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Economic Growth, Health, and the Choice of Polluting Technologies: The Role of Bureaucratic Corruption

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Abstract

I model an economy where the adverse health effects of pollution impede labour productivity and capital accumulation is the source of economic growth. Pollution is generated by firms that choose whether to employ a dirty technology and pay an environmental tax, or employ a clean technology and incur the cost of its adoption. The task of inspecting the environmental impact of each firm's production technology is delegated to bureaucrats who are corruptible since they receive bribes in order to mislead authorities on the firms' actual technology choice. The model can generate multiple steady state equilibria. In this context, the multiplicity of equilibria is associated with indeterminacy, due to the self-fulfilling nature of corruption incentives and the relevant implications for pollution, productivity and economic growth.

Keywords: Corruption; Economic Growth; Health; Pollution; Productivity

JEL Classification: D73; O44; Q58

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1 Introduction

In recent years, researchers and policy makers have become increasingly aware of the possibility that corruption may infringe on aspects pertaining to the quality of the natural environment. Evidence suggests that the effectiveness of policies designed to eradicate environmental degradation and address the rising concerns over climate change (i.e., emission controls; environmental taxes etc.) is undermined by the corrupt practices of some public officials who are involved in their implementation (Fredriksson and Svensson 2003; Welsch 2004; Cole 2007). Other empirical analyses are more explicit on the circumstances associated with the impact of corruption on environmental quality. For instance, Koyuncu and Yilmaz (2009) and Burgess *et al.* (2012) offer a link to deforestation, arguing that corruption can account for cases of widespread illegal logging. Hubbard (1998) and Oliva (2012) find that the incidence of corruption, among some inspection centres involved on vehicle emission controls, implies that actual vehicle emissions are under-reported. The empirical investigation of Ivanova (2011) offers a broader perspective on the idea that, by impeding the effectiveness of environmental regulations, corruption is responsible for situations where pollutant emissions are significantly misreported. Particularly, her empirical results suggest that although countries with less effective regulations report lower emissions, in reality their actual emissions are higher compared to countries with effective implementation of environmental policies.

Even though some existing papers have employed theoretical models that analyse bureaucratic corruption in situations where the implementation of environmental policy requires inspection and emission monitoring by public officials (e.g., Acemoglu and Verdier 2000; López and Mitra 2000; Damania 2002; Damania *et al.* 2004; Stathopoulou and Varvarigos 2013), the idea that such circumstances are linked to the fundamentals of the growth process has so far eluded the attention of researchers.[1] This is despite the fact that there is an abundance of arguments to support the view that economic growth may be central to the relevance of corruption for the implementation of environmental policy. Firstly, there is unambiguous evidence on the relation between corruption and economic growth, a relation that appears to be two-way causal: corruption is a significant impediment to economic growth (Mauro 1995) while, at the same time, it appears to be a feature that is

[1] For alternative approaches on the macroeconomic effects of environmental policy, see Byrne (1997); Itaya (2008); and Heutel (2012) among others.

more salient at lower stages of economic development (Gundlach and Paldam 2009). Secondly, environmental degradation can impinge on the economy's long-term prospects, mainly through its well-documented adverse effects on the population's health (Brunekreef and Holgate 2002; Briggs 2003). For instance, the empirical investigations of Ostro (1983) and Hanna and Oliva (2011) address this issue and show that pollution may have a significantly negative effect on labour productivity. These ideas, when combined with the aforementioned evidence on the association between corruption and environmental policy, offer credence to the view that economic growth and development may be inherently connected to the effect of corruption on pollution and, in particular, on the effectiveness of emission inspections and the adoption of polluting technologies. In fact, this view has already been recognised by the International Labour Organisation (ILO). I am quoting directly from the ILO's webpage (see Footnote 2 for the link) where it is argued that "*industrial practices may also produce adverse environmental health consequences…this is often the case in developing countries where…environmental standards are often inappropriate or not effectively implemented.*"[2]

The purpose of my paper is to fill this gap in the literature. Particularly, I seek to analyse the outcomes that transpire in a framework where bureaucratic corruption, the environmental repercussions of technology choice, and capital accumulation are jointly determined. While I borrow elements from the aforementioned literature on corruption and emission inspection/monitoring, my departure stems from the explicit connection to capital accumulation and economic growth, since I incorporate these elements into a full-fledged dynamic general equilibrium framework. In my model, pollution has an adverse effect on labour productivity through the detrimental impact on the population's health characteristics.[3] The government imposes an environmental tax to firms that employ the more polluting, but less costly to adopt, technology and entrusts bureaucrats with the tasks of verifying the firms' technology choices and advising on the cases where the tax should be applied. Bureaucrats are corruptible however: in exchange for bribes, they may be willing to mislead authorities with regard to the actual technology choice of firms that emit more pollutants, thus relieving them from the tax liability. As I argued before, the economy's dynamics are explicit, driven by the formation of capital through saving and investment.

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[2] See http://www.ilo.org/oshenc/part-vii/environmental-health-hazards/item/497-industrial-pollution-in-developing-countries

[3] Other research articles that incorporate the health effects of environmental quality in models of economic growth, are those by Gradus and Smulders (1993); Gutiérrez (2008); and Varvarigos (2010) among others.

The model's equilibrium is characterised by a complex web of bi-directional effects on the joint determination of capital accumulation, the incidence of corruption and emission intensity (i.e., the aggregate emission rate).[4] Corruption hinders labour productivity and economic growth since it is associated with an increase of pollutant emissions. At the same time, however, the incidence of corruption among bureaucrats and, consequently, the adverse effect on labour productivity due to higher emission intensity, are manifested at low levels of income per capita. What is more, the impact of the aggregate emission rate on labour productivity impinges on the expected utility costs that a corrupt bureaucrat faces in the event that he is detected and punished for his transgression, thus generating strong complementarities in the decision making process that determines the incentives to be corrupt. In other words, a bureaucrat is more likely to be corrupt when the incidence of corruption is widespread among public officials. These complex effects have significant repercussions for the economy's dynamics, since there are conditions under which the model generates multiple steady state equilibria. More importantly, these equilibria are indicative of indeterminacy, in a manner similar to Redding (1996) and, in a more related vein, Blackburn *et al.* (2004). In other words, economies that are identical in terms of both structural parameters and initial conditions may experience drastically different long-term prospects. These circumstances emerge due to the self-fulfilling nature of corruption incentives and the relevant implications for the choice of polluting production processes, productivity and economic growth.

All in all, the aforesaid results justify the endeavour to analyse the link between corruption and pollution in a framework that is explicit on the dynamics of capital accumulation and output growth. The occurrence of corrupt practices in the implementation of environmental policy may have far-reaching repercussions that extent to the economy's overall macroeconomic performance. Thus, this approach may be particularly relevant to those developing countries facing significant environmental problems, but where corruption is ubiquitous.

The remaining analysis is structured as follows. In Section 2, I present the characteristics of the model's set-up. Section 3 delves into the role of the public sector. In Section 4, I

[4] Other theoretical models that analyse the joint determination of economic growth and corruption are constructed by Ehrlich and Lui (1999); Gradstein (2004); Blackburn and Forgues Puccio (2007); and Eicher *et al.* (2009). None of them, however, incorporate any implications for environmental policy and pollution.

derive the model's implications for the incidence of corruption and the determination of the aggregate emission rate, while Section 5 presents the results concerning capital accumulation. Section 6 concludes.

2 An Overview of the Economy

Time is discrete and indexed by $t = 0, 1, 2...$. The economy is (partly) populated by an infinite sequence of overlapping generations of households that face a lifespan of two periods – youth and old age. Each age cohort consists of a constant population mass that is equal to $m > 0$. Nature divides the population of newly-born households into two distinct groups of varying abilities. Particularly, a mass $n > 0$ of households will be born as *bureaucrats* while the remaining mass of $m - n$ households will be born as *workers*. Both types have preferences over their old-age consumption, denoted c_{t+1}, that are represented by a the utility function $u_t = c_{t+1}$. All households are born with a labour endowment equal to a unit of time. Those born as workers are suppliers of labour services to the private sector of the economy. Bureaucrats are also born with the ability to offer labour services to the private sector. What differentiates them from workers is that they also possess the ability to use their unit of time for the alternative opportunity of employment in the economy's public sector. I shall delve into the detailed characteristics of the public sector and the role of its employees during a subsequent part of the analysis. All households (workers and bureaucrats) offer their labour when young and receive labour income that is subject to a flat tax rate $\tau \in (0,1)$. They deposit their entire disposable labour income to financial intermediaries which repay it next period, augmented by the gross rate of interest r_{t+1}.

