Received: 27 October 2020 | Revised: 27 April 2021 | Accepted: 11 June 2021

DOI: 10.1111/ecpo.12196

ORIGINAL ARTICLE

ECONOMICS & POLITICS WILEY

Canals, climate, and corruption: The provisioning of public infrastructure under uncertainty

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Funding information
National Science Foundation, Grant/Award Number: 1920938

Abstract

We develop a two-stage model to study the strategic interaction between a politician (the principal) and a bureaucrat (the agent) over the level of infrastructure provision with uncertainty about possible weather shocks. The bureaucrat chooses how much effort to contribute to infrastructure maintenance and the politician offers either a lump-sum wage (non-corrupt) contract or proportional bribe (corrupt) contract to induce effort. The degree of uncertainty about weather shocks, the size of the fixed wage, and the level of external monitoring to detect corruption all interact to affect (a) the politician's choice of contract and (b) whether this choice improves infrastructure outcomes. Our results suggest that curbing corruption is most likely to yield improvements in infrastructure provision when climate uncertainty is low and when bureaucratic wages are relatively high. If climate uncertainty is high, increasing monitoring has an unambiguous negative effect on infrastructure provision. Previous literature has focused either on public goods provision but not corruption or on bribery in a regulatory context that lacks public goods provision. We extend both literatures by analyzing how bribes between government officials affect a principal's ability to more effectively incentivize public goods provision by her agent.

KEYWORDS

agency theory, corruption, public choice, public good provision

1 | INTRODUCTION

Infrastructure is critical for economic development. Physical systems associated with transportation, electricity, sanitation, drinking water, and irrigation have been identified as cross-cutting needs for achieving the majority of the United Nations' Sustainable Development Goals (Thacker et al., 2019). Moreover, recent research has also highlighted the need for large investment in adaption to prevent costly impacts from climate change for various forms of infrastructure including roads (Schweikert et al., 2014), electric grids (Chen et al., 2021), and irrigation systems (Elliott et al., 2014), especially in the developing world. Unfortunately, many developing countries suffer from underinvestment in infrastructure that has been associated with weak institutions and political corruption (Thacker et al., 2019; Wade, 1982), and previous work has suggested that international aid flows targeted at improving infrastructure can actually lead to increases in corruption in developing countries (Marjit & Mukherjee, 2006).

How can infrastructure provision be improved in the presence of corruption? This paper examines the political economy of infrastructure provision and characterizes the conditions under which various policy levers may help improve outcomes. We build off previous studies of corruption and infrastructure investment in the developing world (e.g., Marjit and Mukherjee (2006)) to focus on the strategic interactions among different levels of government. Although elected politicians may have incentives to improve infrastructure provision, it is often bureaucrats (e.g., engineers and other appointed field staff) who shape outcomes through their direct interactions with stakeholders. Empirical evidence suggests that these appointed bureaucrats may underinvest in infrastructure and instead withhold budgeted resources for personal use. Much of the underinvestment in canal irrigation systems in the Indian subcontinent, for instance, has been attributed to corruption in the irrigation bureaus that maintain this infrastructure (Mollinga, 2001, 2003; Rinaudo, 2002; Wade, 1982).

The principal–agent framework has been widely applied to separately study strategic control of budgets by bureaucrats vs. politicians on the one hand, and bureaucrats' propensity to engage in corruption by accepting bribes on the other hand. However, these literatures have, thus far, developed in relative isolation from one another. This bifurcation stems from each literature's focus on distinct functions of government: the provision of public goods vs. the regulation of private actors. The literature on corruption focuses on the regulation of private economic activity and the incentives of agents to accept bribes from the private sector in exchange for reducing regulatory effort or granting permits (e.g., Rose-Ackerman (1975, 1978, 1999), and Shleifer and Vishny (1993)). In contrast, the literature on public good provision focuses on strategic control of budgets by bureaucrats vs. politicians, but does not incorporate the possibility of outright bribery between levels of government (e.g., Niskanen (1971, 1975); Breton and Wintrobe (1975); Tullock (1965) and Shepsle and Weingast (1984)).

