods i.e. childhood and adulthood. During the first period of their life individuals acquire human capital via public schooling, whereas during adulthood they either enter the private market or they become politicians via a random selection process. Their preferences are defined over their own consumption, as well as over the well being of their offspring, which is captured by the level of human capital and the quality of the environment they bequeath to them.[6]

3.1 The Structure of the Economy

In each period t, a generation of individuals of measure one is born. Each individual has a single parent. During childhood individuals acquire human capital and for simplicity, it is assumed that they are not economically active; their consumption is incorporated into their parents' consumption. During adulthood individuals are economically active allocating their income between current consumption and their offsprings' well being. Formally, individuals born at $t-1$, during their adulthood (i.e., in period t), maximize the following utility function,

$$u_t = c_t\left(h_{t+1} + Q_{t+1}\right) \ , \tag{1}$$

where c_t denotes the adults' level of consumption, h_{t+1} their offspring's human capital and Q_{t+1} the environmental quality handed over to their offsprings. The presence of the offspring's human capital level and environmental quality in the parental utility function captures the adult agent's vested interest in publicly funded education and environmental projects (abatement activities).[7]

[6] Environmental quality affects offsprings' well-being either directly, e.g., they simply gain utility from a clean environment, as we assume in this version of the model, or both directly and indirectly via affecting production as well. The latter case where environmental quality can be an input in the production process is explored in the more elaborate version of the model (see the appendix). In both cases it is not a crucial assumption that can alter our qualitative results.

[7] The introduction of a parameter measuring the relative strength of the altruistic motive associated with each activity, i.e., education and environmental quality, would further complicate our analysis without providing additional insights.

Following the related literature we assume that the learning technology is described by,[8]

$$h_t = H_0 H_{t-1} - v H_{t-1} + B E_{t-1} \ , \tag{2}$$

where t denotes time, h_t the level of human capital acquired by an individual born at $t-1$, H_{t-1} the average stock of human capital present in the economy at time $t-1$, and E_{t-1} the public spending on education in the same period. According to this human capital accumulation process, a young agent born in period $t-1$, can pick up a fraction $H_0 \in [0,1]$ of the existing (average) level of human capital H_{t-1} without any cost, simply by observing what the previous generation does. Existing human capital depreciates at a rate v. The further enhancement of an agent's human capital is possible only with the allocation of public resources to education, E_{t-1}. The parameter $B > 0$ measures the efficiency of the public education system. Therefore, the overall level of human capital reflects the effect of both societal knowledge and formal education.

The evolution of environmental quality is described by,

$$Q_t = Q_0 H_{t-1} - \psi H_{t-1} + A\Pi_{t-1}, \qquad Q_0 > \psi \ , \tag{3}$$

where $Q_0 H_{t-1}$ denotes the initial state of environmental quality Q_0, conditional on the level of production H_{t-1} in period $t-1$. The term ψH_{t-1} captures the environmental damage caused by production in the previous period (we assume that production employs only human capital), and ψ is a technological parameter that can be interpreted as the rate of environmental degradation per unit of output. The term $A\Pi_{t-1}$ captures the beneficial effect of publicly funded abatement activities on environmental quality, where A is a technological parameter.[9]

3.2 Citizens and Politicians

Individuals entering into adulthood, via a random process, are either employed in the private sector (hereafter called citizens) or they become politicians. Individual preferences are independent of occupation. For analytical convenience it is assumed that there is a continuum of agents within each group that is normalized to unity. In terms of notation,

[8] See for example De Gregorio and Kim (2000) and Ceroni (2001).

[9] For analytical convenience we assume that: i) both dynamic equations for the evolution of public goods are symmetric, and ii) environmental quality depends on the level of economic activity. These simplifying assumptions are quite useful in obtaining analytical solutions. However in the appendix we employ a more elaborate version of the model, that adopts more realistic assumptions and yields qualitatively similar results.

the subscripts c and p are used to denote variables that are related to citizens and politicians respectively.

Citizens produce a single good consumed by both groups. In the baseline version of the model we assume that production employs only human capital, while the environment does not contribute to the production process.[10] Thus, using the appropriate normalization of units, each citizen's output y_t is,[11]

$$y_t = h_t. \tag{4}$$

It follows that the aggregate production function is linear to the aggregate level of human capital, that is, $Y_t = H_t$. Notice that since the size of each group is normalized to one, $h_t = H_t$ and thus, $y_t = Y_t$.

The revenue for the provision of public education and abatement comes from taxing citizens' income. In particular, citizens are being taxed at the rate τ, which is assumed to be exogenous and time invariant. Citizens have the option to evade a fraction of their taxes and thus they can decide upon the fraction z_t of their income that is declared to the tax authority. For the shake of brevity it is assumed that the citizen's declaration is never audited; consequently, tax evasion does not involve any risk. Although tax payments are implicitly assumed to be a voluntary contribution, citizens' free riding incentive is mitigated by their altruistic concerns about their offsprings' education and environmental quality and thus they always declare a positive fraction of their income, as will be illustrated in a following section.[12]

Politicians do not participate in the production process. Instead their role lies in determining the allocation of public funds between education (a fraction ϕ of the total tax revenue) and abatement activities. The politician receives a fixed income, as a reimbursement for her service, which for analytical convenience and without loss of generality is assumed to be equal to zero. Moreover, she has the option to embezzle part of the total tax revenue as a means of supplementing her income.[13] More specifically, she

[10] The robustness to this assumption is tested in the more elaborate version of the model in the appendix, where we assume that environmental quality is also an input to the production process.

[11] Since all agents have the same level of human capital we omit the subscript $i = c, p$.

[12] This also implies that adding the possibility of auditing and the subsequent fines would not qualitatively affect the main results, it would only affect the scale of the effect.

[13] Assuming a positive reimbursement for the politician (either a constant amount, or a fraction of the tax revenue) reduces the magnitude of the incentive to embezzle public funds, but it does not qualitatively affect the results. As long as there is an incentive to embezzle part of the funds, the results of the model remain robust to this assumption. In order to focus on the decision of allocating public funds between the two policies, we choose not to model the decision of whether to embezzle or not.

can embezzle a fraction $(1-\omega_q)$ of public funds directed to abatement, and a fraction $(1-\omega_h)$ of the funds earmarked for education. It is assumed that both ω_q and ω_h are exogenously given, strictly positive and less than one. The magnitude of the ωs depends on the economy's institutional, political and social characteristics, whereas their relative magnitude, i.e. whether $\omega_q \gtrless \omega_h$, depends on the public activity's characteristics.

For instance one could argue that $\omega_h > \omega_q$, since education involves mainly transparent transactions, such as wages and equipment that are not overly technologically advanced and thus, it is associated with low rates of rent seeking.[14] On the other hand, abatement technology can be rather sophisticated and thus less transparent. As suggested by Tanzi and Davoodi (1997), the more technology-intensive is an activity, the less susceptible it is to citizens' scrutiny, and thus the higher the level of rent seeking associated with it. However, rent seeking rates related to environmental projects can vary significantly depending on the type of abatement technology. For example, reforestation involves much less sophisticated technology and is thus a much more transparent activity than investment in renewables. In order to be able to discuss the choice between environmental policy and any other type of public policy, we allow the relative magnitude of ωs to vary. We assume that the politician is aware of the values of ω_q and ω_h before allocating the available public funds between the two activities.