In every period, the economy is also populated by the agents that comprise its production structure. Specifically, there is a unit mass of monopolistically competitive intermediate good producers and a unit mass of perfectly competitive final good producers. Both these entities live for one period. The former combine physical capital and labour in order to produce different varieties of intermediate goods, each one indexed by i, while at the end of the period they consume an amount of final goods equal to their profits. They employ a technology described by

$$y_{it} = K_{it}^{a}(A_t L_{it})^{1-a}, \quad 0 < a < 1, \tag{1}$$

where K_{it} denotes physical capital, L_{it} denotes labour, y_{it} denotes the amount of intermediate goods supplied by each firm, and A_t is an economy-wide index of labour productivity. Final good producers combine all the different varieties of intermediate goods as the inputs to a production process that generates Y_t units of the economy's single final good according to

$$Y_t = \left(\int_0^1 y_{it}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} , \tag{2}$$

where $\sigma > 1$ is the elasticity of substitution between different varieties of intermediate inputs. The final good can be used for either consumption or investment purposes.

With regard to the economy-wide variable that determines labour productivity, I assume that it is determined by an indicator of health status. Particularly, it is affected by two distinct externalities that determine each household's health. On the one hand, there is a positive externality in the sense that the health profile of the population improves in an economy with higher per capita income, denoted $\overline{Y}_t$.[5] On the other hand, there is a negative externality that captures the impeding effect of pollution (denoted M_t) on the population's health status. Formally, I capture these ideas by assuming that labour productivity A_t is a function $A_t = A(\overline{Y}_t, \mathrm{M}_t)$, such that $A_{\overline{Y}_t}(\overline{Y}_t, \mathrm{M}_t) > 0$ and $A_{\mathrm{M}_t}(\overline{Y}_t, \mathrm{M}_t) < 0$. To facilitate the tractability of the model, I follow others (e.g., Pautrel 2009; Clemens and Pittel 2011; Aloi and Tournemaine 2013) in assuming that the function $A(\overline{Y}_t, \mathrm{M}_t)$ is homogeneous of degree zero. Hence, I shall be making use of

$$A_t = \overline{A} \left(\frac{\overline{Y}_t}{\mathrm{M}_t} \right)^{\gamma} , \tag{3}$$

where $\overline{A} > 0$ and $\gamma > 0$ are constant parameters. I shall also assume that pollution is a by-product of the production of intermediate goods. Specifically, each firm i emits μ_{it} units of pollution per unit of production. Therefore, total emissions are given by

$$\mathrm{M}_t = \int_0^1 \mu_{it} y_{it} di . \tag{4}$$

[5] This assumption is supported by evidence showing that, as economies develop, people become more aware on health-improving decisions and actions, thus adopting a lifestyle that contributes to improved health status (e.g. Smith 1999). Other arguments that support this assumption relate to better nutrition, access to improved health services etc.

Physical capital is created and channelled to intermediate good producers by perfectly competitive financial intermediaries who operate in the formal financial sector of the economy. The reason I make the distinction of a formal financial sector is because there is also an informal financial sector whose role will be discussed in the subsequent section. Financial intermediaries collect deposits from households and employ them in a technology that transforms units of time-t output into units of time-$t+1$ capital on a one-to-one basis. The capital is subsequently rented out to intermediate good producers. Assuming that capital depreciates fully in production, and given that financial intermediaries are perfectly competitive, the rental rate of capital is equal to the gross return on saving. Therefore, denoting aggregate saving to the formal financial sector by S_t, the equilibrium in the financial market implies that

$$\int_0^1 K_{it+1} di = S_t \,. \tag{5}$$

Denote the price of an intermediate input by P_{it}. The profit maximisation problem of final good firms leads to the demand function[6]

$$y_{it} = p_{it}^{-\sigma} Y_t \,, \tag{6}$$

where

$$p_{it} = \frac{P_{it}}{P_t} \,, \tag{7}$$

is the relative price of firm i and

$$P_t = \left(\int_0^1 P_{it}^{1-\sigma} di \right)^{1/(1-\sigma)} \,, \tag{8}$$

is the average price level across all intermediate good producers. These producers will choose quantities for K_{it} and L_{it}, as well as the relative price of their product, in order to maximise their (variable) profits, taking the real wage (w_t), the rental price of capital (r_t), the average price level (P_t), the productivity of labour (A_t) and aggregate production (Y_t) as given. Let λ_t be the marginal cost of production, corresponding to the Lagrange multiplier of the cost minimisation problem associated with K_{it} and L_{it}. Then

$$w_t = \lambda_t (1-a) K_{it}^{a} L_{it}^{-a} A_t^{1-a} \,, \tag{9}$$

[6] A formal derivation is presented in the Appendix.

and

$$r_t = \lambda_t a K_{it}^{a-1} L_{it}^{1-a} A_t^{1-a} . \tag{10}$$

Using Equation (6), each firm's variable profit can be written as

$$v_{it} = (p_{it} - \lambda_t) y_{it} = (p_{it} - \lambda_t) p_{it}^{-\sigma} Y_t \ , \tag{11}$$

a result that can facilitate us in deriving the (optimal) relative price by setting $\frac{\partial v_{it}}{\partial p_{it}} = 0$. This operation yields

$$p_{it} = \frac{\sigma}{\sigma - 1} \lambda_t , \tag{12}$$

i.e., the familiar condition stating that the price is a mark-up over the marginal cost of production. The results in (9), (10) and (12) reveal that the equilibrium with respect to prices, quantities and variable profits is symmetric across the producers of intermediate goods. In other words, $P_{it} = P_t$, $K_{it} = K_t$, $L_{it} = L_t$, $y_{it} = y_t$ and $v_{it} = v_t \ \ \forall i$. Therefore, Equations (2) and (7) imply that

$$p_{it} = 1 \ \text{ and } \ y_t = Y_t . \tag{13}$$

Recall that, by definition, output per household is $\bar{Y}_t = \frac{Y_t}{m}$ and let

$$\mu_t = \int_0^1 \mu_{it} di , \tag{14}$$

be the aggregate emission rate. It follows that we can combine (3), (4), (13) and (14) to write labour productivity as

$$A_t = \frac{\Omega}{\mu_t^{\gamma}} , \tag{15}$$

where $\Omega \equiv \bar{A} m^{-\gamma}$. Furthermore, using $k_t = \frac{K_t}{m}$ to denote capital per household and denoting the (constant) labour supply by l, we can use the labour market equilibrium ($L_t = l$) together with Equations (9)-(13) and (15) to obtain[7]

$$v_t = \frac{y_t}{\sigma} , \tag{16}$$

$$w_t = \omega k_t^a \mu_t^{-\gamma(1-a)} , \tag{17}$$

[7] An explicit solution for labour supply is presented in Equation (21).

and

$$r_t = Rk_t^{a-1}\mu_t^{-\gamma(1-a)}, \tag{18}$$

where $\omega \equiv \dfrac{(\sigma-1)(1-a)\Omega^{1-a}}{\sigma(ml)^a}$ and $R \equiv \omega aml(1-a)^{-1}$.

3 The Public Sector

As I indicated previously, pollution is generated by the emissions of intermediate good producers. I am going to consider the case where firms have the choice of the technology they will employ in production. Specifically, firms can choose to employ one out of two available technologies that are distinguished in terms of their corresponding emission rates and adoption costs. The first technology is a relatively 'dirty' one, generating $\overline{\mu} > 0$ units of pollution per unit of production. It can be adopted at zero cost, but its use renders firms liable to an emission penalty (i.e., an environmental tax) equal to $\theta > 0$.[8] The second technology is the relatively 'clean' one, as it emits $\underline{\mu} < \overline{\mu}$ ($\underline{\mu} > 0$) pollutants per unit of production. The use of this technology relieves firms from the obligation to pay the environmental tax, but its adoption is costly as it requires firms to devote an amount $q\delta_i$, where $q > 0$ and δ_i is uniformly distributed among the producers of intermediate inputs, with support on the interval $[0,1]$.[9]

The government cannot observe each firm's technology choice directly. This is where the abilities of bureaucrats become relevant to my set-up. Specifically, the government can hire bureaucrats and delegate to them the task of using their unit of time in order to inspect firms, verify their technology choices, and subsequently advise the government on whether to impose an environmental tax or not. All intermediate good producers will have their technology choice verified by a bureaucrat. Assuming that a hired bureaucrat can monitor at most $\psi > 1$ firms with her unit of time, and given that there is a unit mass of intermediate good producers to be monitored, the government can minimise the number of public

[8] The assumption that renders the adoption of the more polluting technology costless is innocuous for my results. It is used simply to avoid excessive notation. What is important is that the 'dirty' technology is less costly to adopt, compared to the 'clean' one.

[9] The source of this heterogeneity is assumed to be private information, in the sense that each firm's type is not observed by the government.

officials necessary to monitor all firms by hiring $\frac{1}{\psi}$ bureaucrats. I assume that $\psi^{-1} \leq n$, meaning that the mass of $n - \psi^{-1} \geq 0$ bureaucrats who do not obtain employment in the public sector, will devote their labour services to intermediate good producers.

