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Cultural persistence in corruption, economic growth, and the environment☆

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ABSTRACT

Evidence that attributes current environmental outcomes to historical and cultural origins has gained momentum in recent years. In this study, I construct a model to demonstrate why the relation between economic growth and environmental quality hinges on the deeply rooted cultural traits that govern attitudes towards corruption. Specifically, I show that the cultural transmission of the traits that determine the corruptibility of public officials, who are entrusted with the inspection and reporting of firms' emissions, leads to history-dependant outcomes. It sets in motion either a vicious circle of corruption, high pollution and low economic growth, or a virtuous circle where corruption does not infringe environmental policy, pollution is lower and economic growth is higher. These outcomes have major policy implications.

1. Introduction

A recent report by the World Health Organization (WHO, 2021) offers yet another grim warning on climate change and its catastrophic impact on health, calling for governments to intensify their actions against pollution. Such calls to action, however, should also raise awareness to the fact that policy efforts to reduce pollution can be overshadowed by corruption, i.e., public officials' advancement of their own interests by means of unlawful abuse of the power entrusted to them. This study's objective is to improve our understanding of the circumstances surrounding the incidence of corruption in the implementation of environmental policy, and to show why the corruption-pollution nexus is deeply rooted to the interdependence between economic development and the prevailing culture. It advances the view that the cultural traits that govern attitudes towards corruption are critical for the relation between economic growth and environmental quality.

On the outset, one may wonder why the analysis of pollution and economic development should give prominence to the role of corruption, let alone the cultural attitudes that determine corruptibility. The response is readily available from the plethora of empirical evidence showing that the adverse impact of corruption on the environmental quality of developing countries is too compelling to ignore. Several authors have pointed out the role of corruption in compromising the imple-

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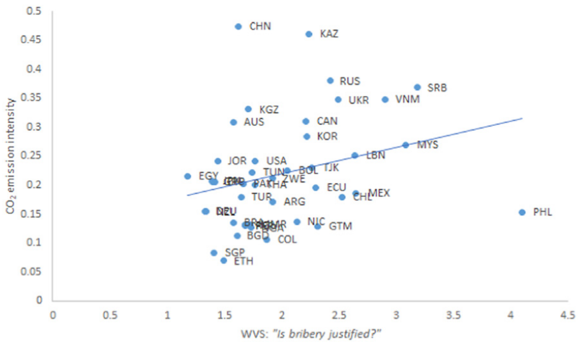

Fig. 1. Attitudes towards corruption and emission intensity.

mentation and effectiveness of policies designed to address the rising concerns over environmental degradation and climate change. Desai (1998) argued that "*corruption is a major culprit in environmental degradation. In many industrializing countries, petty corruption by mid and low level officials and bureaucrats both at the centre and local level is widespread and endemic. Environmental regulations often are observed only in the breach*" (Desai, 1998; p.300). Masron and Subramaniam (2018) used a panel of developing countries to show that the effect of corruption on pollution is pronounced enough to prevent the emergence of an environmental Kuznets curve. Further evidence on the impact of corruption and bribery in undermining the effectiveness and accuracy of emission inspections is presented by Burgess et al. (2012) for Indonesia, Sundström (2013) for South Africa, and Oliva (2015) for Mexico.[1] It should be noted that the International Labor Organisation (ILO) links the issue of corruption with the adverse health consequences of pollution in developing countries. I am quoting directly from the ILO's webpage, 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]

Given the role of corruption as a significant impediment to environmental quality, it is reasonable to consider the possibility that cultural factors have a discernible effect on the corruption-pollution nexus.[3] In fact, Fredriksson and Neumayer (2016) hint at this possibility, by presenting evidence to advance the view that the historical roots of corruption are significant for the adoption and the contemporaneous effectiveness of environmental policies. They argued that "*corruption reduction programs in developing countries and the transition economies need to address the root causes of corruption with deep and long-running reform programs*" (Fredriksson and Neumayer, 2016; p. 452). amongst these 'root causes' of corruption, cultural traits and norms of behavior seem to play an important role. Indeed, there is a wealth of evidence to support the cultural origins of persistent corruption (e.g., Fisman and Miguel, 2007; Barr and Serra, 2010). There is also evidence to suggest that one of the most important policy tools, in reforms intending to curb endemic corruption, is to gradually instil younger generations with attitudes and norms of aversion to corrupt practices and their consequences (e.g., Johnston, 1999; Marquette, 2007; Carrasco et al., 2020).

Although other studies have employed frameworks that account for corruption when the implementation of environmental policy requires inspection by public officials (e.g., Acemoglu and Verdier, 2000; Hong and Teh, 2019), the idea that such circumstances are linked to the interdependence between cultural factors and economic growth has so far eluded the attention of researchers. The previously mentioned empirical studies, together with further evidence on the interrelation of economic development with corruption (e.g., Mauro, 1995; Gundlach and Paldam, 2009), as well as with the formation of cultural traits (e.g., Tabellini, 2010), indicate that this may be an oversight. Indeed, a glance at the data seems supportive of this conjecture: In a cross-section of countries, Figs. 1 and 2 reveal that a measure of cultural attitudes towards corruption is positively correlated with CO2 emission intensity, and negatively correlated with income per capita.[4] The measure of cultural attitudes towards corruption is extracted from Wave 7 (2017–2020) of the World Value Survey.[5] It is the mean score of the survey's question on whether respondents from each country think that the practice of receiving bribes is either never, always, or somehow justified.[6]

Motivated by these arguments and observations, this study is aims at filling an important gap in the literature. While it borrows elements from existing studies on corruption and emission inspection, its departure stems from an explicit connection to (i) the process of capital accumulation and economic growth, and (ii) the intergenerational evolution of the cultural

[1] For evidence regarding the negative effect of corruption on reported emissions in the USA and Europe, see Hubbard (1998) and Ivanova (2011) respectively.

[2] https://www.iloencyclopaedia.org/part-vii-86401/environmental-health-hazards/item/497-industrial-pollution-in-developing-countries

[3] In general, evidence that attributes current environmental outcomes to historical, cultural and legal origins, has gained momentum in recent years (e.g., Ang and Fredriksson, 2017; Mavisakalyan *et al.*, 2018).

[4] Data on the 2018 CO_2 emission intensity (kg per PPP of GDP) and 2018 real GDP per capita are extracted from the World Bank. See https://data.worldbank.org/.

[5] See https://www.worldvaluessurvey.org/wvs.jsp.

[6] Higher scores indicate, on average, less condemnation for the practice of illegal rent-seeking through bribery.

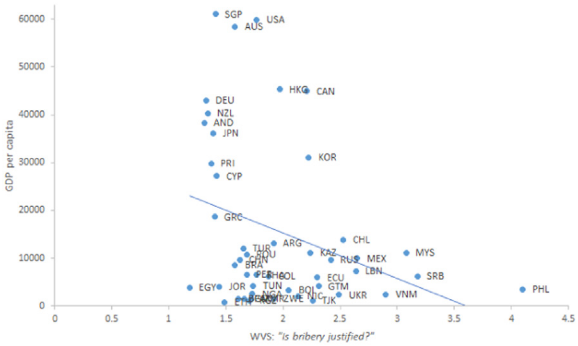

Fig. 2. Attitudes towards corruption and income per capita.

traits that govern the incidence of corruption.[7] These are not trivial issues, as they improve the current understanding on the causes and the effects of the pollution-corruption nexus. They also have important policy implications, as they identify mechanisms that can inform policy efforts to address the problem of environmental degradation and its consequences.

The study is built upon a model in which pollution impedes labor productivity through its detrimental impact on the population's health – an idea that finds strong support from the existing evidence.[8] Firms pay emission taxes and have the choice to adopt less polluting, but more costly to operate, technologies. The government entrusts bureaucrats with the tasks of inspecting firms, verifying their emissions, and imposing emission taxes.[9] Nevertheless, this delegation of power is a potential source of moral hazard: In exchange for bribes, corruptible bureaucrats may be willing to mislead authorities with regard to the actual emissions of the firms they inspect, thus facilitating these firms in evading part of their tax liability. These ideas are consistent with the evidence of Ivanova (2011) who shows that corruption causes a significant underreporting of actual emission levels.

The results show that the incidence of corruption leads to a higher level of pollution, despite impeding capital accumulation and economic growth. This is because the prospect of bribing bureaucrats as a means of evading emission taxes, induces producers to adopt technologies that have a higher emission intensity and are less costly to operate. Ultimately, the positive impact of corruption on emissions per unit of output dominates its negative impact on health, labor productivity, and therefore, the level of output. These mechanisms find support from existing empirical evidence (e.g., Welsch, 2004).

A critical aspect of the model's set up is the distinction of a bureaucrat's profile between 'corruptible' and 'corrupted'. A corruptible bureaucrat is one who, in principle, would be willing to transgress, as long as an opportunity to do so arises; a corrupted bureaucrat is one who actually transgresses. Put differently, corruptibility is necessary but not sufficient for corruption to materialise. In my model, an agreement in which corruptible bureaucrats receive bribes to facilitate firms' emission tax evasion requires that the joint surplus generated by this fraudulent collusion must be high enough to entice both parties to take the risk of this wrongdoing. As it turns out, the joint surplus is high enough only when the fraction of corruptible bureaucrats is sufficiently high. This novel manifestation of the idea that 'corruption corrupts' motivates the other significant departure of this study.[10] Specifically, I introduce a *cultural evolution of corruptibility*, i.e., a process that combines a publicly-funded education system that seeks to instil civic virtues, and a mechanism of oblique intergenerational transmission through which older generations inculcate younger ones with specific cultural values and attitudes, based on their own beliefs and values (Bisin and Verdier, 2001).[11] The emphasis on public education's role in curbing tolerance to corruption, as well as the importance of education funding in facilitating this role, are supported by empirical evidence (e.g., Johnston, 1999; Marquette, 2007; Carrasco et al., 2020).

The combination of these cultural transmission mechanisms sets in motion the endogenous evolution of the share of bureaucrats whose values and attitudes make them susceptible to corruption. In addition to generating a causal effect of economic growth on lower corruptibility, this setting also generates path-dependant outcomes. Crucially, path-dependence is not related to initial income – a usual point of criticism in models that generate multiple development regimes, transition

[7] Other theoretical models that analyse the relation between economic growth and corruption are constructed by Ehrlich and Lui (1999); Dimaria and Le Van (2002); Blackburn *et al.* (2006); and Varvarigos and Arsenis (2015). None of them, however, incorporate any implications for environmental policy and pollution, or for cultural factors. For culture-based theories of corruption, see Hauk and Saez-Marti (2002) and Banerjee (2016).

[8] Indeed, the adverse effects of pollution on the population's health are well-documented (Brunekreef and Holgate, 2002; Briggs, 2003). The empirical investigations of Ostro (1983) and Hanna and Oliva (2015) address this issue and show that pollution has a significant negative effect on labour productivity.

[9] For a general dynamic setting of tax evasion and auditing, see Ravikumar and Zhang (2012).

[10] See Andvig and Moene (1990) for another example of how the incentive to be corrupt is higher in an environment where corruption is rife.

[11] This process shares some similarities with Bisin and Verdier (2001) but differs in that it pinpoints the importance of the education system, rather than the family environment, in promoting civic virtues. What is also noted is the difference with the model of Bezin (2015), in which the cultural transmission process involves traits that determine environmental awareness. In my model, the impact of cultural change on environmental quality operates through the diffusion and establishment of cultural traits that determine corruptibility in the implementation of environmental policy.

between which may not occur.[12] Instead, persistent differences in terms of corruption, income per capita and environmental quality, are deeply rooted to differences in cultural history. When the adherence to cultural values that favour corruptibility is widespread, the joint evolution of economic and cultural dynamics will lead to a persistently high incidence of corruption, a low rate of economic growth, and a high level of pollution. On the contrary, when adherence to such values is limited, the joint dynamics of economic development and cultural change will eradicate any incentive for corruption in the implementation of environmental policy, thus leading to a lower level of pollution and a higher rate of economic growth.