We further assume that the politician is never investigated and hence peculation does not involve any risk. Given that the politician has zero income, she will always have an incentive to embezzle a fraction of the tax revenue. However, the politician's concern over her offspring's well-being ensures that she will always have an incentive to allocate the public funds in both activities and will not direct them only to the more rent-seeking one.[15]

Since only citizens are being taxed, the total tax revenue R_t, collected in period t, is the fraction of the aggregate income that is being declared and therefore taxed, i.e. $R_t = z_t \tau h_t$. In the absence of embezzlement by the politician, a fraction $\phi_t z_t \tau h_t$ of the tax revenue would be earmarked for education and the remaining $(1-\phi_t) z_t \tau h_t$ for abatement.

However, the politician peculates a fraction of this revenue. In particular, she peculates a fraction $1-\omega_h$ $(1-\omega_q)$ of the tax revenue earmarked for education (abatement),

[14] The literature shows that the rate of rent-seeking in education is low but can vary across countries (Reinikka and Svensson, 2005) depending on the overall level of corruption and the associated expenses.

[15] Similarly to the case of the citizen, as long as the politician has an incentive to direct part of the funds in both activities, enriching the model with a probability to be caught and punished would increase the complexity of the model without adding further insights.

and thus, the actual amount spent on education E_t (abatement Π_t) is,

$$E_t = \varphi_t \omega_h z_t \tau h_t, \tag{5}$$

$$\Pi_t = (1-\varphi_t)\omega_q z_t \tau h_t \ , \tag{6}$$

respectively. Overall, individuals' decisions at time t regarding the level of tax evasion and the allocation of public funds, have an indirect effect on the aggregate level of both public goods, i.e. education and abatement, which is enjoyed by the offsprings of both types of individuals. Therefore, citizens' decisions are indirectly affected by the decisions of the politicians and vice versa, driven by the altruistic incentives of both groups, thus suggesting the presence of strategic interactions in their decision making process.

3.3 Optimization

Citizen

As discussed above, citizen's preferences are defined over his own consumption in period t, c_{ct}, and his offspring's well being in the next period $t+1$ as affected by the level of human capital they will acquire h_{t+1}, and the quality of the environment Q_{t+1}. His gross income in period t is h_t, which is taxed at the exogenous rate τ. The citizen chooses the fraction z_t of his income to declare to the tax authorities and pays income tax $\tau z_t h_t$, which implicitly determines consumption at time t and the level of public goods transferred to his offspring.[16] We assume that citizens have full information regarding the politicians' ability to embezzle part of the total tax revenue. That is, they know the values of ω_q and ω_h and they observe the politicians' decision of allocating public funds between the two activities.[17] Therefore, each citizen solves the following optimization problem,

$$\max_{c_{ct}, z_t} c_{ct} \left(H_{t+1}, +Q_{t+1}\right) \ , \tag{7}$$

$$\text{subject to } c_{ct} = (1 - z_t\tau)h_t \ ,$$

$$c_{ct} \geq 0, \quad 1 \geq z_t \geq 0 \ ,$$

where h, Q, E and Π are determined by equations (2), (3), (5) and (6), taking φ_t, Q_0 and H_t as given.

[16] Consumption at time t equals the citizen's disposable income $(1-\tau)z_t h_t + (1-z_t)h_t = (1-z_t\tau)h_t$.

[17] Introducing partial information would unnecessarily complicate the analysis.

Maximization yields the citizen's choice of z_t as function of the model's parameters and the politician's choice of φ. Thus, we get the citizen's best response function to the politician's choice of φ,

$$z_t = f(\varphi_t) = \frac{(A\omega_q - \varphi_t \Omega_T) - \Psi}{2\tau(A\omega_q - \varphi_t \Omega_T)} \ , \tag{8}$$

where $\Omega_T = A\omega_q - B\omega_h$ and $\Psi = Q_0 + H_0 - \psi - \upsilon$. The second order condition, ensuring concavity, requires that $A\omega_q - \varphi_t \Omega_T > 0$, which always holds since $\varphi_t \leq 1$.

Furthermore, an interior solution $(1 > z > 0)$ exists iff $(1-2\tau)(A\omega_q - \varphi_t \Omega_T) < \Psi < A\omega_q - \varphi_t \Omega_T$. On the contrary, a corner solution will emerge if $\Psi \geq (A\omega_q - \varphi_t \Omega_T)$ $(z_t = 0)$ or $\Psi \leq (1-2\tau)(A\omega_q - \varphi_t \Omega_T)$ $(z_t = 1)$.

Comparative statics suggest that when υ and ψ increase, i.e., when there is extensive depreciation of environmental quality and human capital, the incentive to evade decreases and thus individuals choose to evade a small fraction of their income. On the contrary when Q_0 and H_0 increase, then z_t decreases suggesting that there is a reduced incentive to be honest and thus individuals may evade more. Lemma 1 presents the comparative statics with respect to technology and policy parameters.

Lemma 1 *Whenever an interior solution emerges, the tax evasion rate* $(1 - z_t)$ *is reduced:*

i) the more efficient is the use of tax revenues, (i.e. the higher are A *and* B*),*

ii) the lower are the rent seeking rates (i.e., ω_q *and* ω_h*), and*

iii) the lower is the tax rate, τ*.*

Proof. Results (i)-(iii) can be obtained by taking the derivatives of the interior solution with respect to each parameter. ■

Politician

Since we have assumed that individual preferences are independent of occupation, politician's preferences are also given by (1). Assuming zero income from other sources, the politician derives income only via the embezzlement of public funds. Taking as given the rent-seeking rate associated with education $1 - \omega_h$, and abatement $1 - \omega_q$, she determines the allocation of public revenues between the two activities in order to maximize her utility. Her income equals the sum of the funds embezzled from the education and abatement activities, i.e. $(1-\varphi_t)(1-\omega_q)\tau z_t H_t + \phi_t(1-\omega_h)\tau z_t H_t$. The politician solves the following optimization problem with respect to the fraction of revenue that will be allocated in each activity ϕ_t,

$$\max_{c_{pt},\varphi_t} \quad c_{pt}\left(H_{t+1}, +Q_{t+1}\right), \tag{9}$$

$$\begin{aligned} \text{subject to } c_{pt} &= [(1-\varphi_t)(1-\omega_q)+\phi_t(1-\omega_h)]\tau z_t h_t, \\ c_{pt} &\geq 0, \;\; 1 \geq \varphi_t \geq 0, \end{aligned}$$

where h, Q, E and Π are determined by equations (2), (3), (5) and (6), taking z_t, Q_0, H_o and H_t as given.

The first order condition of (9) yields the politician's best response function to citizen's choice of z_t,

$$\varphi_t = g(z_t) = \frac{\Psi\Omega - \tau z_t\left[(1-\omega_q)\Omega_T - A\omega_q\Omega\right]}{2\tau z_t \Omega_T \Omega} = \frac{\Psi}{2\tau z_t \Omega_T} - \frac{(1-\omega_q)\Omega_T - A\omega_q\Omega}{2\Omega_T\Omega}, \tag{10}$$

where $\Omega = \omega_q - \omega_h$ and Ω_T, Ψ as defined above. Second order conditions require that $\Omega_T\Omega > 0$. Furthermore, an interior solution ($0 < \varphi < 1$) emerges iff $\tau z_t\left[1-\omega_q)\Omega_T - A\omega_q\Omega\right]/\Omega < \Psi < \left[2\tau z_t\Omega_T\Omega + \left[(1-\omega_q)\Omega_T - A\omega_q\Omega\right]\right]/\Omega$ (i.e., $0 < \varphi_t < 1$). A corner solution will emerge if $\Psi \geq \left[2\tau z_t\Omega_T\Omega + \left[(1-\omega_q)\Omega_T - A\omega_q\Omega\right]\right]/\Omega$ ($\varphi_t = 1$) or $\Psi \leq \tau z_t\left[(1-\omega_q)\Omega_T - A\omega_q\Omega\right]/\Omega$ ($\varphi_t = 0$).