Each of the hired bureaucrats receives a salary X_t for offering his unit of time to the public sector. Naturally, the option of employment in the private sector implies that no one would accept a contract for which $X_t < w_t$.[10] The willingness to accept such a contract would signal the candidate's expectation to cover the shortfall by engaging in illegal rent-seeking – an issue that is pertinent since the opportunity to seek illegal rents does materialise as we shall see shortly. For this reason, a candidate willing to accept $X_t < w_t$ would be immediately dismissed by the government, implying that candidates would only accept contracts that specify $X_t \geq w_t$. Henceforth, I assume

$$X_t = xw_t, \tag{19}$$

where $x \geq 1$. Similarly to private sector workers, those hired in the public sector are liable to a flat tax rate $\tau \in (0,1)$.

The government operates under a balanced budget rule and finances a flow of expenditures on government consumption, denoted g_t, by using the difference between revenues and expenditures. Denoting the total revenues from the environmental tax by Θ_t (a variable that will be determined later; see Equation 39) we can use the previous discussion to express the government's budget according to

$$g_t = \underbrace{\tau w_t l + \tau x w_t \psi^{-1}}_{\text{income tax revenues}} + \underbrace{\Theta_t}_{\text{revenues from the environmental tax}} - \underbrace{x w_t \psi^{-1}}_{\text{expenses on bureaucratic salaries}}, \tag{20}$$

where

$$l \equiv m - \psi^{-1}, \tag{21}$$

is the total supply of labour in the economy's private sector.

[10] Note that, irrespective of the occupation, the unit of time is supplied inelastically. Thus, I abscond from issues relating to varying effort costs and different status associated with each occupation. Such issues go beyond the scope of this paper.

4 Bureaucratic Corruption and the Emission Rate

Initially, let us consider a scenario where bureaucrats act exactly as instructed by the government, rather than engaging in any illegal rent-seeking. In this case, bureaucrats receive a salary for verifying the technology choice of the firms they monitor and they deposit their disposable labour income to financial intermediaries. Therefore, they enjoy utility

$$u_t^{\text{honest}} = r_{t+1}(1-\tau)xw_t \,. \tag{22}$$

With regard to intermediate good producers, each firm i 's total profit π_{it} is given by[11]

$$\pi_{it} = \begin{cases} v-\theta, & \text{if} \quad \mu_{it} = \overline{\mu} \\ \\ v-q\delta_i, & \text{if} \quad \mu_{it} = \underline{\mu} \end{cases} . \tag{23}$$

Naturally, a firm will choose its technology in order to maximise total profits. Assuming $\theta < q$, there is $\overline{\delta} \equiv \dfrac{\theta}{q}$ such that[12]

$$\mu_{it} = \begin{cases} \underline{\mu}, & \text{for} \quad \delta_i \in [0,\overline{\delta}\,] \\ \\ \overline{\mu}, & \text{for} \quad \delta_i \in (\overline{\delta}\,,1] \end{cases} , \tag{24}$$

meaning that we can combine (14) and (24) to derive the aggregate emission rate as

$$\mu_t = \overline{\mu} - \overline{\delta}(\overline{\mu} - \underline{\mu}) \equiv \mu^{NC} \,. \tag{25}$$

The ideas summarised in (22)-(25) apply to the case where bureaucrats are not corrupt. Nevertheless, the delegation of monitoring by the government to the bureaucrats can be a source of moral hazard issues that would alter the aforementioned outcomes. For instance, a corruptible bureaucrat, who inspects a firm that employs the more polluting technology, may be willing to mislead the authorities by claiming that the firm in question employs a cleaner

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[11] Note that the relevant costs of technology choice, i.e., either the environmental tax or the adoption cost of the cleaner technology, are fixed in nature since they do not vary with production. Consequently, the variable profit is the same, irrespective of the technology choice.

[12] To justify the condition $\theta < q$, I appeal to the case where, given the stock of capital k_t , any $\theta \geq q$ implies that intermediate good producers close to the upper bound of the distribution of costs (δ_i) will end up with negative profits, thus they would prefer not to produce at all. Note, however, that my results remain qualitatively identical even when $\theta \geq q$. In the absence of corruption, the aggregate emission rate would be equal to $\underline{\mu}$. In order to make the analysis in the presence of corruption meaningful though, an additional restriction $z < q/\theta$ would be necessary (see Equation 31 later).

technology, thus advising against the imposition of the environmental tax. In exchange, he will ask for a bribe b_t. Now consider an intermediate good producer contemplating whether to accept this offer. While doing so, the producer will have to consider the possibility that an illegal collusion with a corrupt bureaucrat may be detected by the authorities. Suppose that this happens with probability $z \in (0,1)$ and that the penalty in case of detection is that the producer will be forced to pay the tax obligation associated with the use of the 'dirty' technology. Therefore, the total profit for a firm that adopts a more polluting production technology, but is willing to bribe the bureaucrat to conceal this choice, is $\pi_{it} = v_t - (b_t + z\theta)$. Together with Equation (23), it follows that the firm will be willing to accept the bureaucrat's offer as long as

$$b_t \leq (1-z)\theta . \tag{26}$$

Otherwise, any firm employing the more polluting technology would strictly prefer to reveal its actual choice to the government and pay the environmental tax, rather than bribing the bureaucrat to conceal this information. Later, I will impose a condition to guarantee that (26) does indeed hold. In this case, any producer who does not choose to adopt the clean technology will be willing to offer a bribe in order to have the firm's actual circumstances misreported by a corrupted bureaucrat. It follows that

$$\pi_{it} = \begin{cases} v - (b_t + z\theta), & \text{if} \quad \mu_{it} = \overline{\mu} \\ \\ v - q\delta_i, & \text{if} \quad \mu_{it} = \underline{\mu} \end{cases} . \tag{27}$$

Once more, an intermediate good producer will adopt the technology that is associated with profit maximisation. From (27), we can obtain a threshold

$$\hat{\delta}_t = \frac{b_t + z\theta}{q} , \tag{28}$$

such that

$$\mu_{it} = \begin{cases} \underline{\mu}, & \text{for} \quad \delta_i \in [0, \hat{\delta}_t] \\ \\ \overline{\mu}, & \text{for} \quad \delta_i \in (\hat{\delta}_t, 1] \end{cases} . \tag{29}$$

Now, let us turn our attention to the behaviour and actions of a corruptible bureaucrat. Insofar as some firms are willing to accept his offer, he earns illegal rents from the bribes he receives for deceiving the authorities, in addition to his salary. Provided that the government has perfect access to information regarding the saving deposits of all households in the economy, the corrupted bureaucrat will endanger his position if he deposits his ill-gotten gains to the formal financial sector. For this reason, he can deposit his collected bribes to the informal financial sector. The latter is assumed to access a storage technology that offers a relatively low return of $\zeta_{t+1} < r_{t+1}$ units of time- $t+1$ output, for every unit of output stored during period t. Hereafter, I will specify $\zeta_{t+1} = \varphi r_{t+1}$ such that $0 < \varphi < 1$. Similarly to firms, the bureaucrat faces the probability $z \in (0,1)$ of being apprehended and proven guilty for his misdemeanour. When this happens, he faces a proportional utility cost $\varepsilon \in (0,1)$ which captures the psychological costs of imprisonment, shame, social stigma etc. Recall that each bureaucrat will monitor ψ firms, a fraction $1-\hat{\delta}_t$ of which will be willing to bribe him for concealing their use of a more polluting technology. With this in mind, we can use the previous arguments to express the expected utility of a corrupted bureaucrat according to $E(u_t^{\text{corrupt}}) = [1 - z + z(1-\varepsilon)]r_{t+1}[(1-\tau)xw_t + \varphi\psi(1-\hat{\delta}_t)b_t]$. Substituting (28), we can rewrite the expected utility as

$$E(u_t^{\text{corrupt}}) = (1 - z\varepsilon)r_{t+1}\left[(1-\tau)xw_t + \varphi\psi\left(1 - \frac{b_t + z\theta}{q}\right)b_t\right]. \tag{30}$$

The bureaucrat will demand the bribe that will maximise his expected utility. While determining this, he will have to consider two opposing effects that emerge from his attempt to seek a higher bribe. On the one hand, a higher bribe will improve his expected utility directly since it increases the overall amount of ill-gotten gains. On the other hand, a higher bribe will have an indirect negative effect on his expected gains from corruption because, by increasing $\hat{\delta}_t$, it reduces the number of firms willing to accept his offer to collude in order to mislead the authorities. Using (30), we can calculate $\frac{\partial E(u_t^{\text{corrupt}})}{\partial b_t} = 0$ to obtain the optimal bribe

$$b_t^* = \frac{q - z\theta}{2} \equiv b > 0. \tag{31}$$

In order to guarantee that the condition in (27) holds, we can use the result in Equation (31) and establish that $b \le (1-z)\theta$ holds as long as

$$z \leq 2 - \frac{q}{\theta}, \tag{32}$$

a condition that is henceforth assumed to hold. Next, we can substitute (31) in (28) to get

$$\hat{\delta}_t = \frac{q + z\theta}{2q} \equiv \hat{\delta}, \tag{33}$$

from which it can be verified that $\hat{\delta} < 1$ because $q - z\theta > 0$. Given this, we can combine (14) and (29) to derive the aggregate emission rate in the presence of corruption. That is,

$$\mu_t = \overline{\mu} - \hat{\delta}(\overline{\mu} - \underline{\mu}) \equiv \mu^C. \tag{34}$$