These outcomes reveal that the forces determining environmental quality cannot be assessed in isolation from the overall socioeconomic environment, thus raising awareness to some important policy implications. Direct policy instruments (e.g., environmental taxes and subsidies; regulation; abatement) should be complemented by policies that aim at inciting a gradual change in the cultural attitudes behind (in)tolerance to corruption. Although the impact of these policies may not be as quick to materialize, they can support more directed environmental policies by enhancing their effectiveness in a persistent manner. Therefore, such approaches can lay the foundations for a process of economic growth that is environmentally sustainable.

The existing literature includes studies that have constructed models to investigate the relation between corruption and environmental policy. In a model where corruption emerges because of the government's effort to correct a negative externality (e.g., pollution), Acemoglu and Verdier (2000) emphasise the reasons why public officials' corruptibility may, in fact, increase the optimal size of the bureaucracy and their wages. The public sector salary increases the corruptible bureaucrat's cost of being apprehended and dismissed without pay, while the larger size of the bureaucracy increases the probability of emission inspections, thus reducing the bribe that a bureaucrat can extract from a polluting firm. López and Mitra (2000) employ a framework where polluting firms offer lobby payments to a rent-seeking incumbent who also cares about the chances of being re-elected, hence social welfare. They show that, in comparison to the social optimum, lobbying and the government's rent-seeking behavior entail higher levels of pollution, and a later turning point for the environmental Kuznets curve. Fredriksson and Svensson (2003) also consider a model where a lobby of polluting firms offers payments to a rent-seeking incumbent, in exchange for less stringent environmental regulations. They show that this form of corruption does indeed reduce the stringency of environmental policy, and that the extent of this reduction is conditional on the degree of political instability (defined as the likelihood that the incumbent will lose their power). The key mechanism is that political instability reduces the lobby's incentive to pay bribes, because it increases the likelihood that the corrupted government will not remain in office, thus the promise of less stringent environmental policy may not materialize. In Barbier et al. (2005), lobby payments to a corrupt government intensify the depletion of natural resources – an outcome that is exacerbated if the economy is more dependent on international trade. Hong and Teh (2019) construct a model to investigate how an exogenous shift in the distribution between corruptible, bribe-seeking bureaucrats vs. honest ones affects firms' investments in pollution control. They show that an increase in the share of corruptible bureaucrats can actually induce firms to invest more in pollution abatement, as long as bureaucrats' bargaining power is relatively high; if it is relatively low, however, firms respond by reducing their investments towards pollution abatement.

The focus of my study is different. Contrary to the aforementioned studies, which employ static models, I seek to investigate how the presence of corruption in the implementation of environmental policy affects the relation between pollution and economic growth in a dynamic framework. An even more important departure of my framework involves the distribution of moral attitudes amongst public officials, i.e., whether they are corruptible or honest. Contrary to the previously mentioned studies, in which this distribution is exogenous, in my model it is endogenously determined through an explicit process of cultural diffusion. This is in fact a key element of my model, offering further justification for its explicitly dynamic nature: It is the source of a complementarity in cultural and economic dynamics that perpetuates differences in attitudes towards corruption, thus establishing their persistence and their role as important factors of the pollution-economic development nexus. These are features that none of the previously mentioned theories have considered, despite the fact that the existing empirical evidence offers credence to them (e.g., Marquette, 2007; Barr and Serra, 2010; Fredriksson and Neumayer, 2016).

The remaining analysis is structured as follows: An overview of the model and of a benchmark version without corruption are presented in Section 2. Section 3 shows how the incidence of corruption affects the model's outcomes in terms of pollution and economic growth. In Section 4, I show how the intergenerational evolution of the cultural traits that govern corruptibility generates multiple regimes in terms of economic development and pollution; it also elaborates on the policy implications. Section 5 shows that the main results and implications survive the relaxation of some model restrictions, while Section 6 concludes.

2. An overview of the economy

Time is discrete and indexed by $t = 0, 1, 2 \ldots$.[13] The economy is populated by an infinite sequence of overlapping generations of agents who face a lifespan of three periods – childhood, youth and maturity.[14] Each age cohort consists of a

[12] See Galor (2011) for an example of such criticism.

[13] Appendix A.7 lists and summarises the parameter and variable notation of the model.

[14] Agents are largely inactive in their childhood. This period of their lifetime will assume more relevance at a latter part of the analysis, when the process of cultural transmission will become explicit.

constant population whose mass is normalised to 2. For agents born in $t-1$, their preferences are characterised by the lifetime utility function $u_t = (1-\beta)c_{\nu,t} + \beta c_{\omega,t+1}$, where $c_{\nu,t}$ denotes consumption in youth, $c_{\omega,t+1}$ denotes consumption in maturity, while $\beta = \{0, 1\}$ is a preference shock that is realised at the beginning of an agent's adulthood. Specifically, half of the population will begin adulthood with $\beta = 0$ whereas the other half will begin adulthood with $\beta = 1$. Naturally, this means that agents for whom $\beta = 0$ will consume when young, whereas agents for whom $\beta = 1$ will consume in maturity. Note that the same set-up regarding time preference shocks has been adopted by several other studies (e.g., Diamond and Dybvig, 1983; Greenwood and Smith, 1997).[15]

Each young agent is endowed with a unit of time, which they supply inelastically in exchange for the salary $w_{j,t}$, while their labour income is subject to a flat rate tax $\tau_w \in (0, 1)$. Young agents can be employed in either the private sector ($j = private$) or the public sector ($j = public$). Nevertheless, they cannot divide their labour supply between the two sectors; their whole unit of working time must be devoted to only one of these sectors.

Given that the economy's good is perishable, agents who wish to consume in maturity, can do the following: They can access an investment technology that transforms units of time-t output into units of time-$t+1$ capital on a one-to-one basis. When they reach maturity, they set-up a firm and combine their own capital together with the labour they hire from young agents, to produce a quantity of the homogeneous good that they subsequently supply to the market. Only those agents who worked in the private sector have gained the skills and experience to undertake capital investment and become producers.

An adverse by-product of goods' production is pollution. There is a continuum of production technologies available, characterised by their emission intensities, i.e., the quantity of emissions per unit of output produced. Firm owners face a trade-off when choosing which technology to adopt. On the one hand, they face a flat rate tax τ_e per unit of pollutant emissions; on the other hand, a less-polluting technology entails a higher cost of production.

2.1. The public sector

The government cannot observe each firm's emissions directly. For this reason, it employs young agents as bureaucrats and delegate to them the task of inspecting firms, verifying the amount of pollutants they emit, and imposing the corresponding emissions tax. Note that the government operates under a balanced budget every period. Denoting the flow of expenditures on government consumption by G_t, and the total revenues from the emissions tax by R_t, it follows that the government's budget can be expressed by

$$G_t = \underbrace{\tau_w(w_{private,t}l_{private,t} + w_{public,t}l_{public,t})}_{\text{incometaxrevenues}} + \underbrace{R_t}_{\text{revenuesfromtheemissionstax}} - \underbrace{w_{public,t}l_{public,t}}_{\text{expensesonpublicsectorsalaries}}, \tag{1}$$

where $l_{private,t}$ is employment in the private sector and $l_{public,t}$ is employment in the public sector.

It is assumed that each bureaucrat can inspect at most $\psi > 1$ firms with their unit of time, and that all firms will be subject to inspection. Given the economy's characteristics, it is clear that none of the agents for whom $\beta = 1$ will consider employment in the public sector. The pool of agents that could be potentially attracted to the prospect of public sector employment are those for whom $\beta = 0$. Naturally, the option of employment in the private sector implies that no one would accept a contract for which $w_{public,t} < w_{private,t}$.[16] The willingness to accept such a contract would signal the agent'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 will see shortly. For this reason, an agent willing to accept $w_{public,t} < w_{private,t}$ would be immediately dismissed by the government, implying that candidates would only accept contracts that specify $w_{public,t} \geq w_{private,t}$. Recalling that there is a unit mass of firm owners and a unit mass of young agents who would consider public sector employment, it follows that the government can minimise the cost of having all firms inspected, by hiring ψ^{-1} bureaucrats and by offering a salary

$$w_{public,t} = w_{private,t} = w_t, \tag{2}$$

to each of them.[17] Of course, the previous discussion implies that employment in the public sector will be

$$l_{public,t} = \frac{1}{\psi} \forall t, \tag{3}$$

meaning that the supply of labour in the private sector is

$$l_{private,t} = 1 + \frac{\psi - 1}{\psi} \equiv \tilde{l} \forall t, \tag{4}$$

[15] In this framework, the time preference shock is simply a technical device: It helps to pin down the occupational choice of different agents, at a minimal cost in terms of mathematical complexity. It also limits the notational burden and additional restrictions required for the framework's empirical relevance with regards to the relation between corruption and growth. In Section 5, I show that the model's implications survive the removal of this preference shock.

[16] 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.

[17] This approach in determining the public sector's operation follows Blackburn *et al.* (2006).

where 1 captures the unit mass young agents for whom $\beta = 1$, whereas $(\psi - 1)/\psi$ is the mass of young agents with $\beta = 0$, who do not secure employment in the public sector.

2.2. The private sector

Consider agents who are young in t, and for whom $\beta = 1$. In the first period of their lifetime, they receive a wage (net of income tax) in exchange for their labor services. Subsequently, they access the investment technology and use their disposable income as the input to generate units of the capital stock, denoted k_{t+1}, that will be used in production next period. That is

$$k_{t+1} = (1 - \tau_w) w_t. \tag{5}$$

When agents reach maturity, they combine this capital stock together with labor, denoted n_{t+1}, to produce y_{t+1} units of the economy's good according to

$$y_{t+1} = k_{t+1}^{\alpha} (H_{t+1} n_{t+1})^{1-\alpha}. \tag{6}$$

where $\alpha \in (0, 1)$ and H_{t+1} is a variable that captures labor productivity.

In addition to the cost of labor, firm owners also face the cost of technology adoption. There is a continuum of technologies, ordered by their emission intensity which is denoted $e_{t+1} \in [0, m]$. Obviously, the emission intensity m characterizes the most polluting technology. As stated previously, the choice of e_{t+1} entails a trade-off. On the one hand, the adoption of a less polluting technology reduces the emission tax liability $\tau_e e_{t+1} y_{t+1}$, for given level of production. On the other hand, however, it is more costly to produce under a less polluting technology (see Requate, 2005).[18] Specifically, the cost of technology adoption is $f(e_{t+1}, y_{t+1})$ such that $f_{e_{t+1}} < 0$, $f_{y_{t+1}} > 0$ and $f_{y_{t+1} e_{t+1}} < 0$. Henceforth, I will be using

$$f(e_{t+1}, y_{t+1}) = \frac{(m - e_{t+1})^2}{2} y_{t+1}, \tag{7}$$

where the restriction $\tau_e^2 < m\tau_e < 1 + \tau_e^2$ will later ensure non-negative emission intensity, as well as positive profitability. Given these, we can express the firm's profits, after taking account of (6), as follows:

$$\pi_{t+1} = \left[1 - \tau_e e_{t+1} - \frac{(m - e_{t+1})^2}{2}\right] k_{t+1}^{\alpha} (H_{t+1} n_{t+1})^{1-\alpha} - w_{t+1} n_{t+1}. \tag{8}$$

Pollution is, of course, a significant negative externality. In this model, it has a damaging effect on the health status of the population. The evidence presented by Ostro (1983) and Hanna and Oliva (2015) has shown that labor productivity is one of the factors which are significantly affected by the impeding effect of pollution on health. Formally, I capture these ideas by assuming that $H_{t+1} = H(P_{t+1})$ such that $H'(P_{t+1}) < 0$, where P_{t+1} is the flow of pollution. In what follows, I will adopt the following specification:

$$H_{t+1} = h P_{t+1}^{-\theta}, \tag{9}$$

where $h > 0$ and $\theta \in (0, \frac{1}{2}]$.[19]

2.3. Pollution and economic growth with incorruptible bureaucrats

In this part, I will briefly summarize the results of a baseline version of the model where none of the bureaucrats is corruptible. This version is essential for two reasons: Firstly, it serves as a useful benchmark to make a comparison with the scenario in which some bureaucrats will be corruptible – a scenario for which the analysis will follow shortly. Secondly, some characteristics of this baseline case will actually inform the analysis of the version that involves corruptible bureaucrats. In what follows, the subscript "*NC*" will indicate the outcomes that transpire in the absence of corruption.