Lemma 2 presents the comparative statics with respect to technology and policy parameters.

Lemma 2 *Whenever an interior solution emerges, the fraction of public funds directed to education, φ_t,*

i) is increasing in B and decreasing in A,

ii) decreases (increases) with τ if $\Omega_T > 0$ ($\Omega_T < 0$).

Proof. The above results can be obtained by taking the derivatives of the interior solution with respect to each parameter. ■

The intuition of the second result is as follows. If abatement is the more effective public activity, $A\omega_q > B\omega_h$, then the politician allocates less revenue to education as the tax rate increases and vise versa. She does so in order to maximize the effectiveness of pubic spending and to increase her own income by minimizing citizens' tax evasion.[18]

Overall, politicians' decision process has many analogies to that of citizens. In allocating public funds between the two activities, she balances her own consumption and her offsprings' well being while taking into account citizens' reaction.

[18] Citizens optimally choose to pay higher taxes when they observe that the politician directs a higher share of the tax revenue to the most productive activity.

Strategic Interactions

As suggested by the two groups' reaction functions, given in equations (8) and (10), each group's expectations regarding the other group's choice are an important determinant of their own decision making process. Therefore *strategic interaction* emerges, operating through the common interest for the provision of the public goods, i.e., education and environmental quality. The sign of both reaction functions' slope depends on the sign of the term Ω_T. In particular, we can distinguish two cases.

Lemma 3 *A) If $\Omega_T < 0 \Longrightarrow A\omega_q < B\omega_h \Longrightarrow \frac{\partial z_t}{\partial \varphi_t} > 0$, $\frac{\partial \varphi_t}{\partial z_t} > 0$, i.e., the optimal reactions of politicians and citizens are strategic complements.*

A) If $\Omega_T > 0 \Longrightarrow A\omega_q > B\omega_h \Longrightarrow \frac{\partial z_t}{\partial \varphi_t} < 0$, $\frac{\partial \varphi_t}{\partial z_t} < 0$, i.e., the optimal reactions of politicians and citizens are strategic substitutes.

Proof. Results (A)-(B) can be obtained by taking the derivative of each group's reaction function, equations (8) and (10), with respect to the other group's decision variable, which yields,

$$\frac{\partial z_t}{\partial \varphi_t} = \frac{-\Psi\Omega_T}{2\tau\left(A\omega_q - \varphi_t\Omega_T\right)^2} \gtrless 0 \text{ and } \frac{\partial^2 z_t}{\left(\partial \varphi_t\right)^2} = \frac{-\Psi\Omega_T^2}{2\tau(A\omega_q - \varphi_t\Omega_T)^3} < 0, \quad (11)$$

$$\frac{\partial \varphi_t}{\partial z_t} = \frac{-\Psi}{2\tau^2 z_t\Omega_T} \gtrless 0, \quad \text{and } \frac{\partial^2 \varphi_t}{\left(\partial z_t\right)^2} = \frac{\Psi}{2\tau^2 z_t^2\Omega_T} \gtrless 0. \quad (12)$$

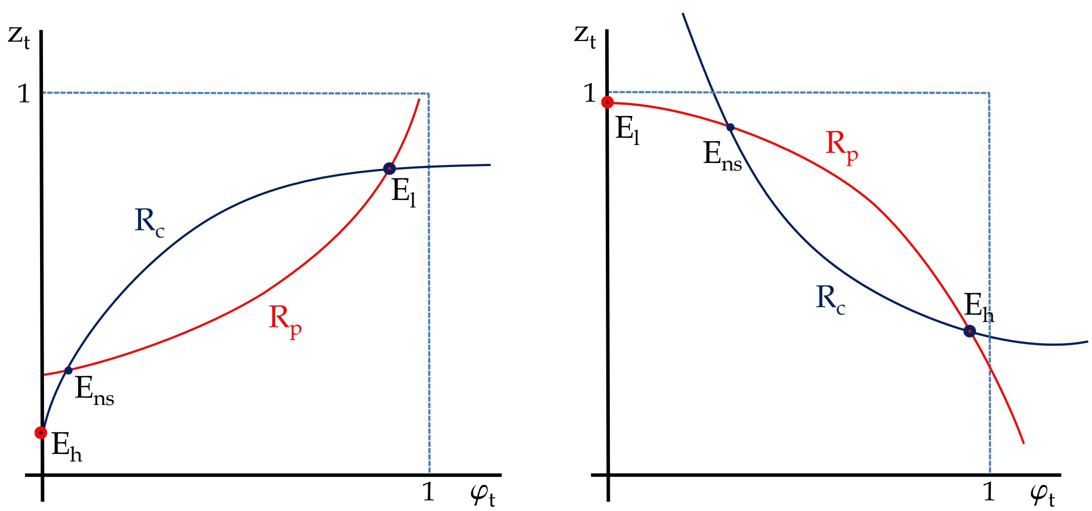
■

Case (A) refers to a situation in which public spending on education is more effective relative to abatement (i.e., $A\omega_q < B\omega_h$), due to either relatively lower rates of rent seeking (i.e., $\omega_q < \omega_h$) and/or due to more efficient technology (i.e., $A < B$). In this case, citizens optimally *reward* the *honest* attitude of the politicians (where honesty is perceived as allocating more money to the most efficient activity, i.e. education) by evading less (i.e., $\partial z_t/\partial \varphi_t < 0$). In case (B) public spending on abatement is more effective relative to education (i.e., $A\omega_q > B\omega_h$), due to either relatively lower rates of rent seeking (i.e., $\omega_q > \omega_h$) and/or due to more effective technology (i.e., $A > B$). In this case citizens' reaction function is decreasing at a decreasing rate while that of politicians, at an increasing rate. Citizens optimally declare a lower fraction z_t of their income to tax authorities as they observe politicians directing a higher share of public funds to education, which is the less productive activity.[19] Each group optimally *reciprocates* to the other

[19]Second order condition of politicians' maximization problem requires that when $\Omega_T < 0$, then $\Omega < 0$, i.e. $\omega_q < \omega_h$.

group's cheating behavior and thus, defining both groups' strategic choices as *cheat - not cheat*, they are mutually reinforcing, i.e. they are always strategic complements.

Figure 1 illustrates the two cases of strategic interactions. In order to keep the graphical illustration aligned with the mathematical notation, we choose to illustrate the reaction functions in the $[z_t, \varphi_t]$ space instead of the *[cheat, not cheat]* space. Figure 1a illustrates citizens' (R_c) and politicians' (R_p) reaction functions when $\Omega_T < 0$, that is, the case of strategic complementarity. In this case, as politicians allocate more funds to education, which is the more productive activity $(A\omega_q < B\omega_h)$, citizens reciprocate by declaring higher part of their income (higher φ_t leads to higher z_t). Figure 1b illustrates both groups' reaction functions when $\Omega_T > 0$, that is, the case of strategic complementarity. In this case, if politicians choose to invest a higher share of public funds on education (higher φ_t), which is the less productive activity $(A\omega_q > B\omega_h)$,[20] thereby signalling a more corrupt behavior, citizens optimally "punish" them by evading a higher fraction of their income (lower z_t). Defining strategic choices as *cheat - not cheat*, the strategic decisions of the two groups are again mutually reinforcing (higher embezzlement on the part of the politicians, leads to higher evasion on the part of the citizens). This is so despite the fact that both reaction functions are decreasing in the $[z_t, \varphi_t]$ space, which implies strategic substitutability.