These tendencies in the literatures reflect the empirical realities of the U.S. political system, where the economic theory of bureaucracy was first developed and has mostly focused (Becker, 1983; Klitgaard, 1988; Lui, 1986; Rose-Ackerman, 1975). Strategic behavior in the U.S. context tends to take the form of manipulation of formal procedures (McCubbins et al., 1987; Weingast & Moran, 1983), resulting in relatively low levels of outright bribery (extralegal cash transfers) in the bureaucracy compared to many developing nations that are characterized by poor infrastructure (Corruption Perceptions Index, 2018; Gerlak et al., 2020; Shleifer & Vishny, 1993).[1]

The nature of infrastructure problems is another important divide between the empirical realities in the developing world and the U.S-focused literature on agency problems in bureaucracy. Information asymmetry—the principal's inability to observe the agent's effort—is what gives rise

[1]See, for example, Roy (2013), Matthews (2016), Cawthorne (2014), NDTV India (2016).

to the principal–agent problem, and the degree of uncertainty can affect the scope for strategic behavior (Cheung et al., 1969; Stiglitz, 1974). In the context of canals, reservoirs, and other types of infrastructure in the developing world, severe weather events compound this information asymmetry by introducing additional stochastic shocks that affect observed outcomes. Given the predicted increase in severe weather events due to climate change (Stott, 2016), it is also important to consider how weather shocks influence the principal–agent problem by making the agent's effort more difficult to discern.

To better understand the relationship between corruption, bribery, and infrastructure provision in the developing world, we develop a principal–agent model with several distinguishing characteristics. First, we model outright bribery *between* government agents. This is in contrast to most corruption studies, which focus on the principal's ability to constrain the agent from accepting bribes from a third party. Second, we focus on how this type of bribery can influence the distribution of public funds (via infrastructure provision), as opposed to regulatory outcomes. Third, we also characterize how actors' beliefs about the probability of severe weather events affects the outcomes of their interactions.

We develop a two-stage model to study the strategic interaction between a principal (the politician) and an agent (the bureaucrat) over the level of infrastructure provision. The bureaucrat chooses how much effort to contribute to infrastructure maintenance. The outcome observed by the politician is the sum of this unobservable effort and a weather shock that affects the quality of infrastructure. In the first stage of the game, the politician chooses between two contracts. In the non-corrupt contract, the politician pays the bureaucrat a fixed wage, and the bureaucrat is sacked if the infrastructure outcome is below a predetermined threshold. In the corrupt contract, the politician does not sack the bureaucrat, but instead demands a bribe that decreases in proportion to the observed infrastructure outcome. In the second stage, the bureaucrat chooses effort based on the contract she faces. The game is solved by backward induction.

We characterize the equilibria of this game and the resulting level of infrastructure provision, with several important results. First, infrastructure provision may actually be greater in the corrupt equilibrium because the bribe mimics an efficient linear contract, whereas the fixed wage payment does not. Second, the politician's choice of contract may result in lower infrastructure provision for some feasible parameter values because her ability to extract a bribe causes her to discount the value of infrastructure provision. The degree of uncertainty about weather shocks, the size of the fixed wage, and the level of external monitoring to detect corruption all interact to affect (a) the politician's choice of contract and (b) whether this choice improves infrastructure outcomes. We show that "cracking down" on corruption can actually worsen infrastructure provision under certain conditions. This finding is consistent with fieldwork in India and elsewhere in the developing world, which suggests that infrastructure maintenance has fallen even as efforts to curb corruption have increased (Borooah, 2016; Kenny, 2007; Lehne et al., 2018).

This paper contributes to a growing literature that finds mixed effects of corruption on public good provision. For example, Chen et al.(2020) find an overall negative impact of anticorruption efforts on productivity and entry rates for firms providing public goods in China. Dastidar (2017) demonstrate how corruption in the quality control process in public infrastructure projects can lead to higher prices, lower quality, and lower total welfare. On the other hand, Burguet and Che (2004) analyze competitive procurement administered by a corrupt agent and find that with complete information and no corruption, the efficient firm will win the contract. Whereas these studies focus on bribery of government officials by *private* actors, we provide new insights on the impact of corruption between multiple levels of government.