The detailed analysis presented in the Appendix shows that the model's outcomes, in the absence of corruption, are summarized by

Lemma 1. *When bureaucrats are incorruptible, the long-run equilibrium is characterized by a stock of capital $\tilde{k}_{NC}$, a level of income $\tilde{y}_{NC}$, an emission intensity e_{NC}, and a level of pollution $\tilde{P}_{NC}$, such that*

$$\tilde{k}_{NC} = \eta_{NC}^{\frac{1+\theta(1-\alpha)}{(1-\theta)(1-\alpha)}} \tag{10}$$

$$\tilde{y}_{NC} = \xi_{NC} \eta_{NC}^{\frac{\alpha}{(1-\theta)(1-\alpha)}} \tag{11}$$

$$e_{NC} = m - \tau_e \tag{12}$$

[18] If this was not the case, then the problem would be trivial as firms would always choose the cleanest possible technology.

[19] Several other studies have incorporated the adverse impact of environmental degradation on agents' health. See, for example, Mariani *et al.* (2010), Wang *et al.* (2015), Goenka *et al.* (2020), and Wei and Aadland (2022) among others.

$$\tilde{P}_{NC} = e_{NC}\xi_{NC}\eta_{NC}^{\frac{\alpha}{(1-\theta)(1-\alpha)}} \tag{13}$$

where composite parameter terms are defined as follows:

$$\eta_{NC} \equiv (1-\tau_w)(1-\gamma_{NC})(1-\alpha)\tilde{l}^{\frac{-[\alpha+\theta(1-\alpha)]}{1+\theta(1-\alpha)}} h^{\frac{1-\alpha}{1+\theta(1-\alpha)}} e_{NC}^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}} \tag{14}$$

$$\xi_{NC} \equiv \tilde{l}^{\frac{1-\alpha}{1+\theta(1-\alpha)}} h^{\frac{1-\alpha}{1+\theta(1-\alpha)}} e_{NC}^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}} \tag{15}$$

and

$$\gamma_{NC} \equiv \tau_e\left(m - \frac{\tau_e}{2}\right) \tag{16}$$

Proof. See Appendix A.1. □

As expected, the result in Eq. (12) shows a negative effect of τ_e on e_{NC}, thus revealing that the emission tax motivates firms to incur the cost of adopting a technology whose emission intensity is lower compared to the most polluting one. Furthermore, Eq. (14) shows the negative effect of e_{NC} on the composite term η_{NC}, which in turn determines the steady state capital stock $\tilde{k}_{NC}$ in Eq. (10). This emanates from the detrimental effect of pollution on the population's health and, hence, their productivity – an outcome that has a detrimental impact on the process of capital formation. Of course, a higher emission intensity also decreases the steady state level of output $\tilde{y}_{NC}$. This happens not only indirectly, through the impact of emissions on the capital stock, but also directly, through the effect of emissions on labor productivity. This direct effect is captured by negative impact of e_{NC} on the composite term ξ_{NC} (see Eq. (15)), which in turn affects the steady state output level in Eq. (11). The combination of (11) and (13) indicates that the level of pollution is determined by $\tilde{P}_{NC} = e_{NC}\tilde{y}_{NC}$. In other words, emission intensity has a direct positive effect for a given level of output, but also an indirect negative effect through its adverse impact on output. If we explicitly account for the composite terms η_{NC} and ξ_{NC} by substituting (14)-(15) in Eq. (13), the combined effect of emission intensity on $\tilde{P}_{NC}$ is captured by the term $e_{NC}^{\frac{1-\theta(1+\alpha)}{(1-\theta)[1+\theta(1-\alpha)]}}$ – a term that has a positive effect for $\alpha \in (0,1)$ and $\theta \in (0, \frac{1}{2}]$: Ultimately, the direct impact dominates, hence a rise in emission intensity increases overall pollution.[20]

These are the outcomes that materialise in the absence of corruption amongst public sector officials. They are the benchmark of comparison with a scenario where the delegation of authority to bureaucrats is a source of moral hazard that may ultimately cause the incidence of corruption. This is the scenario to which I now turn.

3. Pollution and economic growth with corruptible bureaucrats

In this section, I introduce a scenario where bureaucrats and firm owners may enter in a mutually advantageous, but fraudulent, agreement to conceal information from the authorities. In exchange for a bribe, bureaucrats will report a lower amount of pollutants to what firms actually emit, thus allowing producers to evade some of their emission tax burden. This unlawful collusion is possible because, contrary to the previous case, now some bureaucrats are corruptible in the sense that they are willing to abuse their position of power to gain illegal rents. For now, I will assume that a fraction $\delta \in (0,1)$ of bureaucrats are corruptible, hence susceptible to misconduct, whereas the remaining fraction $1-\delta$ of bureaucrats are incorruptible. In a latter section, these fractions will evolve endogenously as a result of a cultural transmission process. To keep the analysis tightly focused on public officials' corruptibility, and to avoid overcomplicating the framework, I will also assume that all producers will consider evading emission taxes through bribe payments, as long as this is a profitable decision.

Focusing on period $t+1$, the sequence of events is as follows: In the first stage, producers adopt their technology and produce output. In the second stage, they are inspected by bureaucrats who, if willing to illegally collude with producers, will falsely report the use of a technology with lower emission intensity, in exchange for a bribe. In the third stage, a monitoring technology will expose a fraction of corrupted bureaucrats, i.e., those who received bribes in order to conceal information from the authorities. This process will automatically reveal the firm owners with whom the bureaucrat colluded. If detected in this manner, tax evading firms and corrupted bureaucrats will face sanctions.

I am going to consider each of these stages separately, using backward induction. Note that, in what follows, the subscript "*C*" will be indicative of the outcomes that transpire in the presence of corruption.

[20] The other parameters that appear in these composite terms capture the positive impact of labour productivity (h), the scale factor from employment on output production ($\tilde{l}$), and the negative impact of labour income taxation (τ_w) on capital formation. Furthermore, (16) and (14) show that $\frac{\partial \gamma_{NC}}{\partial \tau_e} > 0$ and $\frac{\partial \eta_{NC}}{\partial \gamma_{NC}} < 0$ respectively: These capture the negative impact of emission taxes on profitability, for given emission intensity, hence on the wage per unit of labour – an outcome that also affects capital formation.

3.1. Stage 3: payoffs

Similar to the baseline scenario, incorruptible bureaucrats will impose an emission tax based on a truthful account of the pollutants emitted by the firms they inspect. Therefore, their utility will be

$$u_{NC,bureaucrat,t+1} = (1-\tau_w)w_{t+1}. \tag{17}$$

This will also be the utility of corruptible bureaucrats who, nonetheless, do not engage in any nefarious activities. If they do, however, they will receive a bribe b_{t+1} from each of the ψ firms they inspect. If this malpractice escapes the attention of the authorities, they will enjoy utility

$$u_{C(ND),bureaucrat,t+1} = (1-\tau_w)w_{t+1} + \psi b_{t+1}, \tag{18}$$

where the subscript *"ND"* indicates outcomes when corruption is not detected. Nevertheless, the government's monitoring technology will expose a fraction $q \in (0,1)$ of corrupted bureaucrats. In this event, the bureaucrat who is apprehended and proven guilty for this misconduct, faces a proportional utility loss of $\mu \in (0,1)$. This loss of utility captures the psychological costs of shame, social stigma or even imprisonment; it may also capture financial (e.g., legal) costs in the effort to mitigate the severity of the sanctions they face. Using the subscript *"D"* to indicate outcomes when corruption is eventually detected, it follows that the corresponding utility is

$$u_{C(D),bureaucrat,t+1} = (1-\mu)[(1-\tau_w)w_{t+1} + \psi b_{t+1}]. \tag{19}$$

Now, let us consider firm owners. If they did not evade their emission tax payment, their profits and corresponding utility are given by $u_{NC,producer,t} = \pi_{NC,t+1}$ (see Eqs. (A1) and (A7) in the Appendix). If, however, they bribed the bureaucrat who inspected them in order to evade part of their emission tax, then there are two possible outcomes in the third stage: If their emission tax evasion remains undetected, they will enjoy profits equal to $\pi_{C(ND),t+1}$; if their emission tax evasion is revealed by the authorities, they will have to pay the tax they evaded, having already paid a bribe that they cannot claim back. Denote the profits in this latter case by $\pi_{C(D),t+1}$. It follows they the corresponding utility for a firm owner, depending on which outcome materialises, is either $u_{C(ND),producer,t} = \pi_{C(ND),t+1} - b_{t+1}$ or $u_{C(D),producer,t} = \pi_{C(D),t+1} - b_{t+1}$ respectively.

3.2. Stage 2: collusion and bribery

The bribe that secures the fraudulent deal between a corruptible bureaucrat and a firm owner is determined through a process of asymmetric Nash bargaining between the two parties. Naturally, each party's utility in the absence of any collusion – in essence, the utility in the case without corruption – represents the *status quo*. We should also bear in mind the uncertainty regarding the final payoffs in the third stage; that is why, I adopt the expectations operator $E(\cdot)$.