A straightforward comparison between Equations (25) and (34) leads to

Lemma 1. *Corruption is responsible for a higher aggregate emission rate, i.e.,* $\mu^C > \mu^{NC}$. *Consequently, the incidence of bureaucratic corruption reduces labour productivity.*

Proof. The results in (25) and (34) reveal that $\mu^C > \mu^{NC} \Leftrightarrow \overline{\delta} > \hat{\delta}$. Therefore, it is sufficient to show that $\frac{\theta}{q} > \frac{q + z\theta}{2q}$, a condition that is indeed true given (32). The second part of Lemma 1 follows from Equation (15). □

The intuition behind Lemma 1 is the following. Corrupt bureaucrats offer an opportunity that reduces the expected cost of employing the more polluting technology. As a result, there is a fraction of intermediate good producers (equal to $\overline{\delta} - \hat{\delta}$) who find optimal to use that technology, despite the fact that they would have chosen to adopt the cleaner production method in the absence of corruption. This outcome leads to an increase of total emissions and is responsible for impeding labour productivity, due to the detrimental impact of pollution on the population's health.

Of course, the outcome that will ultimately prevail depends on the bureaucrats' disposition while employed by the government. Substituting (31) in (30) allows us to write the expected utility of a corrupted bureaucrat as

$$E(u_t^{\text{corrupt}}) = (1 - z\varepsilon)r_{t+1}\left[(1-\tau)xw_t + f\right], \tag{35}$$

where $f \equiv \frac{\varphi\psi}{2}\left(\frac{q - z\theta}{q}\right)^2$. A bureaucrat will be corrupt as long as the expected utility associated with such behaviour is higher that the utility accruing in the case where he avoids engaging in any type of misconduct. Formally, a bureaucrat will be corrupt as long as

$$E(u_t^{\text{corrupt}}) > u_t^{\text{honest}}. \tag{36}$$

With the purpose of facilitating the subsequent analysis, I shall define $\hat{k}^{NC}$ and $\hat{k}^{C}$ such that

$$\hat{k}^{NC} \equiv H(\mu^{NC})^{\frac{\gamma(1-a)}{a}}, \tag{37}$$

and

$$\hat{k}^{C} \equiv H(\mu^{C})^{\frac{\gamma(1-a)}{a}}, \tag{38}$$

where $H \equiv \left[\frac{(1 - z\varepsilon)f}{z\varepsilon(1-\tau)x\omega}\right]^{1/a}$ and $\hat{k}^{NC} < \hat{k}^{C}$ by virtue of Lemma 1. It follows that the disposition of bureaucrats can be summarised in

Lemma 2. *There exists a threshold* $\hat{k}^{j}$, *where* $j = \{NC, C\}$, *such that for* $k_t < \hat{k}^{j}$ *all bureaucrats are corrupt whereas for* $k_t \geq \hat{k}^{j}$ *none of the bureaucrats is corrupt.*

Proof. See the Appendix. □

According to Lemma 2, the incidence of corruption is an outcome that is salient at relatively low stages of economic development. The intuition behind this result is as follows. A corrupt bureaucrat faces the possibility of being detected and subsequently punished for his transgression. The punishment associated with this outcome implies that the utility increment from being corrupt is decreasing in the capital stock. When the latter is relatively low, the possibility of eventual punishment is not sufficient to deter him from his quest to gain through illegal rent-seeking. Nevertheless, if the capital stock is sufficiently high, the loss of utility that will occur in the event that he is detected and punished for his malfeasance is high enough to induce him to behave honestly.

It is important to note that the threshold determining whether bureaucrats are corrupt or honest is not uniquely determined. Instead, it varies with the incidence of corruption as a result of the two-way causal effects that pervade the determination of corruption incentives. This is because corruption determines labour productivity indirectly through the determination of the aggregate emission rate, implying that in an economy with thriving corruption, the real wage is lower due to lower productivity. This is an outcome that fuels a bureaucrat's incentive to be corrupt and makes it less likely that he will act honestly. In other words, we observe an outcome that echoes the idea that "corruption corrupts" – an outcome that will have significant implications for the economy's long-term equilibrium as we shall see shortly.[13]

Before proceeding to the formal analysis of economic dynamics, I shall devote the last part of this section for the characterisation of the revenues accruing from the environmental tax, i.e., Θ_t. Similarly to the other elements of the model's equilibrium, these revenues will depend on the extent of corruption among bureaucrats.[14] In the absence of corruption, the tax is paid by $1-\overline{\delta}$ (where $\overline{\delta} \equiv \theta / q$) intermediate good producers who opt for the more polluting technology. In the presence of corruption, bureaucrats try to conceal the use of the more polluting technology by $1-\hat{\delta}$ firms (where $\hat{\delta}$ is given in Equation 33). Still, a fraction $z \in (0,1)$ of those firms will be detected by authorities and be forced to pay their tax obligation. It follows that Θ_t is given by

$$\Theta_t = \begin{cases} z(1-\hat{\delta})\theta, & \text{when bureaucrats are corrupt} \\ \\ (1-\overline{\delta})\theta, & \text{when bureaucrats are not corrupt} \end{cases} . \tag{39}$$

5 Capital Accumulation

As I indicated in a previous part of the analysis, the formation of capital is undertaken by intermediaries in the formal financial sector of the economy. These intermediaries use the savings by all households in the economy and transform them into units of physical capital according to Equation (5). Taking account of the results so far, total saving is formally given by $S_t = (1-\tau)w_t l + (1-\tau)xw_t\psi^{-1}$, i.e., it is composed of the disposable labour income of households in both the private (workers and bureaucrats not hired by the government) and

[13] See Andvig and Moene (1990) for an analysis and discussion on a related issue.
[14] The Appendix offers a formal derivation of the goods market equilibrium.

the public sector (bureaucrats hired by the government). Using Equation (17), we can express (5) in per capita terms, according to

$$k_{t+1} = \upsilon k_t^{a} \mu_t^{-\gamma(1-a)} = \eta(k_t, \mu_t), \tag{40}$$

where $\upsilon \equiv (1-\tau)\omega \dfrac{l + x\psi^{-1}}{m}$.

Given the analysis of the previous section, we know that the aggregate emission rate will be either $\mu_t = \mu^C$ or $\mu_t = \mu^{NC}$ depending on whether bureaucrats are corrupt or behave honestly respectively. Evidently, (40) implies that $\eta_{\mu_t}(k_t, \mu_t) < 0$, hence allowing us to write the dynamics of capital accumulation as

$$k_{t+1} = \begin{cases} \eta^{NC}(k_t), & \text{for} \quad \mu_t = \underline{\mu} \\ \\ \eta^{C}(k_t), & \text{for} \quad \mu_t = \overline{\mu} \end{cases}, \text{ where } \eta^{NC}(k_t) > \eta^{C}(k_t) \ \ \forall k_t > 0. \tag{41}$$

The expression in (41) reveals that corruption impinges on the dynamics of capital accumulation through its effect on the aggregate emission rate and, therefore, its implications for pollution, health, and labour productivity. In the presence of corruption, the wage is decreased due to the lower productivity of labour, meaning that, for a given capital stock today, the funds that support the formation of capital are reduced, thus leading to a future capital stock that falls short of the one determined in the absence of bureaucratic corruption. Therefore, the long-run equilibrium of the economy can be characterised through

Proposition 1. *There exists a (locally) asymptotically stable steady state* $\varkappa > 0$ *satisfying* $k_{t+1} = k_t = \varkappa$. *The steady state solution under corruption,* $\varkappa = k^{*}$*, is strictly lower compared to the steady state solution in the absence of corruption,* $\varkappa = k^{**}$. *That is,* $k^{*} < k^{**}$.