(a) if $\Omega_T < 0$ (b) if $\Omega_T > 0$

Figure 1. Citizens' (R_c) and politicians' (R_p) reaction function

[20] Again, the second order condition of (9) requires that when $\Omega_T > 0$, then $\Omega > 0$, i.e. $\omega_h > \omega_q$.

Figures 1a and 1b illustrate citizens' (R_c) and politicians' (R_p) reaction functions within the feasible range of values $[0, 1]$. Three equilibria may occur denoted by points E_h, E_{ns} and E_l. Using best reply dynamics we observe that E_h and E_l are stable equilibria whereas E_{ns} is an unstable equilibrium. Figure 1a depicts the case in which $\Omega_T < 0$ and $\omega_q < \omega_h$, that is, education is the more efficient activity and also the one that allows less rent seeking. E_h denotes the high corruption equilibrium, in which the economy experiences high tax evasion (small z_t) and the total tax revenue is being directed to abatement ($\varphi_t = 0$) which allows for maximum rent seeking. E_l denotes the low corruption equilibrium where citizens declare a large fraction of their income (high z_t) and a positive part of the tax revenue is directed to the less rent seeking activity ($\varphi_t > 0$). Figure 1b illustrates the case in which abatement is the more effective activity ($\Omega_T > 0$) and the one that allows less rent seeking ($\omega_q > \omega_h$). E_l denotes the low corruption equilibrium where citizens declare a large fraction of their income (high z_t) and all public revenue is directed to the less rent seeking activity ($\varphi_t = 0$). E_h denotes the high corruption equilibrium, in which the economy experiences high tax evasion (small z_t) and only a small fraction of the total tax revenue is being directed to abatement (high φ_t) which allows for high rent seeking.

3.4 Equilibrium

The above analysis relies on the implicit assumption that an equilibrium exists. The aim of this section is to establish the conditions under which an equilibrium can be defined.

The literature has examined coordination games in which strategic complementarity exists (for example, Cooper and John, 1988 and Vives, 2005). Games of strategic complementarity are those in which the best response of any player is increasing in the actions of the rival, as is the case for z_t and φ_t when $\Omega_T < 0$. Strategic complementarity is a condition for the existence of multiple equilibria in *symmetric* coordination games.[21] The resulting equilibria are not driven by fundamentals. Instead, they are self-fulfilling and critically depend on one group's anticipation of the other group's behavior.

However, the game analyzed here is not symmetric. Moreover, the boundedness property of the choice set necessitates the consideration of corner solutions. In fact, as we show below, this game does not share many of the properties of games with strategic complementarity. Consider first the following definition of equilibrium:

[21] Notice however that also in games with strategic substitutability multiple equilibria may occur as well (Randon, 2009).

Definition 1 *A Nash equilibrium in this economy consists of sequences* $\{c_{it}\}_{t=0}^{\infty}$, $\{z_t\}_{t=0}^{\infty}$, $\{\varphi_t\}_{t=0}^{\infty}$, $\{y_{ct}\}_{t=0}^{\infty}$, $\{h_t\}_{t=0}^{\infty}$, $\{H_t\}_{t=0}^{\infty}$, $\{E_t\}_{t=0}^{\infty}$, $\{Q_t\}_{t=0}^{\infty}$, $\{\Pi_t\}_{t=0}^{\infty}$, $i = c, p$, *such that, given an initial average stock of human capital* $H_{-1} > 0$ *and an average level of environmental quality* $Q_{-1} > 0$, *in every period* t,

1. Private citizens choose z_t *to maximize their utility, taking* φ_t *as given.*

2. Politicians choose φ_t *to maximize their utility, taking* z_t *as given.*

3. The sequences $\{h_t\}_{t=0}^{\infty}$, $\{y_{ct}\}_{t=0}^{\infty}$, $\{Q_t\}_{t=0}^{\infty}$, $\{E_t\}_{t=0}^{\infty}$, $\{\Pi_t\}_{t=0}^{\infty}$ *and* $\{c_{it}\}_{t=0}^{\infty}$, *are determined according to (2), (4), (3), (5), (6), (7), and (9).*

4. $h_t = H_t$

Each group's individual optimization problem is well defined since the utility function is strictly concave and the budget constraint is linear with respect to the relevant decision variable, z_t or φ_t. Proposition 1 proves the existence of a pair (z_t, φ_t) that satisfies Definition 1 in every period. Given the existence of the equilibrium pair (z_t, φ_t), we can easily establish the equilibrium values of the remaining variables, following Definition 1.

Proposition 1 *An equilibrium pair* (z_t, φ_t) *exists for every* t.

Proof. We must establish the existence of a pair (z_t, φ_t) that satisfies equations (8) and (10) simultaneously. For an arbitrary time period t, let $z_t = f(\varphi_t)$ denote the solution to the citizen's problem, as described by equation (8); for each value of φ_t there exists a unique value of z_t. Similarly, let $\varphi_t = g(z_t)$ denote the solution to each politician's problem, as described by equation (10). Note that both of these functions are continuous (see equations (8) and (10)). Thus, the composite function $g \circ f$ from $[0,1]$ to $[0,1]$ is continuous and, by Brower's fixed point theorem, has a fixed point. ■

Solving the two groups' reaction functions we obtain the following three equilibrium values (z_i^*, φ_i^*), $i = 1, 2, 3$ that correspond to the ones described in Figure 1 above,

$$z_1^* = z_t(\varphi_t = 0) \qquad \varphi_1^* = \varphi_t(z_t = 0)$$

$$z_2^* = \frac{\sqrt{\Xi} - \sqrt{\Xi - 8\Omega\Psi}}{4\tau\sqrt{\Xi}} \qquad \varphi_2^* = \frac{-(1-\omega_q)\Omega_T + 3A\omega_q\Omega - \sqrt{(\Xi - 8\Omega\Psi)\Xi}}{4\Omega_T\Omega}$$

$$z_3^* = \frac{\sqrt{\Xi} + \sqrt{\Xi - 8\Omega\Psi}}{4\tau\sqrt{\Xi}} \text{ or } corner\ (z_3^* = 1) \qquad \varphi_3^* = \frac{-(1-\omega_q)\Omega_T + 3A\omega_q\Omega + \sqrt{(\Xi - 8\Omega\Psi)\Xi}}{4\Omega_T\Omega} \text{ or } corner\ (\phi_3^* = 0)$$

where $\Xi = \omega_h\omega_q (A - B) - \Omega_T$. For the non-zero equilibrium values of z and φ to be real numbers, it is necessary that $\Xi \geq 0$, and $\Xi - 8\Omega\Psi \geq 0$. The first condition implies that $\frac{B}{A} > \frac{(1-\omega_h)/\omega_h}{(1-\omega_q)/\omega_q}$, i.e. the ratio of technological efficiency of education to abatement should exceed the ratio of the rates of embezzlement. This condition leads to the following Lemma that restricts attention to the case of strategic complementarity.

Lemma 4 *A) Only the case of strategic complementarity yields real equilibrium solutions.*
B) In the case of strategic complementarity, i.e., $\Omega_T < 0$, the technology of either activity could be better, i.e., $A \gtrless B$.