With this in mind, consider $\Delta u_{bureaucrat,t+1} = E(u_{C,bureaucrat,t+1}) - u_{NC,bureaucrat,t+1}$, which denotes a bureaucrat's surplus utility from securing an illegal collusion with a producer. In light of the fact that the corrupted bureaucrat's malfeasance will be detected with probability q, their expected utility is

$$E(u_{C,bureaucrat,t+1}) = (1-q)u_{C(ND),bureaucrat,t+1} + qu_{C(D),bureaucrat,t+1}. \tag{20}$$

Combining (17)-(20), it follows that

$$\Delta u_{bureaucrat,t+1} = (1-q\mu)\psi\left[b_{t+1} - \frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}\right]. \tag{21}$$

Analogously, $\Delta u_{producer,t} = E(u_{C,producer,t}) - u_{NC,producer,t}$ denotes a producer's surplus utility from securing an illegal collusion with a corrupted bureaucrat. Given the description of the third stage's outcomes, and that the exposure probability of the tax evading firm owner is q, it follows that

$$\Delta u_{producer,t} = E(\pi_{C,t+1}) - b_{t+1} - \pi_{NC,t+1}, \tag{22}$$

where

$$E(\pi_{C,t+1}) = (1-q)\pi_{C(ND),t+1} + q\pi_{C(D),t+1}. \tag{23}$$

The firm owner and the corrupted bureaucrat will agree on a bribe that allows them to share the joint surplus of their collusion. Formally, the chosen b_{t+1} is the one that maximises $NP = (\Delta u_{bureaucrat,t+1})^{\rho}(\Delta u_{producer,t})^{1-\rho}$ or, after substituting (21) and (22),

$$NP = [(1-q\mu)\psi]^{\rho}\left[b_{t+1} - \frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}\right]^{\rho}[E(\pi_{C,t+1}) - b_{t+1} - \pi_{NC,t+1}]^{1-\rho}, \tag{24}$$

where $\rho \in (0,1)$ measures the bureaucrat's relative bargaining power. Of course, the bribe must be high enough to compensate the bureaucrat for the expected utility loss in the event that their malpractice is exposed; at the same time, it must be low enough to also ensure that the firm owner's participation in this illegal agreement is a profitable decision. Indeed, a look at Eq. (24) reveals that the condition necessary for the bribe to be mutually advantageous, hence ensuring participation by both parties, is

$$E(\pi_{C,t+1}) - \pi_{NC,t+1} > \frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}. \tag{25}$$

Using (24), we can derive

$$\frac{\partial NP}{\partial b_{t+1}} = [(1-q\mu)\psi]^{\rho}\left[b_{t+1} - \frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}\right]^{\rho-1}[E(\pi_{C,t+1}) - b_{t+1} - \pi_{NC,t+1}]^{-\rho} \times S(b_{t+1}), \tag{26}$$

where

$$S(b_{t+1}) = \rho\left[E(\pi_{C,t+1}) - \pi_{NC,t+1} - \frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}\right] + \frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi} - b_{t+1}. \tag{27}$$

If the condition in (25) does not hold, then (26)-(27) reveal that $\frac{\partial NP}{\partial b_{t+1}} < 0 \forall b_{t+1}$; the bureaucrat and the firm owner cannot reach an agreement under these circumstances. As long as (25) holds, however, they will reach such an agreement. This is formally presented in

Lemma 2. *The firm owner and the bureaucrat agree on the mutually advantageous bribe*

$$b^*_{t+1} = \rho[E(\pi_{C,t+1}) - \pi_{NC,t+1}] + (1-\rho)\frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}. \tag{28}$$

Proof. From (26), we can see that the sign of $\frac{\partial NP}{\partial b_{t+1}}$ is dictated by the sign of $S(b_{t+1})$. Using (27), check that $S(0) > 0$ and $S'(b_{t+1}) < 0$. Therefore, we can conclude that the bribe that maximises NP is the one that satisfies $S(b^*_{t+1}) = 0$, i.e., the one in Eq. (28). □

The outcome presented in Lemma 2 is quite intuitive. Since the bribe is agreed under a process of Nash bargaining, it will be one whereby the corrupted bureaucrat and the producer will share the joint surplus of their nefarious activities. The manner by which this joint surplus is shared depends on the relative bargaining power of each party.

3.3. Stage 1: technology choice and emission intensity

In the first stage, producers choose the environmental characteristics of their technology and undertake production activities. In this case, they will assign a probability to the event that they the bureaucrat who will inspect them is corruptible, thus giving them the opportunity to gain through emission tax evasion. This probability is equal to the fraction of corruptible bureaucrats, i.e., δ.

In the event that a bureaucrat and a producer are willing to collude, the emission reporting by the bureaucrat must be credible enough to avoid signaling to the authorities that any wrongdoing has taken place. In this context, it follows that the opportunity offered by corruptible bureaucrats is to report that firms' emission levels are the ones that would apply in the absence of any fraudulent collusion with firm owners. At the same time, firm owners must act in a way that will not alert anyone on their emission tax evasion, because doing so would undermine the secrecy of their actions, thus risking their exposure.

These arguments imply that the fraudulent agreement entails the following: In exchange for a bribe, the bureaucrat will report an emission intensity of e_{NC}, i.e., the one in (12), despite the fact that the firm owner has adopted a more polluting, and less costly, technology. At the same time, the producer will offer a salary, as if their technology has an emission intensity of e_{NC}. In other words, from a firm's perspective, the firm owner is the sole beneficiary of emission tax evasion.

Let us now formalize the previous discussion. The producer expects to be inspected by an incorruptible bureaucrat with probability $1-\delta$; in this case, the profits will be

$$\tilde{\pi}_{t+1} = \left[1 - \tau_e e_{t+1} - \frac{(m-e_{t+1})^2}{2}\right]k^{\alpha}_{t+1}(H_{t+1}n_{t+1})^{1-\alpha} - w_{t+1}n_{t+1}. \tag{29}$$

With probability δ, however, they anticipate inspection by a corruptible bureaucrat, meaning that the producer will have the opportunity to evade part of their emissions tax. In this case, their utility will be $E(\pi_{C,t+1}) - b^*_{t+1}$, where the expected profit of the producer is given in (23) and can be expressed as

$$E(\pi_{C,t+1}) = \left[1 - \tau_e e_{NC} - q\tau_e(e_{\tau+1} - e_{NC}) - \frac{(m-e_{t+1})^2}{2}\right]K^{a}_{t+1}(H_{t+1}n_{t+1})^{1-a} - w_{t+1}n_{t+1}. \tag{30}$$

As we can see, in this case the producer pays a tax on an emission intensity of e_{NC}. With probability q, however, the clandestine activities of the producer-bureaucrat pairing will be exposed, thus the producer will be forced to pay the tax they evaded, having already paid a bribe that they cannot claim back. Combining these arguments with (28), it follows that the producer's expected utility in the first stage of the process is

$$E(u_{producer,t}) = (1-\delta)\tilde{\pi}_{t+1} + \delta(1-\rho)E(\pi_{C,t+1}) - \delta\rho\pi_{NC,t+1} - \delta(1-\rho)\frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}, \tag{31}$$

where $\tilde{\pi}_{t+1}$, $E(\pi_{C,t+1})$ and $\pi_{NC,t+1}$ are given in (29), (30) and (A7) (from the Appendix) respectively. Since the firm owner arranges production in a manner that will retain the secrecy of the actual technology choice, all these terms entail the wage w_{t+1} from Eq. (A5) (from the Appendix) and $n_{t+1} = \tilde{l}$.

The producer will choose e_{t+1} to maximize their expected utility. Combining Eqs. (29)-(31) to calculate $\frac{\partial E(u_{C,producer,t})}{\partial e_{t+1}} = 0$ yields

$$e^*_{t+1} = m - \frac{1-\delta[1-(1-\rho)q]}{1-\delta\rho}\tau_e \equiv e_C, \tag{32}$$

a result that allows us to present

Lemma 3. *$e_C > e_{NC}$ and $\frac{\partial e_C}{\partial \delta} > 0$.*

Proof. See Appendix A.2. □

The result of Lemma 3 summarises the implications of corruption for the environmental characteristics of production technologies. I present these formally in

Proposition 1. *The emission intensity is higher under corruption. The higher the number of corruptible bureaucrats, the more polluting the technologies adopted by producers.*

Proof. It follows from Lemma 3. □

The intuition for this result in the following: Corruptible bureaucrats give firm owners the opportunity to pursue a risky, but potentially profitable decision to evade part of their emission tax burden. In response to this opportunity, producers react by adopting a less costly, but more polluting technology. Naturally, the extent to which producers opt for reducing the adoption cost of environmentally friendlier technologies depends on how likely they expect the inspection by a corruptible bureaucrat to be – a likelihood that is of course higher when more bureaucrats are corruptible.

3.4. The incidence of corruption, pollution, and capital accumulation

Let us define the composite term

$$\sigma(\delta, \rho, q, \tau_e) \equiv \frac{\tau_e^2}{2}\frac{(1-q)\delta(1-\rho)[(1-\delta)(1-q)+1-\delta\rho]}{(1-\delta\rho)^2}, \tag{33}$$

and recall that for the unlawful agreement between firm owner and bureaucrat to be mutually advantageous, the condition in (25) has to hold. The detailed analysis presented in the Appendix shows that this condition can be rewritten as

$$\sigma(\delta, \rho, q, \tau_e) > \frac{q\mu(1-\tau_w)(1-\alpha)}{(1-q\mu)\psi\alpha}\left[1-\tau_e\left(m-\frac{\tau_e}{2}\right)\right], \tag{34}$$

which leads us to the result in

Lemma 4. *Suppose that the condition in (34) holds for $\sigma(1, \rho, q, \tau_e)$. Then there exists $\hat{\delta} \in (0, 1)$ such that the same condition holds if $\delta > \hat{\delta}$, whereas it is violated if $\delta < \hat{\delta}$. Furthermore, $\hat{\delta} = d(q, \tau_e, \tau_w)$ where $d_q > 0$ and $d_{\tau_e}, d_{\tau_w} < 0$.*

Proof. See Appendix A.3. □

With the aid of this result, we can infer the outcomes formally presented in

Proposition 2. *The incidence of corruption will materialise only if the fraction of corruptible bureaucrats is above the threshold $\hat{\delta}$. A mongst other factors, higher income taxes and emission taxes, as well as a lower probability of detection, increase the likelihood that corruption will emerge.*

Proof. It follows from Lemma 4. □

These results merit some discussion. The outcome where corruption emerges only if the number of corruptible bureaucrats is above a threshold, is a novel realization of the idea that 'corruption corrupts'. At the time when producers make their decisions, they face uncertainty on the moral compass of the bureaucrats who will eventually inspect them. Consequently, the fraction of bureaucrats who are susceptible to transgression must be high enough so that, in expectation, the surplus from the collusion is high enough to eventually entice both parties – bureaucrat and firm owner – into taking the risk of their fraudulent activities. Note, however, that this threshold is not entirely exogenous; it depends on several structural characteristics. For example, this threshold is lower, thus making it more likely that a corruptible bureaucrat and a firm owner will conceal information from the authorities, if the likelihood that they will be exposed and face sanctions for their wrongdoing is lower. The same applies if both emission and income taxes are sufficiently high. Indeed, a high emission tax increases a producer's potential gains from tax evasion. The same applies if both emission and income taxes are sufficiently high. Indeed, a high emission tax increases a producer's potential gains from tax evasion. This raises the interesting possibility that a policy designed to induce the adoption of less polluting technologies may become less effective, if it induces producers to seek alternative, mostly nefarious, means for reducing their emission tax burden. Perhaps the role of income taxation is not as obvious, because it works solely through a bureaucrat's incentives; it is still intuitive nonetheless: A higher income tax decreases the corrupted bureaucrats' potential loss in the event that misconducts are revealed. Consequently, it increases their willingness to pursue illegal rents through bribery.