Proof. Use $\mu_t = \mu^j$, $j = \{NC, C\}$, in (40) so that $k_{t+1} = \upsilon k_t^a (\mu^j)^{-\gamma(1-a)} = \eta(k_t)$. Applying the steady state condition $k_{t+1} = k_t = \varkappa$ we can see that there are two possible solutions, i.e., 0 and the interior solution $\varkappa = \upsilon^{1/(1-a)}(\mu^j)^{-\gamma}$. Now, evaluate the first derivative of $\eta(k_t)$ to obtain $\eta_{k_t}(0) = +\infty$ and $\eta_{k_t}(\varkappa) = a \in (0,1)$, thus verifying that the only stationary solution is the interior one. In the presence of corruption, the aggregate emission rate entails $j = C$ and the steady state is $\varkappa = k^*$ such that

$$k^* \equiv \upsilon^{1/(1-a)}(\mu^C)^{-\gamma}, \tag{42}$$

whereas in the absence of corruption we have $j = NC$ and a steady state $\varkappa = k^{**}$ such that

$$k^{**} \equiv \upsilon^{1/(1-a)}(\mu^{NC})^{-\gamma}. \tag{43}$$

Finally, combining (42) and (43) with Lemma 1 establishes that $k^* < k^{**}$. □

The results so far reveal a complex web of bi-directional effects involving the incidence of corruption, the aggregate emission rate through technology choice, and capital accumulation. On the one hand, pollution affects the household's health status, thus impeding labour productivity and capital accumulation. On the other hand, the economy's endowment in terms of capital stock per household determines pollution via its effect on the incidence of corruption and, therefore, the aggregate emission rate. Moreover, the impact of the aggregate emission rate on labour productivity generates strong complementarities in the decision making process that determines whether bureaucrats will be corrupt or honest, implying that the relation between pollution and corruption is two-way causal as well. These rich effects may generate different possibilities concerning the characteristics of the equilibrium to which the economy will converge in the long-run. I shall begin the formal analysis of economic dynamics with circumstances leading to a unique long-run equilibrium, as it is evident in

Proposition 2. *If $k^{**} < \hat{k}^{NC}$ then, for any $k_0 > 0$, the economy will converge to an equilibrium characterised by k^*, whereas if $k^* > \hat{k}^C$ then, for any $k_0 > 0$, the economy will converge to an equilibrium characterised k^{**}.*

Proof. See the Appendix. □

The scenarios summarised in Proposition 1 are depicted in Figures 1 and 2. When $k^{**} < \hat{k}^{NC}$, the economy cannot sustain the resources necessary to deter bureaucrats from being corrupt. Whatever the initial endowment in terms of capital stock, in the long-run the economy will converge to an equilibrium where bureaucrats will be corrupt and, therefore, the high aggregate emission rate will impede productivity, resulting in a low level of income per capita. On the contrary, when $k^* > \hat{k}^C$, the economy will be able to sustain the resources necessary to discourage bureaucrats from seeking bribes in order to improve their personal circumstances. For that reason, the economy will converge to an equilibrium where the aggregate emission rate will be lower, due to all bureaucrats being honest, and income per capita will be high as a result of improved labour productivity.

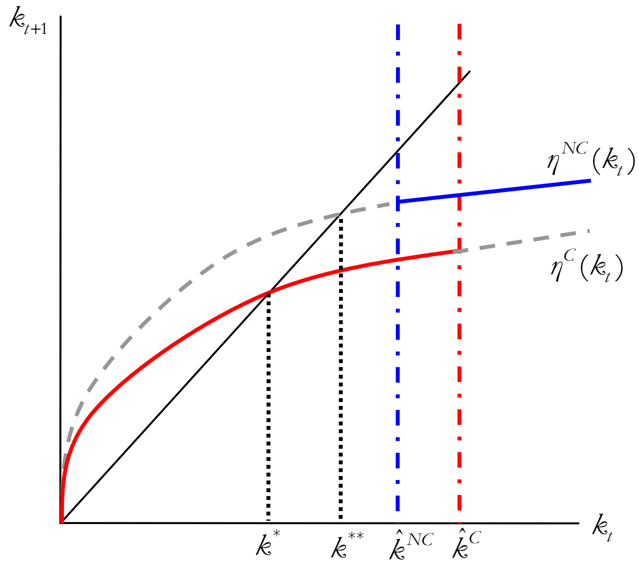

Figure 1. Unique equilibrium (k^*)

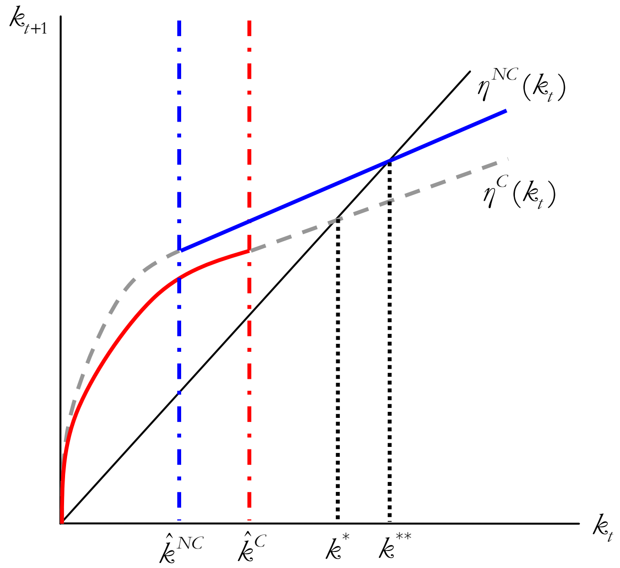

Figure 2. Unique equilibrium (k^{**})

The previous result establishes the conditions under which a unique equilibrium occurs in the long-run. Yet, the two-way causal effects between capital accumulation and the aggregate emission rate, as well as the complementarities on the determination of corruption incentives, to which I alluded during the discussion that followed Lemma 2, are responsible for a richer set of equilibria. I shall begin the exposition of these cases with

Proposition 3. *If* $\hat{k}^{NC} < k^* < k^{**} < \hat{k}^{C}$ *holds, then there are multiple equilibria characterised by either* k^* *or* k^{**}. *These are not path-dependent though. Instead, the economy may converge to any of these two equilibria, regardless of the initial stock of capital* $k_0 > 0$.

Proof. See the Appendix. □

The case that is outlined in Proposition 3 is effectively a case of equilibrium indeterminacy. Here multiplicity is not dependent on the initial condition (i.e., the history); hence the initial endowment in terms of capital per person is irrelevant for the outcomes that transpire in the long-run as it is evident from Figure 3. What matters here is the self-fulfilling nature of corruption incentives. If bureaucrats expect the others to be corrupt (honest) then they will find optimal to be corrupt (honest) themselves, thus generating the outcome that verifies their initial belief. Economies that, on the outset, are identical in every respect (i.e., in terms of both structural parameters and initial endowments) may experience drastically different long-term prospects, simply because bureaucrats believe on the materialisation of these prospects.

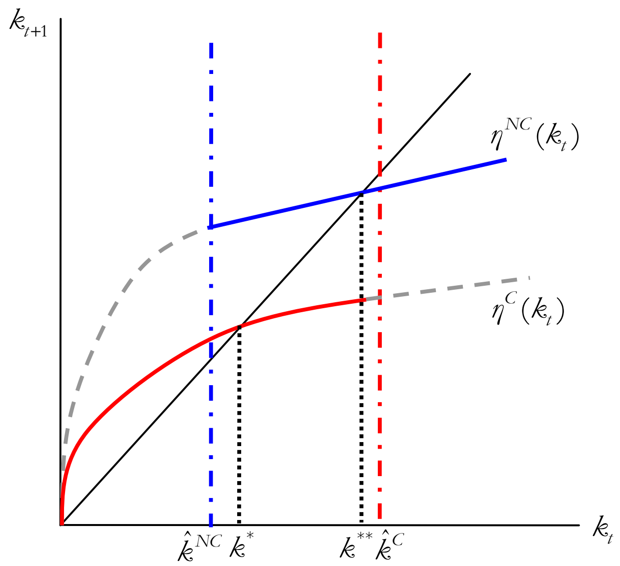

Figure 3. Equilibrium indeterminacy

The possibility of multiple equilibria is not restricted to the scenario outlined in Proposition 3. Instead, there are other cases which differ, however, in that initial conditions (partially) determine the outcomes that transpire in the long-run. This is established in

Proposition 4. *Multiple equilibria that are permeated by both path dependency and indeterminacy emerge in the following cases:*

i. *If* $\hat{k}^{NC} < k^* < \hat{k}^C < k^{**}$ *then the economy will converge to the equilibrium characterised by* k^{**} *if* $k_0 > \hat{k}^C$. *For* $k_0 < \hat{k}^C$, *the economy may converge to any of the two equilibria characterised by either* k^* *or* k^{**}*;*

ii. *If $k^* < \hat{k}^{NC} < k^{**} < \hat{k}^{C}$ then the economy will converge to the equilibrium characterised by k^* if $k_0 < \hat{k}^{NC}$. For $k_0 > \hat{k}^{NC}$, the economy may converge to any of the two equilibria characterised by either k^* or k^{**};*

iii. *If $k^* < \hat{k}^{NC} < \hat{k}^{C} < k^{**}$ then the economy will converge to the equilibrium characterised by k^* if $k_0 < \hat{k}^{NC}$ and to the equilibrium characterised by k^{**} if $k_0 > \hat{k}^{C}$. For $k_0 \in (\hat{k}^{NC}, \hat{k}^{C})$, the economy may converge to any of the two equilibria characterised by either k^* or k^{**}.*