Proof. Result (A) can be obtained by considering the first condition for real equilibrium solutions, i.e. $\Xi = \omega_h \omega_q (A - B) - \Omega_T > 0$. Assume strategic substitutability i.e. $\Omega_T > 0$. Then for $\Xi > 0$ it must necessarily be that $A > B$. However, $\Xi > 0 \Rightarrow B\omega_h (1 - \omega_q) > A\omega_q (1 - \omega_h)$. Recall that, from second order conditions, when $\Omega_T > 0$, it is necessary that $\Omega > 0 \Rightarrow \omega_q > \omega_h$. Thus, for $\Xi > 0$ it is necessary that $B > A$, which contradicts the previous assumption. Therefore, to obtain real solutions we must restrict the analysis to the case of strategic complementarity, i.e., $\Omega_T < 0$.
Result (B) follows again from the restriction that $\Xi > 0$. In the case of strategic complementarity, i.e., $\Omega_T < 0$, this inequality can be satisfied for $A \gtrless B$, as long as $\frac{B}{A} > \frac{(1-\omega_h)/\omega_h}{(1-\omega_q)/\omega_q}$.
■

3.5 Effectiveness of Environmental Policy

After establishing the existence of equilibrium and restricting our attention to strategic complementarity we examine the effect of environmental policy on environmental quality. For strategic complementarity $\Omega_T < 0$ and $\Omega < 0 \Rightarrow \omega_q < \omega_h$, which implies that abatement is the more prone to rent seeking activity. Abatement could be either more or less technologically advanced relative to education, $A \gtrless B$ depending on the ω's difference. Under these conditions, does shifting more public funds towards abatement improves environmental quality?

Interestingly, the effect of φ_t on environmental quality is not obvious. A precocious presumption, resulting from direct observation of equations (3) and (6), is that an increase in the share of public funds directed towards abatement activities has always a positive effect on environmental quality. However, this is not always true, since the effectiveness of publicly funded abatement depends on both the levels of rent seeking and tax evasion and on technological efficiency. Proposition 2 provides an answer to the above stated question.

Proposition 2 *Increasing the share of public spending on abatement activities, does not necessarily improve environmental quality. The effect depends on both the relative technological efficiency and the rent seeking opportunities.*

Proof. From equations (3) and (6) we get, $\frac{\partial Q_t}{\partial(1-\varphi_t)} = -\frac{\partial Q_t}{\partial \varphi_t} = -\left[-\omega_q z_t + (1-\varphi_t)\frac{\partial z_t}{\partial \varphi_t}\right]\tau h_t$. Since, by Lemma 4, we restrict our attention to strategic complementarity, we have $\frac{\partial z_t}{\partial \varphi_t} > 0$. Thus,

$$\frac{\partial Q_t}{\partial(1-\varphi_t)} \lesseqgtr 0 \text{ if } (1-\varphi_t)\frac{\partial z_t}{\partial \varphi_t} \gtreqless \omega_q z_t. \tag{13}$$

The above inequality could hold either way, depending on the parameter values. Therefore, for a range of parameter values, $(1-\varphi_t)\frac{\partial z_t}{\partial \varphi_t} > \omega_q z_t \Rightarrow \partial Q_t/\partial(1-\varphi_t) < 0$, which implies that increasing public spending on abatement actually decreases environmental quality. Recall that abatement is the high rent seeking activity ($\omega_q < \omega_h$). ■

Proposition 2 formally proves that increasing the share of public revenue allocated to the less effective public activity can potentially be detrimental. This result holds for economies with relatively loose enforcement mechanisms, in which reciprocity of corrupt behavior between citizens and politicians is a key determinant of raising tax revenue. Anecdotal evidence cited in Section 2, accords with our findings suggesting that a large number of corrupt economies cannot increase their environmental quality even after increasing the funds allocated to environmental protection. Shifting public revenues towards such activities, despite of the great potential they present, it might prove not only ineffective but also detrimental if $\Omega_T < 0$ and condition (13) holds.

Policy implications

In terms of policy, our results suggest that an intervention towards decreasing the rate of embezzlement of the public money allocated in environmental policy, is crucial for improving environmental quality. In economies that are highly susceptible to corruption, successful anti-corruption campaigns could play a crucial role in improving the effectiveness of investment in technologically advanced environmental projects.

Although we have treated the rates of embezzlement $1-\omega_h$ and $1-\omega_q$ as exogenous, institutional changes, aiming at reducing rent seeking opportunities associated with each type of public activity, could substantially increase ω_h and ω_q. As far as tax policy is concerned, the lower is the tax rate the smaller is tax evasion. The condition $\tau < \frac{1}{2}$ is necessary (but not sufficient) for a nil-evasion ($z_t = 1$) equilibrium to be feasible. Therefore, not very high tax rates coupled with low rent seeking opportunities can improve the model's outcome. Overall, a society has to ensure the well functioning of the public sector by strengthening its institutions in order to improve the effectiveness of environmental policy.

In order to obtain analytical results several restrictive assumptions have been employed in the baseline analysis. However, our results are robust to adopting more realistic assumptions. The appendix illustrates a more elaborate model where different assumptions are tested. Whereas we cannot derive analytical results, numerical simulations confirm our findings.

4 Conclusions

We develop a model that allow us to establish an additional channel via which corruption affects the environmental quality. In particular, we suggest that, in the presence of corruption, environmental projects do not necessarily yield the expected improvements in environmental quality, given the amount of public funds allocated to them and could actually have detrimental effects on environmental quality. In a model where politicians decide about policies and citizens pay taxes, this effect is reinforced in two ways: i) the allocation of public funds to environmental projects may facilitate the extraction of rents (on the part of the politicians), particularly when the technologies involved are advanced and thus the investment process less transparent; and ii) the citizens who observe the poor outcome of public investment choose to increase their tax evasion, thus leading to a vicious circle of extensive tax evasion, rent seeking and eventually to low environmental quality.

In light of increasing environmental awareness that pushes for higher spending on environmental projects and considering the recent scandals suggesting that public environmental projects can be a rather "profitable" domain for corrupt politicians, our analysis provides interesting policy suggestions. In order to achieve substantial improvements in environmental quality, a society has to strengthen its institutions, targeting to the reduction of rent seeking opportunities and to the improvement of transparency.

Appendix 1

A A More Elaborate Model

A.1 The Structure of the Economy

The basic structure of the model is identical to the benchmark model. In short, individuals live for two periods i.e. childhood and adulthood. During the first period of their lives individuals acquire human capital via public schooling whereas in the second period of their lives they either enter the private market or they become politicians via a random selection process. Their preferences are defined over their own consumption as well as the well being of their offsprings, which is reflected by the level of human capital they acquire as well as by the quality of environment their receive from their parents.

Accumulation of Human Capital

The learning technology in the public education system is quite similar as in the benchmark model and given by,

$$h_t = V + BE_{t-1} \ . \tag{1}$$

where t denotes time, h_t the level of human capital acquired by an individual born at $t-1$, E_{t-1} the public spending on education in the same period whereas the parameter $B > 0$ measures the efficiency of the public education system. According to this human capital accumulation process, a young agent born in period $t-1$, can acquire, without effort, a minimum level of human capital V of the previous period's accumulated human capital. Contrary to the baseline model, we will assume that the fraction of human capital to be freely obtained does not depend on the human capital of the period $t-1$.[1] As in the benchmark model the revenue for financing public schooling comes from taxing the economic activity of agents.

Production

[1] This assumption, coupled with the assumptions of the baseline model, allows us to cover a wide range of equations of motion for human capital and ensure the robustness of our results to alternative specifications.

Production uses both human capital and the environment/natural resources as inputs.[2] That is, we assume that output y_{ct} is,[3]

$$y_t = \Gamma h_t Q_t, \tag{2}$$

where Γ is the production technology. Evidently at the aggregate level there are increasing returns to scale. This is a simplifying assumption that allows us to make the model slightly more tractable.