Obviously, if $\delta < \hat{\delta}$ there will be no corruption involved in the pairing of firm owners and bureaucrats; therefore, the outcomes are the ones presented in Lemma 1. For this reason, what follows will be the analysis of outcomes that transpire

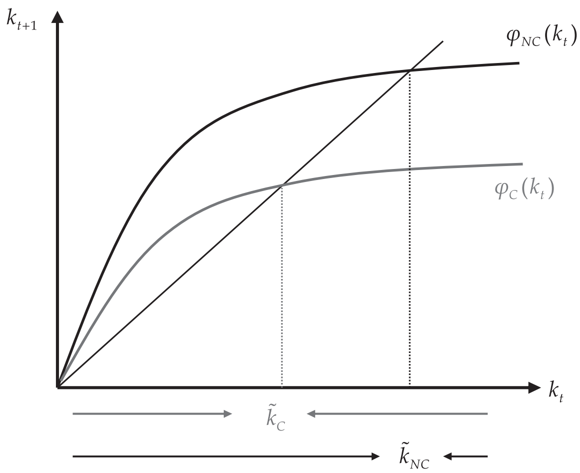

Fig. 3. Capital formation with and without corruption.

under $\delta > \hat{\delta}$. In this case, all corruptible bureaucrats will be corrupted. Furthermore, after weighting the probabilities of being inspected by a corruptible bureaucrat and, subsequently, remaining undetected by the authorities, producers choose technologies with an emission intensity of e_C. The analysis in the Appendix reveals that the model's outcomes in this case are summarized by

Lemma 5. *When corruptible bureaucrats are corrupted, the long-run equilibrium is characterized by a stock of capital $\tilde{k}_C$, a level of income $\tilde{y}_C$, an emission intensity e_C, and a level of pollution $\tilde{P}_C$, such that*

$$\tilde{k}_C = \eta_C^{\frac{1+\theta(1-\alpha)}{(1-\theta)(1-\alpha)}} \tag{35}$$

$$\tilde{y}_{NC} = \xi_C \eta_C^{\frac{\alpha}{(1-\theta)(1-\alpha)}} \tag{36}$$

$$e_c = m - \frac{1-\delta[1-(1-\rho)q]}{1-\delta\rho}\tau_e \tag{37}$$

$$\tilde{P}_C = e_C \xi_C \eta_C^{\frac{\alpha}{(1-\theta)(1-\alpha)}} \tag{38}$$

where composite terms are defined as follows:

$$\eta_C \equiv (1-\tau_w)(1-\gamma_{NC})(1-\alpha)\tilde{l}^{\frac{-[\alpha+\theta(1-\alpha)]}{1+\theta(1-\alpha)}} h^{\frac{1-\alpha}{1+\theta(1-\alpha)}} e_C^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}} \tag{39}$$

$$\xi_C \equiv \tilde{l}^{\frac{1-\alpha}{1+\theta(1-\alpha)}} h^{\frac{1-\alpha}{1+\theta(1-\alpha)}} e_C^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}}. \tag{40}$$

Given these, it is $\tilde{k}_C < \tilde{k}_{NC}$, $\tilde{y}_C < \tilde{y}_{NC}$ and $\tilde{P}_C > \tilde{P}_{NC}$.

Proof. See Appendix A.4. □

In general, the results of Lemma 5 allow us to identify the implications of corruption for the economy's prospects in terms of income and environmental quality. This is done through[21]

Proposition 3. *Corruption leads to a lower level of income and a higher level of pollution in the long-run.*

Proof. It follows from Lemma 5. □

The intuition is straightforward, given the forces that determine pollution and economic activity. Corruption impinges on the dynamics of capital accumulation through its effect on the average emission intensity and, therefore, its implications for pollution, health, and labor productivity. In the presence of corruption, labor productivity is lower, meaning that, for a given capital stock today, the funds that support the formation of capital are reduced, thus converging to a steady state capital stock that falls short of the one determined in the absence of corruption (see the phase diagram of Fig. 3). Naturally, the lower capital stock also undermines the economy's long-term prospects in terms of income. With regard to the long-run level of pollution, the incidence of corruption instigates two conflicting effects, in the sense that, compared to the scenario without corruption, the economy will be producing less output but with a higher emission intensity. The latter effect dominates, however, thus showing why, despite producing less output, the economy will be generating a flow of pollution that is higher.

[21] Note that in terms of the impact of emission intensity on the equilibrium solutions for capital, output, and pollution, the intuition discussed in Section 2 applies here as well.

4. The cultural evolution of corruptibility

Thus far, I have treated the share of corruptible bureaucrats as an exogenous parameter. A natural extension is to consider the possibility that attitudes towards corruption, and their distribution across public officials, are the result of several factors – mainly, of the education system and of the prevailing culture. In other words, it is possible that the fraction of corruptible bureaucrats evolves endogenously over time. This is the scenario envisaged and analysed in this section.

Let us assume that, in every period t, the government commits an amount g_t of its revenues towards public education. It follows that the government's budget constraint – originally in Eq. (1) – changes to

$$G_t = \tau_w(w_{private,t}l_{private,t} + w_{public,t}l_{public,t}) + R_t - w_{public,t}l_{public,t} - g_t. \tag{41}$$

Following others (e.g., Barro, 1990; Glomm and Ravikumar, 1997), it is assumed that, in each period, the government commits an amount that is proportional to equilibrium output. Note that, after accounting for the effect of pollution on labor productivity, the equilibrium level of output is $y_{i,t} = \xi_i k_t^{\frac{\alpha}{1+\theta(1-\alpha)}}$, for $i = \{NC, C\}$. With this in mind, it can be assumed that the government commits to the following rule for education expenditures:

$$g_t = \tilde{g}k_t^{\frac{\alpha}{1+\theta(1-\alpha)}}, \quad \tilde{g} < \xi_C; \tag{42}$$

which together with (2)-(4), (6), (9), (14)-(15), (39)-(41), (A8), (A10b), (A19), (A21b) (see the Appendix) and $n_{t+1} = \tilde{l}$, implies that government consumption is either

$$G_t = \left[\frac{\eta_{NC}(2\tau_w - \psi^{-1})}{1-\tau_w} + \tau_e e_{NC}\xi_{NC} - \tilde{g}\right]k_t^{\frac{\alpha}{1+\theta(1-\alpha)}}, \tag{43a}$$

in the absence of corruption, or

$$G_t = \left\{\frac{\eta_C\left(2\tau_w - \psi^{-1}\right)}{1-\tau_w} + \tau_e[e_{NC} + \delta q(e_C - e_{NC})\xi_C] - \tilde{g}\right\}k_t^{\frac{\alpha}{1+\theta(1-\alpha)}}. \tag{43b}$$

in the presence of corruption. Of course, an appropriate restriction on the upper bound of $\tilde{g}$ ensures that $G_t > 0$ under all circumstances.

One of the many important roles of the public education system is to inculcate individuals with civic virtues, i.e., a collection of habits, values and norms of behavior that, amongst other factors, affect attitudes towards corruption (e.g., Carrasco et al., 2020).[22] Naturally, the extent to which public education will be successful in instilling such civic virtues depends on the resources devoted to it (e.g., Marquette, 2007). With this in mind, it is assumed that a fraction $\lambda_t \in (0, 1)$ of children will leave education without having fully assimilated civic virtues, therefore they will be *prone to corruptibility* if, in the future, they secure employment in the public sector. Naturally, it is assumed that

$$\lambda_t = L(g_t), \tag{44}$$

such that $L'(g_t) < 0$. Of course, the remaining fraction $1 - \lambda_t$ will complete their education having adopted civic virtues; hence they will begin their adulthood being *prone to incorruptibility* if they secure employment in the public sector.

Nevertheless, the education system is not the only factor that determines the moral stance and the behavior of agents who are employed as bureaucrats. What also matters is the prevailing culture, and how this may either solidify or change agents' values, attitudes and behavior, as a result of becoming familiar with other agents' viewpoints through socialisation. To capture this mechanism, I will assume that, after leaving education, but before adulthood, each agent randomly meets and interacts with a young adult who is employed as a bureaucrat. This interaction will ultimately determine the agent's conduct, in the event that they secure public sector employment in their youth.

Consider an agent who, having completed public education, is prone to corruptibility. If they interact with a bureaucrat who is susceptible to corruption, then this will solidify their prior views, hence the agent will become corruptible. If, however, they interact with an incorruptible bureaucrat, the agent will retain their prior views and become corruptible only with probability $x_{PC} \in (0, 1)$; with probability $1 - x_{PC}$, their prior viewpoint will change and they will be incorruptible if they secure employment as bureaucrats. In this case, we can think of x_{PC} as the innate psychological resistance of agents who are prone to corruptibility, in changing their attitudes and values, despite becoming a familiar with – and instructed to adopt – a different stance.

Naturally, the analogous reasoning applies to the ultimate moral stance adopted by agents who, having completed public education, are prone to incorruptibility: If they interact with incorruptible bureaucrats, then this will solidify their prior viewpoint and these agents will be incorruptible in the event that they secure public sector employment. If, on the other hand, they interact with corruptible bureaucrats, they will retain their prior views and become incorruptible only with probability $x_{PI} \in (0, 1)$; with probability $1 - x_{PI}$, their prior stance will change and they will ultimately become susceptible

[22] This idea is reminiscent of Hong Kong's Independent Commission Against Corruption (ICAC). A major component of ICAC's strategy to eradicate endemic corruption was an ambitious education programme, applied to all levels of education, whose objective was to inculcate young generations with an intolerance to corruption and its adverse consequences (Johnston, 1999).

to corruption.[23] Likewise, x_{PI} is the innate psychological resistance of young agents, who are prone to incorruptibility, in changing their attitudes and values, and ultimately becoming corruptible.

Given the description above, the share of young bureaucrats who, in period $t+1$, will be corruptible is expressed as

$$\delta_{t+1} = \lambda_t[\delta_t + (1-\delta_t)x_{PC}] + (1-\lambda_t)\delta_t(1-x_{PI}), \tag{45}$$

Note that, by virtue of (42) and (44), $\lambda_t = L(\tilde{g}k_t^{\frac{\alpha}{1+\theta(1-\alpha)}}) = \tilde{L}(k_t)$, such that $\tilde{L}'(k_t) < 0$. Substituting this in (45), and rearranging, yields

$$\delta_{t+1} = [\tilde{L}(k_t)(1-x_{PC}) + (1-\tilde{L}(k_t))(1-x_{PI})]\delta_t + \tilde{L}(k_t)x_{PC}. \tag{46}$$

The time-varying fraction of corruptible bureaucrats implies that, using (32) and (39) as a guide, in period t we have $e^*_{C,t} = e_C(\delta_t)$ and $\eta_{C,t} = \eta_C(\delta_t)$, such that $e'_C(\delta_t) > 0$ and $\eta'_C(\delta_t) < 0$ respectively. Furthermore, in period t the condition in (34) will be expressed as

$$\sigma(\delta_t, \rho, q, \tau_e) > \frac{q\mu(1-\tau_w)(1-\alpha)}{(1-q\mu)\psi\alpha}\left[1 - \tau_e\left(m - \frac{\tau_e}{2}\right)\right]. \tag{47}$$

Together with (A11), (A22) (see the Appendix) and Lemma 4, it follows that the process of capital accumulation is governed by

$$k_{t+1} = \varphi(k_t, \delta_t) = \begin{cases} \eta_C(\delta_t)k_t^{\frac{\alpha}{1+\theta(1-\alpha)}} & if \quad \delta_t > \hat{\delta} \\ \\ \eta_{NC}k_t^{\frac{\alpha}{1+\theta(1-\alpha)}} & if \quad \delta_t < \hat{\delta} \end{cases}. \tag{48}$$

As we can see from (46) and (48), the dynamics of the economy are driven by a planar system of difference equations on δ_t and k_t, pinpointing to the fact that the culture of corruption and economic development affect each other mutually and, therefore, are jointly determined. As before, a higher incidence of corruption has a negative impact on economic growth due to its detrimental impact on environmental quality and, consequently, labor productivity. Indeed, we can define $\Delta k_{t+1} \equiv k_{t+1} - k_t$ and apply in (48) to rewrite it as

$$\Delta k_{t+1} \begin{cases} \begin{cases} > 0 & for \quad k_t < \tilde{k}_{C,t} \\ < 0 & for \quad k_t > \tilde{k}_{C,t} \end{cases} & if \quad \delta_t > \hat{\delta} \\ \\ \begin{cases} > 0 & for \quad k_t < \tilde{k}_{NC} \\ < 0 & for \quad k_t > \tilde{k}_{NC} \end{cases} & if \quad \delta_t < \hat{\delta} \end{cases}, \tag{49}$$

where $\tilde{k}_{NC}$ is given in (10), and

$$\tilde{k}_{C,t} = (\eta_C(\delta_t))^{\frac{1+\theta(1-\alpha)}{(1-\theta)(1-\alpha)}} = k_C(\delta_t), \tag{50}$$

such that $k'_C(\delta_t) < 0$ and $\tilde{k}_{C,t} < \tilde{k}_{NC}$ by virtue of Lemma 5. The additional element in this scenario is the fact that economic development is now a major factor in determining the culture of corruption. To see this, define $\Delta\delta_{t+1} \equiv \delta_{t+1} - \delta_t$ and apply in (46) to rewrite it as

$$\Delta\delta_{t+1} \begin{cases} > 0 & for \quad \delta_t < \tilde{\delta}_t \\ < 0 & for \quad \delta_t > \tilde{\delta}_t \end{cases}, \tag{51}$$

where

$$\tilde{\delta}_t = \frac{\tilde{L}(k_t)x_{PC}}{\tilde{L}(k_t)x_{PC} + (1-\tilde{L}(k_t))x_{PI}} = \delta(k_t). \tag{52}$$