Proof. See the Appendix. □

In all the cases described in Proposition 4, the history is one of the characteristics that may matter for the economy's long-term prospects, because it determines the extent to which the economy will be able to sustain the resources necessary to eliminate the incidence of corruption and, therefore, improve its environmental quality through a more widespread use of cleaner technologies. In Part (i), $k_0 > \hat{k}^{C}$ implies that, in the absence of corruption, a greater number of intermediate good firms adopt the cleaner production technology. Labour productivity is high and through the process of capital accumulation, it supports a capital stock which is high enough to guarantee that bureaucrats remain honest, thus allowing the economy to converge to a high income equilibrium. For any $k_0 < \hat{k}^{C}$, however, the economy's capital stock will at some point reach the region located in the interval $(\hat{k}^{NC}, \hat{k}^{C})$. Thus, the long-run equilibrium cannot be determined with certainty, since the indeterminacy that pervades the bureaucrats' decision to be either corrupt or honest impinges on the outcomes that transpire in the long-run (see Figure 4). In Part (ii), an economy with $k_0 < \hat{k}^{NC}$ sees a greater number of intermediate good firms opting for the more polluting production method, partly because of the opportunities offered by corrupt bureaucrats. As the pollution externality becomes more pronounced, labour productivity falls and drags down capital accumulation to the extent that the capital stock remains low enough to sustain an equilibrium where bureaucrats are corrupt. This reinforces the previous sequence of events, thus obstructing the economy from escaping the low income-high corruption equilibrium. Nevertheless, when $k_0 > \hat{k}^{NC}$ the economy's capital stock will eventually reach the region defined by $(\hat{k}^{NC}, \hat{k}^{C})$, thus leading to equilibrium indeterminacy for the same reasons that I discussed previously (see Figure 5). Finally, Part (iii) describes a scenario where the equilibrium can be uniquely determined only for a pre-existing capital stock that is either low (below $\hat{k}^{NC}$) or high (above $\hat{k}^{C}$). For intermediate levels, the self-fulfilling nature of corruption incentives, and their corresponding implications for pollution and capital accumulation, lead to equilibrium indeterminacy (see Figure 6).

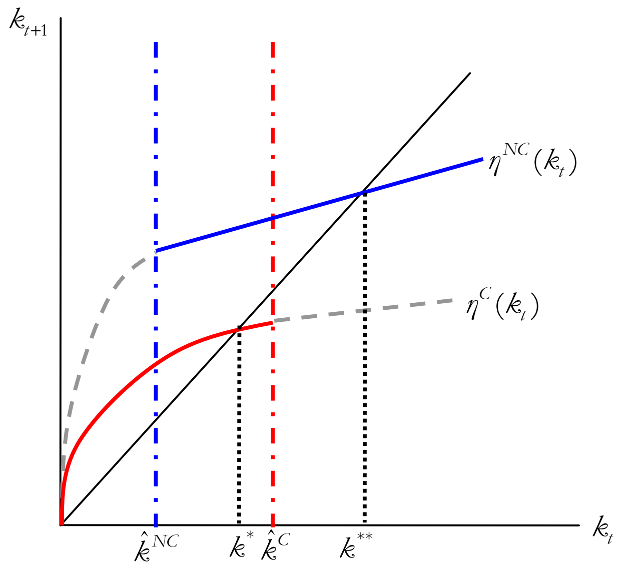

Figure 4. Part (i) of Proposition 4

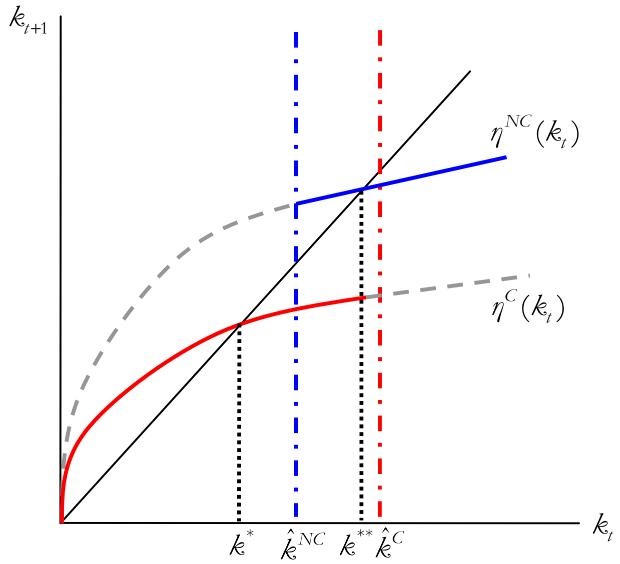

Figure 5. Part (ii) of Proposition 4

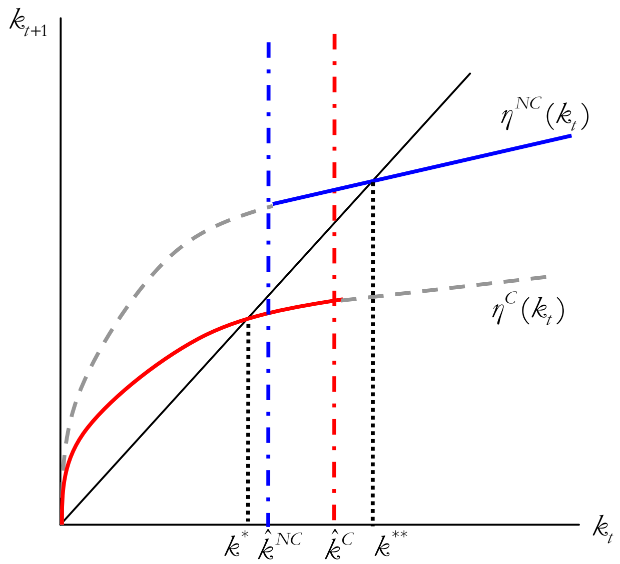

Figure 6. Part (iii) of Proposition 4

It should be pointed out that all the outcomes that were analysed so far are based on the pure strategy equilibria that emerge from the decision making process that determines the bureaucrats' behaviour while employed by the government. Despite the fact that the process determining the incentives to be corrupt generates mixed strategy equilibria as well, I should reemphasise the fact that this process involves strategic complementarities – a situation for which researchers have shown that mixed strategy equilibria are unstable (Echenique and Edlin 2004; Vives 2005).[15] To see this, let us examine what happens if each bureaucrat is corrupt with probability $\beta_t \in (0,1)$, meaning that, by the law of large numbers, a fraction β_t of bureaucrats will be corrupt and the remaining fraction $1-\beta_t$ of bureaucrats will be honest. In terms of the aggregate emission rate, it follows that that

$$\mu_t = \hat{\delta}\underline{\mu} + (1-\overline{\delta})\overline{\mu} + \beta_t(\overline{\delta}-\hat{\delta})\overline{\mu} + (1-\beta_t)(\overline{\delta}-\hat{\delta})\underline{\mu} \Leftrightarrow$$

$$\mu_t = \overline{\mu} - [\overline{\delta} - \beta_t(\overline{\delta}-\hat{\delta})](\overline{\mu}-\underline{\mu}) \equiv \tilde{\mu}(\beta_t), \qquad (44)$$

such that $\tilde{\mu}'(\beta_t) > 0$, $\tilde{\mu}(1) = \hat{\mu}^C$ and $\tilde{\mu}(0) = \hat{\mu}^{NC}$. Given this, we can use the proof to Lemma 2 (see the Appendix) to write the condition for which a bureaucrat decides to be corrupt as

$$\left(\frac{k_t}{H}\right)^a < [\tilde{\mu}(\beta_t)]^{\gamma(1-a)}, \qquad (45)$$

a condition that can retrieve the pure strategy equilibria as follows. Firstly, note that for $k_t \leq \hat{k}^{NC}$ the LHS of (45) is lower than or equal to $(\hat{\mu}^{NC})^{\gamma(1-a)}$. Nevertheless, it is $\tilde{\mu}'(\beta_t) > 0$ and $\tilde{\mu}(\beta_t) \in [\hat{\mu}^{NC}, \hat{\mu}^C]$, meaning that (45) holds, i.e., all bureaucrats are corrupt ($\beta_t = 1$). Analogously, for $k_t \geq \hat{k}^C$ the LHS of (45) is greater than or equal to $(\hat{\mu}^C)^{\gamma(1-a)}$. Given $\tilde{\mu}'(\beta_t) > 0$ and $\tilde{\mu}(\beta_t) \in [\hat{\mu}^{NC}, \hat{\mu}^C]$, it follows that (45) cannot hold; in fact, it is $(k_t / H)^a > [\tilde{\mu}(\beta_t)]^{\gamma(1-a)}$ and, therefore, none of the bureaucrats is corrupt ($\beta_t = 0$). Of course, the mixed strategy equilibrium is characterised by the value of β_t for which the bureaucrat is indifferent between being corrupt or honest, i.e., the β_t for which (45) holds as an equality. Using Equation (44), we can obtain this value as

$$\beta_t^* = \left[\overline{\delta} - \frac{\overline{\mu} - (k_t / H)^{a/\gamma(1-a)}}{\overline{\mu} - \underline{\mu}}\right](\overline{\delta} - \hat{\delta})^{-1}, \qquad (46)$$

such that $\beta_t^* \in (0,1)$ for $k_t \in (\hat{k}^{NC} \hat{k}^C)$.