Environmental Quality

The evolution of environmental quality is described by

$$Q_t = Q_{t-1} - \psi \Gamma H_{t-1} Q_{t-1} + A \Pi_{t-1} \tag{3}$$

where Q_{t-1} denotes the state of the environment in the previous period and ψ the extent of environmental degradation due to previous period's aggregate economic activity $\Gamma H_{t-1} Q_{t-1}$.[4] The term $A\Pi_{t-1}$ captures the beneficial effect of public spending on abatement on environmental quality, where A is a technological parameter associated with abatement. We assume that $1 - \psi \Gamma H_{t-1} > 0$. This formulation is rather common in the literature.[5]

Tax Revenue

Both types of individuals maximize their utility function as described by equation (1) in the basic model. The citizen chooses the fraction z of his income to declare to the tax authority and the politician the fraction φ of the total tax revenue to allocate to environmental projects.

The total tax revenue collected in period t is $R_t = z_t \tau \Gamma h_t Q_t$. As in the previous model a fraction $\phi_t z_t \Gamma B h_t Q_t$ of the total tax revenue is earmarked for public education. Since the politician peculates a fraction $1 - \omega_h$ of $\phi_t R_t$ and $1 - \omega_q$ of $(1 - \phi_t) R_t$, of the actual amounts spent on education E_t and abatement Π_t are,

$$E_t = \varphi_t \omega_h z_t \tau \Gamma h_t Q_t, \tag{4}$$

[2]We enrich the production function in order to extend our results to the natural resource strand of the literature and to highlight the robustness of our results to a more elaborate production structure. See for example Gennaioli and Tavoni (2011) for the link between renewable resources and corruption.

[3]Since all agents have the same level of human capital and the natural resource is commonly owned, we omit the subscript $i = c, p$ from both variables.

[4]This is an additional robustness control to the equation of motion for the environment, in which case in the absence of any economic activity the initial environmental quality Q_0 would be positive.

[5]See for example Economides and Philippopoulos (2008), and John and Pecchenino (1994).

$$\Pi_t = (1 - \varphi_t)\omega_q z_t \tau \Gamma h_t Q_t, \tag{5}$$

respectively. Individual optimization decisions regarding z_t and φ_t affect the sum and the allocation of public spending between education and abatement and consequently the human capital and the state of the environment enjoyed by the next generation.

A.2 Individual Optimization

Citizen

Citizens declare a fraction z_t of their income y_t to the tax authority. Hence, citizens' disposable income is $(1 - \tau)z_t\Gamma h_t Q_t + (1 - z_t)\Gamma h_t Q_t = (1 - z_t\tau)\Gamma h_t Q_t$. The individual optimization problem solved by each citizen born in period $t - 1$ is,

$$\max_{c_c t, z_t} \quad c_{ct}[h_{t+1}, +Q_{t+1}] \tag{6}$$

subject to

$$\begin{aligned} c_{ct} &= (1 - z_t\tau)\Gamma h_t Q_t \ , \\ c_{ct} &\geq 0, \quad 1 \geq z_t \geq 0 \ , \end{aligned} \tag{7}$$

where h, Q, E and Π are determined by equations equations (1), (3) (4) and (5), taking φ_t, H_t and Q_t as given.

The first order condition of the above problem yields citizen's best response function,

$$z_t = f(\varphi_t) = \frac{(A\omega_q - \varphi_t\Omega_T)\,\Gamma H_t Q_t - \Psi_n}{2\tau\Gamma H_t Q_t\,(A\omega_q - \varphi_t\Omega_T)} \ , \tag{8}$$

where $\Omega_T = A\omega_q - B\omega_h$ and $\Psi_n = Q_t + V - \psi\Gamma H_t Q_t$. Concavity holds since $B\omega_h - \varphi_t\Omega_T > 0$.

Citizens' reaction function in (8) has similar characteristics as the one in the benchmark model (equation (8)).[6] However, in this case the reaction function is path dependent, since z_t depends on the the level of economic activity, y_t, that is, on H_t and Q_t. These variables evolve over time until the economy approaches a steady state (whenever a steady state exists) and therefore the optimal strategy is changing over time.

[6] The slope of the citizen's reaction function is, $\partial z_t/\partial\varphi_t = -\Psi_n\Omega_T/2\tau 2H_tQ_t(A\omega_q - \varphi\Omega_T)^2$ and $\partial^2 z_t/\left(\partial\varphi_t\right)^2 = -\Psi_n\Omega_T^2/2\tau 2H_tQ_t(A\omega_q - \varphi\Omega_T)^3 < 0$ since $A\omega_q - \varphi\Omega_T > 0$. Therefore, as in the benchmark model, the sign of citizen reaction function's slope depends on the sign of the term Ω_T.

It is important to note that at time t the values of H_t and Q_t have been already determined by the previous generation and therefore each generation treats them as exogenous.

Inspection of equation (8) reveals that an interior solution ($0 < z < 1$) exists iff $(2\tau - 1)\Gamma H_t Q_t (A\omega_q - \varphi_t \Omega_T) < \Psi_n < \Gamma H_t Q_t (A\omega_q - \varphi_t \Omega_T)$. A corner solution $z_t = 1$ will emerge if the rate of human capital transferred freely to the next generation, V, is sufficiently high (low), the rate of degradation of environmental quality, ψ, sufficiently low (high) and the rent reeking rates, $(1-\omega_h)$ and $(1-\omega_q)$, sufficiently high (low). As in the benchmark model, for sufficiently high τ ($\tau > \frac{1}{2}$), the tax evasion rate is never zero, since $z < 1$.

Whenever an interior solution emerges, the comparative statics with respect to technology and policy parameters are given in Lemma A.1.

Lemma A.1 *Whenever an interior solution emerges, the tax evasion rate ($1 - z_t$) is reduced,*

i) the more efficient is the use of tax revenues, (i.e. the higher are A and B),

ii) the lower are the rent seeking rates (i.e., ω_q and ω_h), and

iii) the lower is the tax rate, τ.

Proof. Results (i)-(iii) can be obtained by taking the derivatives of the interior solution with respect to each parameter. ■

Politician

The politician's income is derived solely from peculation of tax revenue and is $[\varphi_t(1-\omega_q) + (1-\phi_t)(1-\omega_h)]\tau z_t \Gamma h_t Q_t$. The politician's optimization problem is,

$$\max_{c_{pt},\mu_t} \quad c_{pt}[h_{t+1}, +Q_{t+1}] \tag{9}$$

subject to

$$\begin{aligned} c_{pt} &= [(1-\varphi_t)(1-\omega_q) + \phi_t(1-\omega_h)]\tau z_t \Gamma h_t Q_t \ , \\ c_{pt} &\geq 0, \quad 1 \geq \varphi_t \geq 0 \ , \end{aligned} \tag{10}$$

where h, Q, E and Π are determined by equations equations (1), (3) (4) and (5), taking φ_t, H_t and Q_t as given.

Maximization of the politician's best response function yields,

$$\varphi_t = g(z_t) = \frac{\Omega\Psi_n - X\tau z_t \Gamma H_t Q_t}{2\Omega_T \Omega \tau z_t \Gamma H_t Q_t} = -\frac{X}{2\Omega_T \Omega} + \frac{\Psi}{2\Omega_T \tau z_t \Gamma H_t Q_t}, \tag{11}$$

where $\Omega = \omega_q - \omega_h$ and $X = (1-\omega_q)\,\Omega_T - A\omega_q\Omega$.[7]

For interior solutions ($0 < \varphi < 1$) it is required that $\tau z_t X \Gamma H_t Q_t/\Omega < \Psi_n < \tau z_t \Gamma H_t Q_t (2\Omega_T \Omega + X)/\Omega$. On the other hand, corner solutions of directing revenue to a unique policy ($\varphi_t = 0$ and $\varphi_t = 1$, respectively) emerge depending on the values of ω_h, ω_q.