Clearly, given the dynamics of cultural transmission, the share of corruptible bureaucrats will gradually converge to the solution in (52) – a result that allows us to infer the outcome in

Proposition 4. *A higher level of economic development attenuates the culture of corruptibility and, thus, reduces the incidence of corruption.*

Proof. Using (52), check that $\delta'(k_t) = \frac{x_{PC}x_{PI}\tilde{L}'(k_t)}{[\tilde{L}(k_t)x_{PC}+(1-\tilde{L}(k_t))x_{PI}]^2} < 0$. □

The intuition behind this outcome can be explained as follows: In a more developed economy, the government will have more resources at its disposal to dedicate to the efficiency of the public education system. This ensures that a higher

[23] One could envisage a scenario in which corrupted bureaucrats, who were eventually apprehended, could advise agents to pursue public sector employment with integrity, having regretted for their misconduct and the repercussions they faced. This approach would change nothing from the main results, message and implications of the model; in the presence of corruption, it would just add some scale parameters to the process of cultural change. At the same time, it would impose significant technical burden, as it requires cultural change to depend on δ_t being higher or lower than $\hat{\delta}$ (recall that, for $\delta_t < \hat{\delta}$, even corruptible bureaucrats abstain from any wrongdoing). In any case, this model's set-up is certainly appropriate for cases where the interactions between bureaucrats and their 'cultural children' occur before any misconduct is revealed.

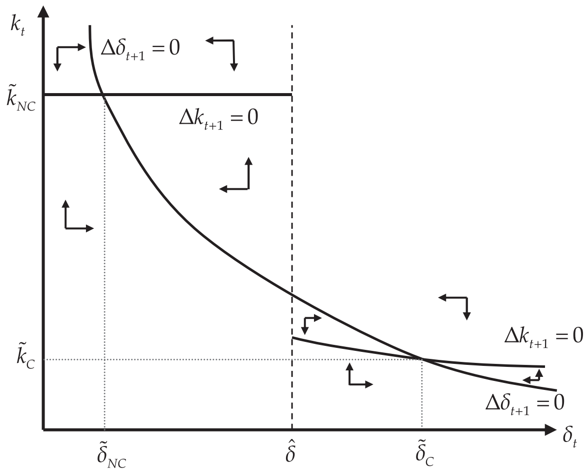

Fig. 4. Dynamics under the endogenous cultural evolution of corruptibility.

fraction of those who will eventually be hired as bureaucrats, will complete their education having being inculcated with civic virtues. These agents are more likely to retain these cultural norms over their lifetime, thus remaining incorruptible during their tenure as bureaucrats in the public sector.

Before we proceed with the analysis and discussion of the dynamics, we need to note that, when $\delta_t > \hat{\delta}$, the steady state solution is defined by the system of simultaneous equations in $\tilde{k}_{C,t}$ and $\tilde{\delta}_t$ from (50) and (52). The following Lemma ensures the existence of such a solution:

Lemma 6. *Assume that* $\hat{\delta} < \frac{\tilde{L}(k_C(\hat{\delta}))x_{PC}}{\tilde{L}(k_C(\hat{\delta}))x_{PC}+[1-\tilde{L}(k_C(\hat{\delta}))]x_{PI}}$ *holds. Then (50) and (52) define at least one equilibrium pair* $(\tilde{k}_C, \tilde{\delta}_C)$ *when* $\delta_t > \hat{\delta}$. *This pair satisfies* $\tilde{k}_C < \tilde{k}_{NC}$ *and* $\tilde{\delta}_C > \hat{\delta}$.

Proof. See Appendix A.5 □

In fact, an appropriate restriction on the shape of the function $L(\cdot)$ ensures that the equilibrium pair derived through Lemma 6 is also unique. Under these circumstances, the possible equilibrium outcomes are presented in

Proposition 5. *The economy's prospects are path-dependant in the sense that they depend on its cultural history. When* $\delta_0 > \hat{\delta}$, *an economy's long-term outcomes entail a higher level of corruption, a lower level of income and a higher level of pollution, compared to the long-term outcomes of an economy where* $\delta_0 < \hat{\delta}$.

Proof. See Appendix A.6 □

To facilitate a better understanding of the path-dependence that may emerge under an endogenous cultural evolution of attitudes towards corruption, the dynamics are illustrated on the phase diagram of Fig. 4. In this case, the cultural history characterises the fraction of bureaucrats whose behavioral profile, in terms of values, attitudes, and norms, makes them susceptible to corruption.

When $\delta_0 < \hat{\delta}$, and despite the fact that some bureaucrats may be corruptible, none of them is actually corrupted in their role of inspecting firms' emissions and imposing emission taxes. As explained in a previous part, this is because the joint surplus generated by an illegal collusion is not sufficient to entice neither bureaucrats nor firm owners in an illegal agreement involving bribery and emission tax evasion. Anticipating this, producers adopt less polluting production technologies – an outcome that reduces the level of pollution which, in turn, promotes productivity and economic growth. The process of growth generates high income; therefore it allows for sufficient resources towards public education to ensure that a high number of agents will begin their adulthood having adopted the civic virtues that will make them less likely to become corruptible. Therefore, the evolution of cultural characteristics will ensure that the number of corruptible bureaucrats remains relatively low, thus reinforcing this virtuous circle. With no corruption taking place in the implementation of environmental policy, the long-term outcomes for capital stock, income and pollution are the ones in (10), (11) and (13). Although some bureaucrats are corruptible ($\tilde{\delta}_{NC}$), in the sense that, given an opportunity, they would be willing to abuse their position to gain illegal rents, such opportunity does not arise – at least, in the implementation of environmental policy.

When $\delta_0 > \hat{\delta}$, however, the outcomes are different: Anticipating a high enough surplus, which will entice corruptible bureaucrats to accept bribes in exchange for misreporting emissions, producers have the incentive adopt more polluting technologies. The high level of pollution is an impediment to productivity and economic growth – a process that results in relatively low income. Public spending in education is correspondingly low, meaning that fewer agents will develop the civic virtues that may deter them from becoming susceptible to corruption. Ultimately, the evolution of cultural characteristics will ensure that the number of corruptible bureaucrats remains relatively high, thus reinforcing this vicious circle. The long-term equilibrium entails the outcomes in (35), (36) and (38), for $\delta = \tilde{\delta}_C$.

In essence, path-dependant outcomes emerge because of the two-way causal relation between the culture of corruptibility and low economic growth – a relation that affects and, at the same time, is affected by the extent of environmental degradation. It should be emphasised that, in this case, path-dependence is not driven by initial income – an issue that is always a point of criticism for models that generate multiple development regimes (Galor, 2011). In this case, the multiplicity of development regimes, and the lack of transition between them, are attributed to deeply rooted cultural differences with regard to public officials' susceptibility to – and acceptability of – corruption.

At this point, it should be emphasised that the process of cultural transmission is what generates the causal impact of economic development on lower levels of corruption – an outcome that finds strong support in the data (see Gundlach and Paldam, 2009). Indeed, from the analysis of Section 3, the expressions in (33)-(34) reveal that whether corruptible bureaucrats will eventually be corrupted or not, does not depend on either the capital stock or the labor productivity parameter h. In other words, neither income nor its expansion process affect the level of corruption when the framework considers exogenous cultural attitudes on corruption. On the contrary, this section showed that economic growth is a key factor in suppressing the incidence of corruption, by contributing to the endogenous decline in the share of bureaucrats whose moral disposition makes them susceptible to misconduct. Furthermore, the joint evolution of economic development and the diffusion of attitudes on corruption is the key mechanism that eventually materializes in persistent differences of both economic and environmental outcomes, originating from the economy's history of corruption. This is an outcome that also accords with empirical evidence (e.g., Fredriksson and Neumayer, 2016).

4.1. Policy implications

The outcomes we analyzed in this section, and the circumstances surrounding them, call for alternative policy approaches in the efforts to address concerns about the future impact of pollution and climate change. These approaches should recognize the fact that the overall policy framework to eradicate pollution should not be planned without consideration for the overall socioeconomic environment in which it is implemented. If anything, this study has shown that the interplay between economic activity and the prevailing culture is a major factor in determining environmental quality, through their impact on the implementation of environmental policy. In this respect, the policy design should also be directed towards institutional and cultural factors, even though such factors may not be specifically related to environmental issues. Policies that target at eradicating incentives to be corrupt, and at gradually changing people's perceptions and attitudes towards corruption, may still have wide and important positive repercussions, as long as they can make the implementation of environmental policy more effective.

Consider, for example, a policy that aims at improving the government's monitoring and detection of corruption. This is a policy that targets corruption incentives: By raising the threshold $\hat{\delta}$, this policy may allow a transition from the low income/high pollution regime, to the high income/low pollution one. Of course, the success of this approach depends (i) on this policy achieving a significant shift of $\hat{\delta}$, and (ii) the prevailing culture of corruptibility (measured by the share of corruptible bureaucrats) being already relatively close to this threshold. In other words, the effectiveness of such a policy may be questionable in circumstances where the culture of corruptibility is endemic amongst public officials.

Another policy that can facilitate the transition between the two regimes is one that aims directly at the culture of corruptibility. An increase in $\tilde{g}$ can improve the education system's effectiveness in instilling the values of integrity, honesty and community in younger generations. This process can gradually move the share of corruptible bureaucrats below the threshold necessary for them to become corrupted while implementing the government's environmental policy. The caveat here is the fact that cultural change is a slow process; therefore, the benefits of this approach may take long to materialize. Nevertheless, these benefits will be persistent and ensure an effective implementation of policies designed to improve the quality of the natural environment bequeathed to many future generations.

5. An alternative approach to preferences

One notable restriction of the model is perhaps the time preference shock, which implies that half of the population will consume all their income in their youth. This role of this assumption is twofold: First, it is a technical device to distinguish those who will undertake entrepreneurial activities, from those who will not – the latter group being the pool of agents out of whom the government can hire bureaucrats.[24] Second, it facilitates the model in delivering its message in the most tractable and least perplexing manner, without being critical for the robustness of this message. In this section I will show that same implications can be derived under a different setting, in which all agents have access to a financial market for saving purposes.

Consider, for example, the case where all agents have preferences over their old-age consumption – an assumption that has been used extensively in OLG models of growth, under a variety of settings that include not only corruption (e.g., Blackburn et al., 2006) or pollution (e.g., Raffin and Seegmuller, 2017), but also unemployment (Betts and Bhattacharya, 1998); demographic change (e.g., Galor and Weil, 1996); and public investment (e.g., Chakraborty and Dabla-

[24] The fixed size of the bureaucracy can be seen as another restriction. In a related setting, Acemoglu and Verdier (2000) endogenised the number of bureaucrats but their objective was to investigate the implications of corruption for the public sector's size. The focus of my model is quite different though. Give the already large number of moving parts in it, I opted for the approach of Blackburn et al. (2006) and Hong and Teh (2019) who also keep the size of the bureaucracy constant to focus on issues more pertinent to their analyses. In any case, my model accounts for endogenous changes in the percentage of the bureaucracy who are susceptible to corruption.