[15] The notion of instability applied here is that, starting from a point in the neighbourhood of the equilibrium, the adjustment process of each agent's best response to the other agents' strategies diverges away from the mixed strategy equilibrium.

If we undertake some simple comparative statics in the result of Equation (46), it will become immediately obvious that it cannot represent a meaningful (stable) equilibrium. For instance, it is straightforward to establish that $\frac{\partial \beta_t^*}{\partial k_t} > 0$ and $\frac{\partial \beta_t^*}{\partial z} = \frac{\partial \beta_t^*}{\partial H}\frac{\partial H}{\partial z} > 0$. In other words, corruption rises in a more developed economy and when the probability of being detected and punished by authorities is higher – results that are at odds with the actual characteristics of a bureaucrat's decision making process. We can conclude that the solution in (46) is nothing else other than a 'knife-edge' scenario, determining which one of the two pure strategy equilibria will emerge in equilibrium.[16] If bureaucrats believe that a fraction greater (lower) than β_t^* of their peers are corrupt, they will decide to be corrupt (honest), thus leading to a situation that verifies their initial belief. In this respect, $\frac{\partial \beta_t^*}{\partial k_t} > 0$ indicates that, in a less developed economy, it is more likely that the incidence of bureaucratic corruption will eventually emerge.

6 Conclusion

Empirical evidence suggests that corruption fuels environmental degradation by impeding the implementation and effectiveness of policies designed to mitigate the use of polluting production technologies. For example, there is an abundance of empirical investigations arguing that corruption is responsible for cases where the damaging effect of economic activity on the natural environment is significantly under-reported, as a means of circumventing environmental regulations. So far, the idea that such circumstances are linked to economic growth has not received the attention it certainly merits, despite the fact that there is a wealth of arguments to support the idea that economic growth is central to these issues. The purpose of my analysis was to fill this gap by providing an explicit link between the dynamics of capital accumulation and the effect of corruption on the choice of production technologies.

[16] Since the mixed strategy requires that all bureaucrats remain indifferent between the outcomes that transpire whether they are corrupt or honest, any event that reduces the incentive to be corrupt should generate a mixed strategy so that all agents remain indifferent. The strategic complementarity inherent in this process means that such events will actually increase the fraction of corrupt bureaucrats in the mixed strategy equilibrium. Nevertheless, as argued previously, this is not a stable equilibrium.

As it turns out, the causality of the relation between economic growth and the incidence of corruption in the implementation of environmental policy can be bi-directional. On the one hand, corruption impedes economic growth through its detrimental impact on environmental quality and the latter's effect on labour productivity. On the other hand, economic growth determines the extent to which the effectiveness of environmental policy is hindered by corruption. These outcomes have significant implications for an economy's long-term prospects, thus verifying the importance of economic dynamics for a more comprehensive understanding of the relation between corruption and the environmental repercussions of technology choice, as well as their relevance for economic performance.

Appendix

Proof of Lemma 2

Combining (22) and (35), we can write the condition in (36) as

$$(1-z\varepsilon)\left[(1-\tau)xw_t + f\right] > (1-\tau)xw_t \Leftrightarrow$$

$$(1-z\varepsilon)f > (1-\tau)xw_t z\varepsilon . \tag{A1}$$

Substituting (17) in (A1) and rearranging yields

$$\omega k_t^a \mu_t^{-\gamma(1-a)} < \frac{(1-z\varepsilon)f}{(1-\tau)xz\varepsilon} \Leftrightarrow$$

$$k_t < \left[\frac{(1-z\varepsilon)f\mu_t^{\gamma(1-a)}}{z\varepsilon(1-\tau)x\omega}\right]^{1/a} . \tag{A2}$$

Suppose that all bureaucrats are corrupt. By virtue of Equation (34), the aggregate emission rate is $\mu_t = \mu^C$, so we can use (38) and (A2) to get the condition for which a bureaucrat decides to be corrupt, according to

$$k_t < \left[\frac{(1-z\varepsilon)f}{z\varepsilon(1-\tau)x\omega}\right]^{1/a} (\mu^C)^{\frac{\gamma(1-a)}{a}} = H(\mu^C)^{\frac{\gamma(1-a)}{a}} \equiv \hat{k}^C . \tag{A3}$$

Similarly, let us now consider the case where none of the bureaucrats is corrupt and where Equation (25) yields the aggregate emission rate $\mu_t = \mu^{NC}$. Combining (37) and (A2) allows us to write the condition under which a bureaucrat decides to be corrupt, according to

$$k_t < \left[\frac{(1-z\varepsilon)f}{z\varepsilon(1-\tau)x\omega}\right]^{1/a} (\mu^{NC})^{\frac{\gamma(1-a)}{a}} = H(\mu^{NC})^{\frac{\gamma(1-a)}{a}} \equiv \hat{k}^{NC}, \tag{A4}$$

thus completing the proof. □

Proof of Proposition 2

Consider $k^{**} < \hat{k}^{NC}$, a condition that, after combining (37) and (43), can be rewritten as

$$k^{**} < \hat{k}^{NC} \Leftrightarrow (\mu^{NC})^{\gamma/a} > \Lambda, \tag{A5}$$

where $\Lambda \equiv [(1-\tau)\omega]^{(1+a)/a}\left(\frac{z\varepsilon}{1-z\varepsilon}\right)^{1/a}\left(\frac{x}{f}\right)^{1/a}\frac{l+x\psi^{-1}}{m}$. Given Lemma 2, Proposition 1 and $\hat{k}^{NC} < \hat{k}^{C}$, a long-run equilibrium where none of the bureaucrats is corrupt cannot exist. As long as (A5) holds, the economy will eventually converge to an equilibrium where all bureaucrats are corrupt, implying that the only feasible steady state solution is k^{*}.

By analogy, suppose now that $k^{*} > \hat{k}^{C}$ holds. Using (38) and (42), this condition corresponds to

$$k^{*} > \hat{k}^{C} \Leftrightarrow (\mu^{C})^{\gamma/a} < \Lambda. \tag{A6}$$

Given Lemma 2, Proposition 1 and $\hat{k}^{NC} < \hat{k}^{C}$, a long-run equilibrium where bureaucrats are corrupt cannot exist under (A6). The economy will eventually converge to an equilibrium where all bureaucrats are honest and the steady state capital stock is characterised by k^{**}. □

Proof of Proposition 3

Assume that $a < 1/2$. In that case, it is straightforward to establish that $(\mu^{C})^{\gamma(1-a)/a}(\mu^{NC})^{\gamma} > (\mu^{C})^{\gamma}(\mu^{NC})^{\gamma(1-a)/a}$. Now combine (37), (38), (42) and (43) to establish that

$$(\mu^{C})^{\gamma(1-a)/a}(\mu^{NC})^{\gamma} > \Lambda \Leftrightarrow k^{**} < \hat{k}^{C}, \tag{A7}$$

and

$$(\mu^{C})^{\gamma}(\mu^{NC})^{\gamma(1-a)/a} < \Lambda \Leftrightarrow k^{*} > \hat{k}^{NC}. \tag{A8}$$

Assuming that (A7) and (A8) hold simultaneously, we have $\hat{k}^{NC} < k^{*} < k^{**} < \hat{k}^{C}$. Given Lemma 2 and Proposition 1, both equilibria k^{*} and k^{**} are possible stationary solutions, irrespective of the economy's initial stock $k_0 > 0$. Particularly, $k^* < k^{**} < \hat{k}^C$ is consistent with an equilibrium where bureaucrats are corrupt (i.e., an equilibrium characterised by k^*) but, at the same time, $\hat{k}^{NC} < k^* < k^{**}$ is also consistent with an equilibrium where none of the bureaucrats is corrupt (i.e., an equilibrium characterised by k^{**}). □

Proof of Proposition 4

Combining the conditions in (A6)-(A8), it follows that as long as $(\mu^C)^{\gamma/a} > \Lambda$ and

$$\max\{(\mu^C)^\gamma (\mu^{NC})^{\gamma(1-a)/a}, (\mu^C)^{\gamma(1-a)/a} (\mu^{NC})^\gamma\} < \Lambda, \tag{A9}$$

hold simultaneously, we have $\hat{k}^{NC} < k^* < \hat{k}^C < k^{**}$. In that case, the only possible stationary solution for $k_0 > \hat{k}^C$ is the one characterised by k^{**}. For $k_0 < \hat{k}^C$, however, the fact that $\eta_{k_t}(0) = +\infty$ implies that the capital stock will always reach the region $(\hat{k}^{NC}, \hat{k}^C)$. By virtue of (41) and Proposition 1, any of the two steady states defined by k^* and k^{**} represents a possible equilibrium outcome, since $k^* < \hat{k}^C$ is consistent with an equilibrium where bureaucrats are corrupt but, at the same time, $k^{**} > \hat{k}^{NC}$ is consistent with an equilibrium where bureaucrats are honest.