Lemma A.2 *Whenever an interior solution emerges, the fraction of public funds directed to education,* φ_t*,*

i) is increasing in B*, and decreasing in* A*,*

iii) the effect of τ*,* ψ *and* Q_0 *and* V *depends on the sign of* Ω_T*. Specifically*

$$A\omega_q - B\omega_h \gtreqless 0 \Longrightarrow \frac{\partial \varphi_t}{\partial \tau} \lesseqgtr 0, \frac{\partial \varphi_t}{\partial \psi} \lesseqgtr 0, \frac{\partial \varphi_t}{\partial Q_0} \gtreqless 0 and \frac{\partial \varphi_t}{\partial V} \gtreqless 0.$$

Overall we observe that despite the fact that our setting is more complex and realistic, the predictions of the model are quite similar with respect to the reaction functions. As was the case with the citizen's reaction function, the politician's reaction function also depends on the realized values of H_t and Q_t which are predetermined by the previous generation and therefore each generation of politicians treats them as exogenous.

Strategic Interactions

Strategic interactions in this setting are similar to the benchmark case. As we show above, the sign of both reaction functions' slope depends on the sign of the term Ω_T. Analytically,

$$\begin{array}{ll} i)\ \Omega_T < 0 \Longrightarrow A\omega_q < \beta\omega_h \Longrightarrow & \frac{\partial z_t}{\partial \varphi_t} > 0,\ \frac{\partial \varphi_t}{\partial z_t} > 0 \ \text{ i.e. } \textit{Strategic Complements} \\ ii)\ \Omega_T > 0 \Longrightarrow A\omega_q > \beta\omega_h \Longrightarrow & \frac{\partial z_t}{\partial \varphi_t} < 0,\ \frac{\partial \varphi_t}{\partial z_t} < 0 \ \textit{ i.e. Strategic Substitutes} \end{array}$$

yielding similar predictions to the benchmark model. Namely, in the case of strategic complements citizens will choose to "punish" politicians in case they perceive their behavior as corrupt, whereas in the case of strategic substitutes they behave more honestly in order to keep public revenues high.

[7] Similar to the benchmark model, for concavity to hold we must have $\Omega_T \Omega > 0$. The slope of the politician's reaction function is, $\partial\varphi_t/\partial z_t = -\Psi_n/2\tau z_t^2 2\Gamma H_t Q_t \Omega_T$, with $\partial^2 \varphi_t/\left(\partial z_t\right)^2 = \Psi_n/4\Gamma\tau z_t^3 2 H_t Q_t \Omega_T$. The sign of reaction functions' slope depends on the sign of the term Ω_T.

A.3 Equilibrium

The definition of equilibrium remains the same in both models. Each group's individual optimization problem is well defined since its utility function is strictly concave and the budget constraint linear with respect to the relevant decision variable, z_t or φ_t. In Proposition A.1 below, we prove the existence of a pair (z_t, φ_t) that satisfies Definition 1 in every period, for given values of H_t and Q_t. Given the existence of the equilibrium pair (z_t, φ_t), we can easily establish the equilibrium values of H_t and Q_t and subsequently of the remaining variables, following Definition 1 in the main body of the paper.

Proposition A.1 *An equilibrium pair* (z_t, φ_t) *exists for given values of* H_t *and* Q_t.

Proof. We must establish the existence of a pair (z_t, φ_t) that satisfies equations (8) and (11) simultaneously. For an arbitrary time period t, let $z_t = f(\varphi_t, h_t, Q_t)$ denote the solution to each citizen's problem, as described by equation (8); for each value of φ_t there exists a unique value of z_t. Similarly, let $\varphi_t = g(z_t, h_t, Q_t)$ denote the solution to each politician's problem, as described by equation (11). Note that both of these functions are continuous (see equations (8) and (11)). Thus, the composite function $g \circ f : [0,1] \to [0,1]$ is continuous and, by Brower's fixed point theorem, has a fixed point. ■

Solving for the equilibrium values of the model we obtain,[8]

$$\begin{array}{ll} z_1^* = f^1(h_1^*, Q_1^*) \text{ or } \textit{corner } (z_1^* = 0) & \varphi_1^* = g^1(h_1^*, Q_1^*) \text{ or } \textit{corner } (\phi_1^* = 0) \\ z_2^* = f^2(h_2^*, Q_2^*) & \varphi_2^* = g^2(h_2^*, Q_2^*) \\ z_3^* = f^3(h_3^*, Q_3^*) \text{ or } \textit{corner } (z_3^* = 1) & \varphi_3^* = g^3(h_3^*, Q_3^*) \text{ or } \textit{corner } (\phi_3^* = 0) \end{array} \tag{12}$$

Therefore in terms of strategies there always exists an equilibrium for given values of h_t and Q_t. Since however there is a law of motion describing how these two variables evolve, there will be different equilibrium values in each period for z_t and φ_t unless the system approaches a steady state. The dynamics of the model are analyzed in the following subsection.

A.4 Dynamic Behavior of the System of Difference Equations

As noted above the stable solutions of the model (if all three are valid) are (z_1^*, φ_1^*) and (z_3^*, φ_3^*) using best reply dynamics. Since the set (z_1^*, φ_1^*) represents a trivial equilibrium

[8] We omit analytical expression due to their complexity.

of high levels of corruption we will focus on the low-corruption equilibrium (z_3^*, φ_3^*). Replacing the equilibrium values for (z_3^*, φ_3^*) from equation (12) into equations (1) and (3) we obtain the following system of two autonomous non-linear first order difference equations

$$\begin{aligned} h_{t+1} &= F(h_t, Q_t) \ , \\ Q_{t+1} &= G(h_t, Q_t) \ . \end{aligned}$$

The dynamics of the system are too complex to be analytically studied. However, we can describe analytically the kind of solution that is desirable in order for our model to be meaningful and provide numerical simulations.

In order to approximate the dynamics of our benchmark model, i.e. a set of equilibrium values for (z_t, φ_t) that remain unchanged in every period, our system of difference equations must reach a steady state. Therefore we first assume that the dynamic system has steady-state equilibrium $(\bar{h}, \bar{Q})$. Namely, $\exists\ (\bar{h}, \bar{Q})$ such that,

$$\begin{aligned} \bar{h} &= F(\bar{h}, \bar{Q}) \ , \\ \bar{Q} &= G(\bar{h}, \bar{Q}) \ . \end{aligned}$$

A Taylor expansion of the system around the steady state values $(\bar{h}, \bar{Q})$, yields:

$$\begin{aligned} h_{t+1} &= F(h_t, Q_t) \\ &= F(\bar{h}) + F_h(\bar{h}, \bar{Q})(h_t - \bar{h}) + F_Q(\bar{h}, \bar{Q})(Q_t - \bar{Q}) + R_1 + R_2 \ , \end{aligned} \tag{13}$$

$$\begin{aligned} Q_{t+1} &= G(h_t, Q_t) \\ &= G(\bar{Q}) + G_h(\bar{h}, \bar{Q})(h_t - \bar{h}) + G_Q(\bar{h}, \bar{Q})(Q_t - \bar{Q}) + R_1 + R_2 \ , \end{aligned} \tag{14}$$

where $F_h(\bar{h}, \bar{Q})$ and $G_h(\bar{h}, \bar{Q})$ are the partial derivatives of the functions $F(h_t, Q_t)$ and $G(h_t, Q_t)$ evaluated at $(\bar{h}, \bar{Q})$ and R_1 and R_2 are the error terms which are very small in the neighborhood of $(\bar{h}, \bar{Q})$ and have little influence on the behavior of the system. Thus, the non-linear system is being approximated, locally (around the steady-state equilibrium) by the linear system:

$$\begin{bmatrix} h_{t+1} \\ Q_{t+1} \end{bmatrix} = \begin{bmatrix} F(\bar{h}) \\ G(\bar{Q}) \end{bmatrix} + \begin{bmatrix} F_h(\bar{h}, \bar{Q}) & F_Q(\bar{h}, \bar{Q}) \\ G_h(\bar{h}, \bar{Q}) & G_Q(\bar{h}, \bar{Q}) \end{bmatrix} \begin{bmatrix} h_t - \bar{h} \\ Q_t - \bar{Q} \end{bmatrix} \ ,$$

where,

$$J(\bar{h},\bar{Q}) = \begin{bmatrix} F_h(\bar{h},\bar{Q}) & F_Q(\bar{h},\bar{Q}) \\ G_h(\bar{h},\bar{Q}) & G_Q(\bar{h},\bar{Q}) \end{bmatrix} , \tag{15}$$

is the Jacobian matrix evaluated at the steady-state equilibrium. Q_o and h_0 denote the initial values for h_t and Q_t and are exogenously given.