2 | MODEL

The empirical motivation for our model is a government-supplied public infrastructure system. We focus on the strategic interaction between a politician and her agent, the bureaucrat, who she appoints to implement maintenance projects. This setup is typical of public infrastructure in the developing world, such as irrigation systems described by Wade (1982) in South India. Because our focus is on the bureaucrat–politician interaction, we assume that the politician's preferences about infrastructure provision reflect the importance of infrastructure to voters (farmers) who elect the politician, but we do not model the politician's election.

The bureaucrat has discretion over the use of public funds to pay for infrastructure maintenance. The quality of infrastructure, q, is sum of the bureaucrat's maintenance efforts, M, plus a shock, ϵ.

$$q = M + \epsilon$$

Shocks refer to extreme weather events, such as floods, that may result in deterioration of infrastructure. This shock is realized after a contract is set and maintenance decisions are made. We characterize the players' beliefs over possible shocks as a diffuse prior with a uniform distribution with zero mean between the limits $[-\beta/2, \ \beta/2]$.[2] That is, the players' beliefs assign a positive probability to a range of weather outcomes they view as possible, β. An increase in the value of β reflects a greater range of possible weather events so that a larger β reflects a more uncertain climate regime (Milly et al., 2002).

The politician cannot directly observe maintenance expenditures incurred by the bureaucrat. Instead, she observes the quality of infrastructure, q, which is jointly determined by the bureaucrat's maintenance spending and the severity of random weather events. Therefore, the politician faces a classic principal–agent problem and must choose a compensation mechanism to constrain opportunistic behavior by the bureaucrat.

We examine two institutional responses to this problem. Throughout, we assume that both the politician and bureaucrat are risk-neutral. For the remainder of our discussion, we use the following notation to denote the utilities of the bureaucrat and politician: $U_i^j(..)$, where i denotes the players: bureaucrat (B) and politician (P), j denotes the corrupt (C) or non-corrupt (NC) contract.

2.1 | Non-corrupt contract

The non-corrupt contract is a fixed wage contract between the politician and the bureaucrat. In the non-corrupt wage contract, the bureaucrat receives a fixed wage that does not vary with infrastructure outcomes, but she is fired if the observed quality of infrastructure falls below some threshold, T. This characterizes employment contracts in many bureaus that do not allow for performance-based compensation and instead operate only at the extensive margin (Heckman et al., 1997; Heinrich, 1999; Wade, 1982).

There are institutional barriers to firing government employees and bureaucrats based on outputs that are partially stochastic. This is especially true in developing countries like India (Iyer & Mani, 2012).[3] Hence, it is often the case that the bureaucrat is not punished (or rewarded) for performance in a continuous fashion that would be akin to a linear contract. Instead, non-linear, extensive margin

[2]We focus on players' *beliefs* about possible weather events, rather than on the "true" probability distribution of weather events, because the former is the basis for players' choices.

[3]See, e.g., Reuters (2015); BBC (2012); The Hindu (2016)

contracts are common in public agencies because output—and hence the marginal product of labor—is more difficult to value than in profit-maximizing firms (Niskanen, 1971, 2012; Ostrom & Ostrom, 1991; Tullock, 1965).[4]

Under the non-corrupt contract, the bureaucrat chooses a level of effort, M, that maximizes their expected utility, represented by

$$U_B^{NC}(M_{NC}) = \max_{M_{NC}} \left[\overline{w}Pr(q > T) - \psi(M_{NC})\right] \tag{1}$$

where $\overline{w}$ is the fixed wage determined outside the model and earned by the bureaucrat infrastructure provision is above the threshold, T (also determined outside the model). We assume the general form of the cost-of-effort function to be $\frac{\theta M^{\gamma}}{\gamma}$. For simplicity, we discuss the results of a quadratic cost-of-effort function: $\psi(M) = \frac{\theta M^2}{2}$. We provide results for the more general case in Appendices A and B.