Norris, 2011). In such a setting, also consider the case where nature endows a fraction (e.g., half) of the population with the ability to become producers, meaning that the remaining fraction is the pool out of which the government will hire bureaucrats. In this setting, everyone will save their income through access to financial intermediaries who will return saving plus interest when agents are old. In this case, the right hand-side of the expressions in (17), (18) and (19) will be multiplied by r_{t+2}, which is the gross interest on saving and – assuming full depreciation – the marginal product of capital. Given these, the expression in (21) would change to

$$\Delta u_{bureaucrat,t+1} = (1-q\mu)r_{t+2}\psi\left[b_{t+1} - \frac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi}\right]. \tag{52}$$

Substitution of (52) in $NP = (\Delta u_{bureaucrat,t+1})^{\rho}(\Delta u_{producer,t})^{1-\rho}$ reveals that r_{t+2} will only introduce a scale effect in the expression of (24), without affecting the result in Lemma 2 and Eq. (28). As for producers, in the absence of corruption (8) will change to

$$\pi_{t+1} = \left[1 - \tau_e e_{t+1} - \frac{(m-e_{t+1})^2}{2}\right]k_{t+1}^{\alpha}(H_{t+1}n_{t+1})^{1-\alpha} - w_{t+1}n_{t+1} - r_{t+1}k_{t+1}, \tag{53}$$

while the corresponding utility is $\pi_{t+1} + r_{t+1}(1-\tau_w)w_t$ – the second term indicating the income available from saving. Given this, it is straightforward to establish that $r = (1-\gamma_{NC})\alpha y/k$ and that the results of (12) and (16) still apply. Furthermore, the formation of capital is governed by $k_{t+1} = 2(1-\tau_w)w_t$, where the scale factor of 2 reflects that all agents save income when young. This only introduces a scale factor in the solutions of (10), (11) and (13) – the qualitative characteristics remain intact.

In the presence of corruption, and similar to the analysis of Section 3, bribe-paying producers are the sole beneficiaries of emission tax evasion and will act in a manner that will not signal their fraudulent activities. In other words, they will report an emission intensity of e_{NC} and offer payments to labor and capital corresponding to the use of this technology. In this case, (29) and (30) change to

$$\pi_{t+1} = \left[1 - \tau_e e_{t+1} - \frac{(m-e_{t+1})^2}{2}\right]k_{t+1}^{\alpha}(H_{t+1}n_{t+1})^{1-\alpha} - w_{t+1}n_{t+1} - r_{t+1}k_{t+1}, \tag{54}$$

$$E(\pi_{C,t+1}) = \left[1 - \tau_e e_{NC} - q\tau_e(e_{\tau+1} - e_{NC}) - \frac{(m-e_{t+1})^2}{2}\right]k_{t+1}^{\alpha}(H_{t+1}n_{t+1})^{1-\alpha} - w_{t+1}n_{t+1} - r_{t+1}k_{t+1}, \tag{55}$$

while the expected utility in (31) changes to

$$\begin{aligned} E(u_{producer,t}) = {} & (1-\delta)\tilde{\pi}_{t+1} + \delta(1-\rho)E(\pi_{C,t+1}) - \delta\rho\pi_{NC,t+1} - \delta(1-\rho)\tfrac{q\mu(1-\tau_w)w_{t+1}}{(1-q\mu)\psi} \\ & + r_{t+1}(1-\tau_w)w_t \end{aligned}. \tag{56}$$

Again, it is straightforward to establish that the chosen emission intensity will be e_C as in (32), meaning that Lemmas 3–4 and Propositions 1–2 remain intact. The issue, however, is that a corrupted bureaucrat's income also includes the illegal rents he gets from bribery. Using the model's notation, Eq. (5) will be replaced by

$$k_{t+1} = \left(1 + \frac{\psi - 1}{\psi}\right)(1-\tau_w)w_{private,t} + \frac{1}{\psi}(1-\tau_w)w_{public,t} + \delta\frac{1}{\psi}\psi b_t \overset{Eq.(2)}{\Leftrightarrow} k_{t+1} = 2(1-\tau_w)w_t + \delta b_t, \tag{57}$$

where $\delta$is the share of corruptible bureaucrats in period t and b_t represents the bribes that each one gets. An obvious problem is that, under this setting, corruption will also have a positive impact on capital formation and growth, as bribes add to bureaucrats' disposable income and, therefore, their saving. Such a positive effect of corruption on capital accumulation, however, would be completely at odds with the existing empirical evidence, thus being detrimental to the empirical relevance of some of the model's implications. One way to overcome this issue is through additional parameter restrictions to ensure that the negative effect of corruption through health/labor productivity is dominant. Another way is to assume that deposits can be monitored by authorities, thus excessive saving signals a bureaucrat's bribe-taking. In this case, bureaucrats could access an 'underground' storage technology (e.g., an offshore account), offering a lower return of $\varsigma r (0 < \varsigma < 1)$, to 'save' their illegal rents without alerting the authorities on their excessive deposits. The 'underground' storage parameter only introduces a scale factor in the determination of the bribe, whereas capital formation is expressed as $k_{t+1} = 2(1-\tau_w)w_t$, thus the results of Lemma 5 and Proposition 3 remain qualitatively intact.[25]

[25] The difficulty of retaining tractability in a setting where agents have preferences over consumption in both periods of their lifetime would be insurmountable. This technical complication would most likely add little of significance to the analysis of the bureaucrat-firm owner collusion. After all, in the settings presented in Sections 3 and 5, both parties make decisions in light of their lifetime incomes – in essence, similar to a setting of intertemporal choice with preferences like $u_t = c_t^{1-\beta}c_{t+1}^{\beta}$ which leads to an equilibrium outcome $u_t^* = \bar{V}_t \times Lifetimeincome$, where $\bar{V}_t$ is a composite of parameters and variables. However, the presence of the corresponding composites $\bar{V}_t$ for bureaucrats and firm owners would add significant cost of notational burden and technical complexity, which would blur the intuition and underlying mechanisms, with minimal gain in terms of actual implications.

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. So far, the idea that such circumstances are linked to the interdependence of culture and economic development had eluded researchers' awareness. This study has shown that issues pertaining to culture and economic growth are pertinent to the corruption-pollution nexus, thus they certainly merit much more attention.

The results and implications of this study direct attention to important policy inferences. Policy makers should acknowledge that future-orientated efforts to address climate change may also include policies that facilitate a transition from a low income/high pollution regime to a high income/low pollution one. Given the cultural origins of multiple development regimes, such policies could be aimed at shaping a culture that will gradually reduce the incidence and the persistence of corruption. On the outset, this may not seem as the most obvious approach, as it does not directly involve an instrument of environmental policy *per se*. This study shows that it may be an equally important approach though, as it gradually lays the foundations of a more rigorous and more effective implementation of environmental policy, thus facilitating a process of environmentally sustainable economic growth.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

A.1 Proof of Lemma 1

Consider the events that take place in period $t+1$. Firm owners decide how much to produce and under which technology, knowing that the bureaucrats who inspect them will honestly report – and collect taxes on – the actual emissions of their production activities. Therefore, producers will enjoy utility

$$u_{NC,producer,t} = \pi_{NC,t+1}, \tag{A1}$$

meaning that utility maximisation is equivalent to firm owners maximising their profits. They do this by choosing n_{t+1} and e_{t+1}, while taking w_{t+1} and H_{t+1} as given. The first order conditions for this problem are the following:

$$\frac{\partial \pi_{NC,t+1}}{\partial n_{t+1}} = 0 \Rightarrow \left[1 - \tau_e e_{t+1} - \frac{(m - e_{t+1})^2}{2}\right](1-\alpha)k_{t+1}^{\alpha} H_{t+1}^{1-\alpha} n_{t+1}^{-\alpha} = w_{t+1}, \tag{A2}$$

$$\frac{\partial \pi_{NC,t+1}}{\partial e_{t+1}} = 0 \Rightarrow (-\tau_e + m - e_{t+1})k_{t+1}^{\alpha}(H_{t+1}n_{t+1})^{1-\alpha} = 0. \tag{A3}$$

We can use (A3) to infer the optimal choice of technology and the corresponding emission intensity. That is $e_{t+1}^* = m - \tau_e \equiv e_{NC}$, which is the result in Eq. (12). Now, define

$$\gamma_{t+1} = \tau_e e_{t+1} + \frac{(m - e_{t+1})^2}{2}. \tag{A4}$$

Substituting (12) in (A4) yields $\gamma_{t+1} = \gamma_{NC}$, where $\gamma_{NC} \equiv \tau_e(m - \frac{\tau_e}{2})$, is the composite term in Eq. (16). Combining (4), (A4), (16) and the labor market equilibrium condition $n_{t+1} = l_{private,t}$, we can use (A2) to derive

$$w_{t+1} = (1-\gamma_{NC})(1-\alpha)k_{t+1}^{\alpha} H_{t+1}^{1-\alpha} \tilde{l}^{-\alpha} = \frac{(1-\gamma_{NC})(1-\alpha)y_{t+1}}{\tilde{l}}. \tag{A5}$$

Of course, (2) and (A5) reveal that the utility of an incorruptible bureaucrat in $t+1$, i.e., $u_{NC,bureaucrat,t+1} = (1-\tau_w)w_{t+1}$, is equal to

$$u_{NC,bureaucrat,t+1} = (1-\tau_w)(1-\gamma_{NC})(1-\alpha)k_{t+1}^{\alpha} H_{t+1}^{1-\alpha} \tilde{l}^{-\alpha}, \tag{A6}$$

whereas the producer's utility is obtained by combining (2), (8), (A1), (A4), (A5) and (16). That is

$$u_{NC,producer,t} = \pi_{NC,t+1} = (1-\gamma_{NC})\alpha k_{t+1}^{\alpha}(H_{t+1}\tilde{l})^{1-\alpha}. \tag{A7}$$

Next, we move into the derivation of the economy's long-term outcomes with regard to income and pollution. Given that we have a unit mass of firms, the level of pollution in $t+1$ is

$$P_{t+1} = e_{NC} y_{t+1}. \tag{A8}$$

We can substitute $n_{t+1} = \tilde{l}$, (6), (A8) in (9), and solve for H_{t+1} to get

$$H_{t+1} = (he_{NC}^{-\theta}\tilde{l}^{-\theta(1-\alpha)})^{\frac{1}{1+\theta(1-\alpha)}}k_t^{-\frac{\theta\alpha}{1+\theta(1-\alpha)}}. \tag{A9}$$

Further substitution of (A9) in (A5) yields

$$w_{t+1} = (1-\gamma_{NC})(1-\alpha)\tilde{l}^{\frac{-[\alpha+\theta(1-\alpha)]}{1+\theta(1-\alpha)}}h^{\frac{1-\alpha}{1+\theta(1-\alpha)}}e_{NC}^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}}k_{t+1}^{\frac{\alpha}{1+\theta(1-\alpha)}}, \tag{A10a}$$

or, in terms of period t,

$$w_t = (1-\gamma_{NC})(1-\alpha)\tilde{l}^{\frac{-[\alpha+\theta(1-\alpha)]}{1+\theta(1-\alpha)}}h^{\frac{1-\alpha}{1+\theta(1-\alpha)}}e_{NC}^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}}k_t^{\frac{\alpha}{1+\theta(1-\alpha)}}. \tag{A10b}$$

Now recall that a unit mass of those who work in the private sector in period t will operate an investment technology, generating the capital stock that they will employ as firm owners in period $t+1$. It follows that the we can express the dynamics of capital formation after substituting (A10b) in (5). That is

$$k_{t+1} = \eta_{NC}k_t^{\frac{\alpha}{1+\theta(1-\alpha)}} = \varphi_{NC}(k_t), \tag{A11}$$

where η_{NC} is the composite parameter term in (14).