If all eigenvalues of $J(\bar{h},\bar{Q})$ have moduli strictly less than 1, $(\bar{h},\bar{Q})$ is asymptotically stable (a sink). If at least one eigenvalue of $J(\bar{h},\bar{Q})$ has modulus greater than 1, then $(\bar{h},\bar{Q})$ is unstable (a source). If the eigenvalues of $J(\bar{h},\bar{Q})$ are all inside the unit circle, but at least one is on the boundary (has modulus 1), then $(\bar{h},\bar{Q})$ may be stable, asymptotically stable or unstable. Therefore we take the following steps: Test whether our system approaches the steady state $(\bar{h},\bar{Q})$. For this steady state to be a feasible solution, the dynamics of the system must satisfy the limitations of the model, namely concavity and the implied values $\bar{z} \leq 1$ and $\bar{\varphi} \leq 1$. Also the dynamics of the system must be characterized by stability, i.e. the eigenvalues must be inside the unit circle.

If the above restrictions hold, then we are fully able to describe the behavior of the equilibrium values of (z^*, φ^*) in every period of the model up to the steady state. It is important to have a stable steady state since otherwise h_t and Q_t grow without limits, and taking into account that $\frac{\partial z^*}{\partial h_t} > 0$ and $\frac{\partial z^*}{\partial Q_t} > 0$, the value of z_t will increase continuously reaching eventually unity.

B Numerical Approximations

The enriched model closely follows the benchmark model up to the point were we obtain the reaction functions. However due to the system of non-linear difference equations it quickly becomes rather complicated. Therefore we resort to numerical simulations in order to illustrate our results.

The model uses a number of parameters, namely A, B, Γ, τ, ω_h, ω_q, V, and ψ. As the above analysis reveals, the most important term driving our results is $\Omega_T = A\omega_q - \beta\omega_h$, determining the type of strategic interaction between the two groups of agents.

Evidently the model is a rough approximation of reality therefore it is hard to clarify what values of the parameters can be considered as "realistic". Still though with respect to tax evasion there is some evidence that in the Western developed countries the rates of tax evasion are estimated around 5%-25% of potential tax revenue (Feige, 1989, Pyle, 1989, Thomas, 1992) while for developing countries higher rates may appear (Tanzi and Shome, 1994). For the year 1988 in the US, the TCMP has estimated that only a 53% of tax payers paid their taxes correctly. Of course non compliance does not apply to all these cases, since a 7% has overpaid its taxes while a part of the remaining 40% has underpaid due to errors that result from the complicated procedure involved. According to Fanzoni (1998) the federal income tax gap of the US had been estimated for 1998 at 17%.

Concerning the values of ω_h and ω_q there is much evidence that different allocations of public budget are associated with different rent-seeking rates. Mauro (1998) finds evidence that public expenditure on high-technology goods is associated with higher rent-seeking due to low detectability and the same goes for military expenditure. On the other hand education and health sectors involve more transparent expenditure and are thus associated with lower rent-seeking rates. The range of these rates varies enormously depending on the quality of institutions in each country. The rates of embezzlement could be as low as 0.5%-2% for developed countries and could be as high as 30%-50% for developing countries. Since our model primarily targets to account for abatement in highly corrupt countries we will allow for high embezzlement rates (i.e., ω_h and ω_q, can be as low as 0.5-0.6). Tax rates vary between 0.25-0.55.

As to the parameters A, B, and Γ it is harder to pin down which range of values would be plausible. Therefore we will focus on their between ratio as implied by our model, namely A, B and $\Gamma > 0$ and $A\omega_q < B\omega_h$ for strategic complementarity which is the case we analyze. For the value of υ there is also no evidence, still though it is plausible to assume that it will take rather small values, well below unity (e.g. Ceroni (2001) takes values of υ as low as $\upsilon = 0.2$).

Having pinned down the range of parameter values and having imposed the restrictions mentioned earlier, namely concavity, strategic complementarity and an asymptotically stable steady state we obtain a number of feasible steady states. Figure 1 illustrates a numerical example with specific values of the model's parameters.

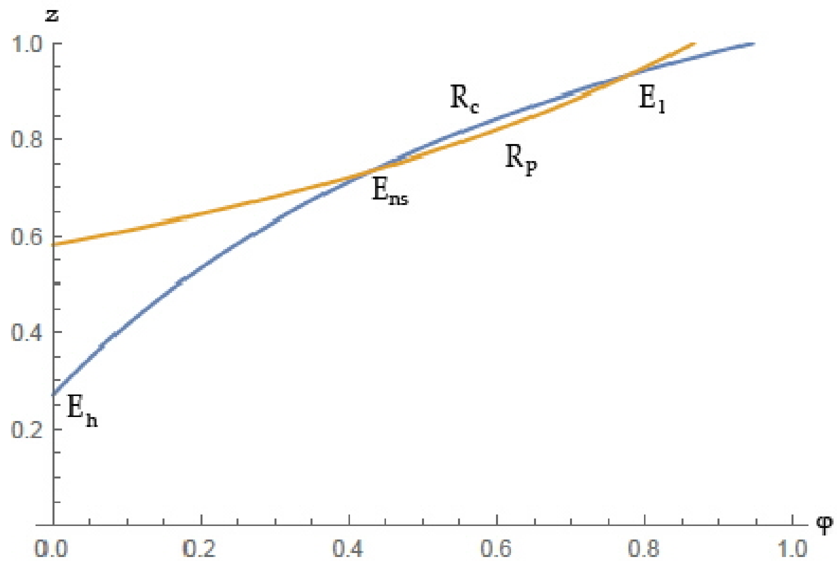


Figure A.1: Numerical Reaction Functions-The parameter values are $A = 5$, $B = 9$, $\omega_h = 0.6$, $\omega_q = 0.5$, $\tau = 0.3$, $\upsilon = 0.2$, $\psi = 0.4$, $\Gamma = 4$, $Q_0 = 0.11$ and $H_0 = 0.28$.

In this example, in line with the predictions of our baseline model, there are two stable and one unstable $(z_2^*, \phi_2^*) = (0.734, 0.430)$ equilibria emerging. The two stable equilibria are the high $(z_1^*, \phi_1^*) = (0.268, 0)$ and the low $(z_3^*, \phi_3^*) = (0.931, 0.776)$ corruption equilibria. In the high corruption equilibrium (z_1^*, ϕ_1^*) the politician allocates the entire tax revenue to the corrupt activity, i.e., abatement and the citizen declares a small potion of his income. In the low corruption equilibrium she allocates a high portion of public fund to education and the citizen reciprocates by declaring almost all his income.

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