Similar arguments can be used to prove the second part of Proposition 4. From (A5), (A7) and (A8), it follows that we have $k^* < \hat{k}^{NC} < k^{**} < \hat{k}^C$, as long as $(\mu^{NC})^{\gamma/a} < \Lambda$ and

$$\min\{(\mu^C)^\gamma (\mu^{NC})^{\gamma(1-a)/a}, (\mu^C)^{\gamma(1-a)/a} (\mu^{NC})^\gamma\} > \Lambda, \tag{A10}$$

hold simultaneously. Given (41), Proposition 1 and $\eta_{k_t}(0) = +\infty$, the only possible stationary solution for $k_0 < \hat{k}^{NC}$ is the one characterised by k^*. For $k_0 > \hat{k}^{NC}$, the capital stock will always reach the region $(\hat{k}^{NC}, \hat{k}^C)$, implying that any of the two steady states defined by k^* and k^{**} represents a possible equilibrium outcome. Particularly, $k^* < \hat{k}^C$ is consistent with an equilibrium where bureaucrats are corrupt but, at the same time, $k^{**} > \hat{k}^{NC}$ is consistent with an equilibrium where none of the bureaucrats is corrupt.

In order to prove the third part of Proposition 4, assume that $a > 1/2$ so that $(\mu^C)^{\gamma(1-a)/a} (\mu^{NC})^\gamma < (\mu^C)^\gamma (\mu^{NC})^{\gamma(1-a)/a}$. Furthermore, assume that $(\mu^C)^{\gamma(1-a)/a} (\mu^{NC})^\gamma < \Lambda$ and $(\mu^C)^\gamma (\mu^{NC})^{\gamma(1-a)/a} > \Lambda$ hold simultaneously. Using (A7) and (A8), it follows that

$k^{*} < \hat{k}^{NC} < \hat{k}^{C} < k^{**}$. Taking account of the discussion so far, for $k_0 < \hat{k}^{NC}$ ($k_0 > \hat{k}^{C}$), the only possible long-run equilibrium is k^{*} (k^{**}). If $k_0 \in (\hat{k}^{NC}, \hat{k}^{C})$, however, a long-run equilibrium is consistent with either k^{*} or k^{**}. □

Derivation of Equation (6)

The producers of final goods choose quantities for y_{it} in order to maximise profits $\left(\int_0^1 y_{it}^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}} - \int_0^1 P_{it} y_{it} di$. After some straightforward algebra, the first order condition can be written as

$$\left(\int_0^1 y_{it}^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}-1} y_{it}^{\frac{\sigma-1}{\sigma}-1} = P_{it}. \tag{A11}$$

The next step is to multiply both sides of (A11) by y_{it} and integrate them to get

$$\left(\int_0^1 y_{it}^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}-1} \left(\int_0^1 y_{it}^{\frac{\sigma-1}{\sigma}} di\right) = \int_0^1 P_{it} y_{it} di. \tag{A12}$$

Combining (A11) and (A12) yields

$$\frac{y_{it}^{\frac{\sigma-1}{\sigma}-1}}{\int_0^1 y_{it}^{\frac{\sigma-1}{\sigma}} di} = \frac{P_{it}}{\int_0^1 P_{it} y_{it} di}, \tag{A13}$$

in which we can substitute Equation (2) from the main part of the analysis. That is,

$$\frac{y_{it}^{\frac{\sigma-1}{\sigma}-1}}{Y_t^{\frac{\sigma-1}{\sigma}}} = \frac{P_{it}}{\int_0^1 P_{it} y_{it} di}. \tag{A14}$$

Using the expression for the price level $P_t = \left(\int_0^1 P_{it}^{1-\sigma} di\right)^{1/(1-\sigma)}$ together with (2) yields

$$\int_0^1 P_{it} y_{it} di = P_t Y_t. \tag{A15}$$

Following the substitution of (A15) in (A14), we can rearrange terms and combine with Equation (7) in order to get

$$y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\sigma} Y_t = p_{it}^{-\sigma} Y_t, \tag{A16}$$

which is the result of Equation (6). □

The Equilibrium in the Final Goods Market

Let us begin with the case where there is no corruption among public officials (bureaucrats). The goods market equilibrium must satisfy

$$Y_t = C_t + S_t + g_t + Q_t, \tag{A17}$$

where

$$S_t = (1-\tau) w_t l + (1-\tau) x w_t \psi^{-1}, \tag{A18}$$

is aggregate saving in the formal financial sector, C_t is aggregate consumption, and Q_t denotes the aggregate expenses on the adoption of the cleaner technology. It follows that

$$Q_t = q \int_0^{\bar{\delta}} \delta_i f(\delta_i) di . \tag{A19}$$

Aggregate consumption incorporates the consumption expenditures of old households (bureaucrats and workers) as well as the consumption expenditures of intermediate good producers. Combining (5), (39), (A18) and (A19), we can write C_t according to

$$C_t = l r_t (1-\tau) w_{t-1} + \psi^{-1} r_t (1-\tau) x w_{t-1} + \bar{\delta} v_t - q \int_0^{\bar{\delta}} \delta_i f(\delta_i) di + (1-\bar{\delta})(v_t - \theta) \Leftrightarrow$$

$$C_t = r_t K_t + v_t - \Theta_t - Q_t . \tag{A20}$$

From Equation (20), government spending can be rewritten as

$$g_t = l \tau w_t + \Theta_t - \psi^{-1}(1-\tau) x w_t . \tag{A21}$$

Therefore, we can combine (A18), (A20) and (A21) to establish that,

$$C_t + S_t + g_t + Q_t = r_t K_t + w_t l + v_t . \tag{A22}$$

From (9), (10), (12), (13), (16) and the labour market equilibrium $l = L_t$, it follows that

$$r_t K_t + w_t l + v_t = Y_t . \tag{A23}$$

Thus, (A22) and (A23) reveal that the goods market equilibrium condition in (A17) is satisfied.

Now, consider the case where bureaucrats are corrupt. The goods market equilibrium must satisfy

$$Y_t + J_t = C_t + S_t + S_t^{INF} + g_t + Q_t, \tag{A24}$$

where

$$J_t = \zeta_t b_{t-1}(1-\hat{\delta}), \tag{A25}$$

is the output generated by the informal financial sector. To understand what generates this output, recall that, during the previous period, ψ^{-1} bureaucrats collected a bribe b_{t-1} from each of the $(1-\hat{\delta})\psi$ firms that were willing to pay them. These bribes were deposited in the informal financial sector which returns this output in the current period, augmented by the gross rate ζ_t. The variable S_t^{INF} is the current total saving to the informal sector, i.e.,

$$S_t^{INF} = b_t(1-\hat{\delta}). \tag{A26}$$

Note that the total expenditures on the adoption of the clean technology are now given by

$$Q_t = q\int_0^{\hat{\delta}} \delta_i f(\delta_i)di. \tag{A27}$$

If we combine (5), (39), (A18), (A26) and (A27), we can write aggregate consumption as

$$C_t = lr_t(1-\tau)w_{t-1} + \psi^{-1}r_t(1-\tau)xw_{t-1} + \psi^{-1}\zeta_t b_t(1-\hat{\delta})\psi$$
$$+\hat{\delta}v_t - q\int_0^{\hat{\delta}} \delta_i f(\delta_i)di + (1-\hat{\delta})(v_t - b_t - z\theta) \Leftrightarrow$$

$$C_t = r_t K_t + v_t + J_t - \Theta_t - Q_t - (1-\hat{\delta})b_t. \tag{A28}$$

Using (A18), (A21), (A25), (A26) and (A28), we get

$$C_t + S_t + S_t^{INF} + g_t + Q_t = r_t K_t + w_t l + v_t + J_t. \tag{A29}$$

Together with (A23), Equation (A29) reveals that the goods market equilibrium condition in (A24) is satisfied. □

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