The steady state solution is obtained by solving for $k_{t+1} = k_t$ in (A11). Doing so reveals that there is only one stable solution, which is the one in (10). Next, substitute (A5) in (A10a) to write output as

$$y_{NC,t+1} = \xi_{NC}k_{t+1}^{\frac{\alpha}{1+\theta(1-\alpha)}}, \tag{A12}$$

where ξ_{NC} is defined in (15). Evaluating (A12) at the steady state and substituting (14) yields the solution in Eq. (11). Finally, Eq. (13) is derived after evaluating (18) at the steady state and substituting (11). □

A.2 Proof of Lemma 3

Note that, by virtue of $q<1$, it is $1-\delta\rho > 1-\delta[1-(1-\rho)q]$. Combining with (12), this reveals that $e_C > e_{NC}$. Next, we can differentiate (32) to get

$$\frac{\partial e_C}{\partial \delta} = \frac{-\tau_e\langle -(1-\delta\rho)[1-(1-\rho)q] + \{1-\delta[1-(1-\rho)q]\}\rho\rangle}{(1-\delta\rho)^2} = \frac{\tau_e(1-\rho)(1-q)}{(1-\delta\rho)^2}. \tag{A13}$$

Clearly, the expression in (A13) is a positive one, thus completing the proof. □

A.3 Proof of Lemma 4

Define the composite term

$$z = \frac{1-\delta[1-(1-\rho)q]}{1-\delta\rho}, \tag{A14}$$

which satisfies $z \in (0,1)$. Next, define the expression

$$\gamma_C = \tau_e e_{NC} + q\tau_e(e_C - e_{NC}) + \frac{(m-e_C)^2}{2}, \tag{A15}$$

and substitute (12), (32) and (A14) to rewrite it as

$$\gamma_C = \tau_e\left\{m - \frac{\tau_e}{2}[2-q(1-z)-z^2]\right\}. \tag{A16}$$

Combining (6), (30), (A5), (A7), (A14)-(A16) and $n_{t+1} = \tilde{l}$, we can obtain

$$E(\pi_{C,t+1}) - \pi_{NC,t+1} = \alpha k_{t+1}^{\alpha}(H_{t+1}\tilde{l})^{1-\alpha}\sigma(\delta, p, q, \tau_e), \tag{A17}$$

where $\sigma(\delta, p, q, \tau_e)$ is the expression in Eq. (33).

Now, define

$$\Omega = \alpha\sigma(\delta, \rho, q, \tau_e) - \frac{q\mu(1-\tau_w)(1-\alpha)}{(1-q\mu)\psi}\left[1-\tau_e\left(m-\frac{\tau_e}{2}\right)\right], \tag{A18}$$

and combine with (33) and (34) to establish that $\Omega < 0$ for $\delta = 0$ and $\Omega > 0$ for $\delta = 1$. Furthermore, we can differentiate (A18) to get

$$\frac{\partial\Omega}{\partial\delta} = \frac{\alpha\tau_e^2(1-\rho)(1-q)(1-\delta\rho)\{(1+\delta\rho)(1-\delta)(1-q)+(1-\delta\rho)[1-\delta(1-q)]\}}{2(1-\delta\rho)^4} > 0. \tag{A19}$$

These reveal that there exists a unique $\hat{\delta} \in (0,1)$ such that $\Omega(\hat{\delta}) = 0$ and $\Omega > 0$ for $\delta > \hat{\delta}$. The expressions in (33) and (A18) can also be used to verify that $\frac{\partial\Omega}{\partial\tau_w} > 0$, $\frac{\partial\Omega}{\partial\tau_e} > 0$ and $\frac{\partial\Omega}{\partial q} < 0$. Combining all these results, we can conclude that $\frac{\partial\hat{\delta}}{\partial\tau_w} = -\frac{\partial\Omega/\partial\tau_w}{\partial\Omega/\partial\hat{\delta}} < 0$, $\frac{\partial\hat{\delta}}{\partial\tau_e} = -\frac{\partial\Omega/\partial\tau_e}{\partial\Omega/\partial\hat{\delta}} < 0$ and $\frac{\partial\hat{\delta}}{\partial q} = -\frac{\partial\Omega/\partial q}{\partial\Omega/\partial\hat{\delta}} > 0$. □

A.4 Proof of Lemma 5

Eq. (37) was derived through the analysis that led to Eq. (32). Now, note that the level of pollution in $t+1$ is

$$P_{t+1} = e_C y_{t+1}. \tag{A19}$$

Substituting $n_{t+1} = \tilde{l}$, (6), (A19) in (9), and solving for H_{t+1}, yields

$$H_{t+1} = (he_C^{-\theta}\tilde{l}^{-\theta(1-\alpha)})^{\frac{1}{1+\theta(1-\alpha)}} k_t^{\frac{-\theta\alpha}{1+\theta(1-\alpha)}}. \tag{A20}$$

We can substitute (A20) in (A5) to get

$$w_{t+1} = (1-\gamma_{NC})(1-\alpha)\tilde{l}^{\frac{-[\alpha+\theta(1-\alpha)]}{1+\theta(1-\alpha)}} h^{\frac{1-\alpha}{1+\theta(1-\alpha)}} e_C^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}} k_{t+1}^{\frac{\alpha}{1+\theta(1-\alpha)}}, \tag{A21a}$$

or, in terms of period t,

$$w_t = (1-\gamma_{NC})(1-\alpha)\tilde{l}^{\frac{-[\alpha+\theta(1-\alpha)]}{1+\theta(1-\alpha)}} h^{\frac{1-\alpha}{1+\theta(1-\alpha)}} e_C^{\frac{-\theta(1-\alpha)}{1+\theta(1-\alpha)}} k_t^{\frac{\alpha}{1+\theta(1-\alpha)}}. \tag{A21b}$$

Now we can determine the process of capital accumulation and the long-run outcomes in an economy where corruption is a persistent phenomenon. Substituting (A21b) in (5) yields

$$k_{t+1} = \eta_C k_t^{\frac{\alpha}{1+\theta(1-\alpha)}} = \varphi_C(k_t), \tag{A22}$$

where η_C is the composite parameter term in (39). The steady state solution is obtained by solving for $k_{t+1} = k_t$ in (A22). Doing so reveals that there is only one stable solution, which is the one in (35). Next, substitute (A5) in (A21a) to write output as

$$y_{C,t+1} = \xi_C k_{t+1}^{\frac{\alpha}{1+\theta(1-\alpha)}}, \tag{A23}$$

where ξ_C is defined in (40). Evaluating (A23) at the steady state and substituting (35) yields the solution in (36). Finally, (38) is derived after evaluating (A19) at the steady state and substituting (36).

Finally, we can compare these outcomes with the ones that emerge in the absence of corruption. A comparison of (10) and (35) reveals that $\tilde{k}_{NC} > \tilde{k}_C$ holds as long as $\eta_{NC} > \eta_C$. It is straightforward to establish that this is indeed the case, by virtue of (14), (39) and $e_C > e_{NC}$ (see Lemma 3). For the same reason, it is $\xi_C < \xi_{NC}$ (see Eq. (15) and 40), meaning that $\tilde{y}_{NC} > \tilde{y}_C$. Next, we can substitute (14)-(25) in (13), (39)-(40) in (38), and compare the resulting expressions to establish that $\tilde{P}_{NC} < \tilde{P}_C$ as long as

$$\left(\frac{e_C}{e_{NC}}\right)^{\frac{1-\theta(1+\alpha)}{(1-\theta)[1+\theta(1-\alpha)]}} > 1. \tag{A24}$$

Indeed, the condition in (A24) holds because $e_C > e_{NC}$ and $\theta \leq \frac{1}{2}$. □

A.5 Proof of Lemma 6

Consider the expression in (52) after substituting (50), and check that both the left- and the right-hand side (*RHS*) of this expression are increasing in δ_t. In the latter case, this is indeed the case because $\frac{\partial RHS}{\partial \delta_t} = \frac{\partial RHS}{\partial \tilde{L}(k_C(\delta_t))}\frac{\partial \tilde{L}(k_C(\delta_t))}{\partial k_C(\delta_t)}\frac{\partial k_C(\delta_t)}{\partial \delta_t} > 0$. Obviously, for $\delta_t = 1$ we have $\frac{\tilde{L}(k_C(1))x_{PC}}{\tilde{L}(k_C(1))x_{PC}+[1-\tilde{L}(k_C(1))]x_{PI}} < 1$. This means that, as long as the condition $\hat{\delta} < \frac{\tilde{L}(k_C(\hat{\delta}))x_{PC}}{\tilde{L}(k_C(\hat{\delta}))x_{PC}+[1-\tilde{L}(k_C(\hat{\delta}))]x_{PI}}$ holds as well, there is at least one value $\delta_t = \tilde{\delta}_C$ in the $(\hat{\delta}, 1)$ interval, for which (52) will hold as an equality. By virtue of (50), the corresponding equilibrium value for the stock of capital will be $\tilde{k}_C = k_C(\tilde{\delta}_C)$. Furthermore, $\tilde{k}_C < \tilde{k}_{NC}$ follows from Lemma 5. □

A.6 Proof of Proposition 5

Consider the expressions in (49)-(52). For $\delta_t < \hat{\delta}$, there is no corruption (see Lemma 4) and the equilibrium values for the capita stock, income and pollution are the ones in Lemma 1. The number of corruptible (but not corrupted because $\delta_t < \hat{\delta}$) bureaucrats is obtained from (52) according to $\tilde{\delta}_{NC} = \delta(\tilde{k}_{NC})$. For $\delta_t > \hat{\delta}$, and given the result of Lemma 6, the outcomes are the ones in Lemma 5 – for $\delta_t = \tilde{\delta}_C$ – from which we also know that this equilibrium entails lower capital and income, and higher pollution. Note that (49) and (51) reveal that the equilibrium pairs $(\tilde{k}_{NC}, \tilde{\delta}_{NC})$ and $(\tilde{k}_C, \tilde{\delta}_C)$ are both asymptotically stable (see also the phase diagram of Fig. 4). □

A.7 Parameter and variable notation

β: Time preference shock	$c_{\nu,t}$: consumption in youth
τ_w: Flat-rate tax on labor income	$c_{\omega,t+1}$: consumption in maturity
τ_e: Flat-rate tax on emissions	y_t: Output
ψ: Max. number of firms a bureaucrat can inspect	k_t: Capital stock
α: Capital's share in production	$l_{private,t}$: Employment in private sector (no. of workers)
m: Emission intensity of the most polluting technology	$l_{public,t}$: Employment in public sector (no. of bureaucrats)
h: Labor productivity	δ_t: Share of corruptible bureaucrats
θ: Elasticity of health/productivity with respect to pollution	$w_{private,t}$: Workers' wage
q: Share of corrupted bureaucrats who are apprehended	$w_{public,t}$: Bureaucrats' wage
ρ: Bureaucrat's relative bargaining power	P_t: Pollution
μ: Utility loss of a corrupted bureaucrat who is apprehended	e_t: Emission intensity
$\tilde{g}$: Public spending parameter	H_t: Index of workers' health/productivity
x_{PC}: attitudes' persistence of agents who are prone to corruptibility	b_t: Bribe
x_{PI}: attitudes' persistence of agents who are prone to incorruptibility	π_t: Producer's profits
	G_t: Government spending
	R_t: Revenues from emissions' taxation
	g_t: Public spending on education
	λ_t: Share of agents who have not adopted civic virtues after their education

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