We assume that the politician's utility is linear in the quality of infrastructure and the amount of money paid to the bureaucrat.[5] Hence, the politician's expected utility under the non-corrupt contract is given by

$$U_P^{NC}(M_{NC}) = \mathbb{E}[q - \overline{w}Pr(q > T)] = M_{NC} + \mathbb{E}[\epsilon] - \overline{w}Pr(q > T) \tag{2}$$

2.2 | Corrupt contract

In the corrupt contract, the politician demands a bribe from the bureaucrat that depends on the latter's performance. This assumption is an accurate description of many regimes observed in the developing world (Rose-Ackerman & Palifka, 2016). For example, the well-institutionalized system of corruption that surrounds irrigation in India makes positions in the irrigation bureau valuable assets (Quah, 2008). Not only do bureaucrats have to pay for transfer to desirable positions, but bureaucrats who do not perform well or threaten to enforce the law against those who engage in corruption may simply be transferred somewhere else by the politician (Iyer & Mani, 2012; Wade, 1982).

Unlike the formal compensation in the non-corrupt contract, bribery can be proportional to the output of the bureaucrat's efforts. That is, the bribe allows compensation to vary continuously with observed output, as with a standard linear contract in the agency literature. We assume that the politician offers linear contract of the form:

$$s = \overline{w} - (b - Hq)$$

where, $\overline{w}$ is the fixed wage (exogenous to the model) earned by the bureaucrat, b is the maximum feasible bribe that the politician can extract, and $H \in [0, 1]$ is a reduction in the bribe—proportional to observed infrastructure outcomes—that is chosen by the politician.

[4]Weitzman (1974) also notes that quantity-based instruments that focus on a ``pass-fail litmus type test'' for meeting a threshold have advantages over pricing performance at the margin in settings where the cost of measuring or observing marginal output is high.

[5]Risk neutrality of the principal (e.g., a linear utility function) is standard in the contract theory literature (Holmstrom and Milgrom, 1987; Salanié, 2005), as is assuming additive separability between the action and the payoff in the agent's utility function (as we do in equation 3).

The politician chooses a marginal reduction in the bribe, Hq, that varies with the quality of the infrastructure. The *net bribe* paid by the bureaucrat to the politician is equal to: $\hat{b} = b - Hq$. Hence, b is the upper limit on the amount that the politician *could* extract from the bureaucrat, whereas $\hat{b} = b - Hq$ is the amount the politician actually extracts based on the the contract and the bureaucrat's choice of q.

We assume that the maximum feasible bribe, b, is determined outside the model by factors that may vary by country and by bureau based on informal norms around bribery. However, we do require that the maximum feasible bribe is less than the bureaucrat's wage, that is $b < \overline{w}$.[6] The bribe also includes an implicit promise of protection for the bureaucrat so that there is no longer a threshold of system quality that results in the bureaucrat being fired. Instead, they pay the politician for protection.

Finally, we define $(1 - \sigma)$ to be the probability of being caught and punished when engaging in corruption. If corruption is detected, both players are fired and earn a payoff of zero. Hence, $\sigma \in [0, 1]$ is the probability of successful corrupt activity and reflects government-wide efforts to curb bribery in corrupt government agencies.[7] Hence, the expected net wage payment in the corrupt contract is σs. Both σ and $\overline{w}$ can be thought of as policy controls available to the central government to potentially affect both corruption and infrastructure provision. In what follows, we characterize how changes in these two parameters interact with other exogenous variables to affect the outcomes of the model.

In the corrupt contract, the bureaucrat maximizes her expected utility by choosing a level of maintenance effort M, taking as given the bribe contract H offered by the politician:

$$U_B^C\left(M_C, H\right) = \max_{M_C} \mathbb{E}\left[\sigma(\overline{w} - b + Hq) - \frac{\theta M_C^2}{2}\right] \tag{3}$$

Hence, the bureaucrat trades off the marginal cost of supplying additional effort with the marginal reduction in the net bribe they must pay to the corrupt politician. The bureaucrat's performance affects the politician's payoffs in two ways. First, the maintenance effort of the bureaucrat improves the condition of infrastructure, increasing the politician's utility.[8] Second, the bribe that the politician receives from the bureaucrat is proportional to the latter's effort. The politician's problem is then to choose a bribe, H, taking as given the bureaucrat's optimal choice of M_C for a given H.

$$U_P^C(M_C, H) = \max_{H} \mathbb{E}[\sigma(q + b - Hq - \overline{w})] \tag{4}$$

The politician faces a tradeoff in setting H. On the one hand, a more generous contract (larger H) provides stronger incentives for the bureaucrat to contribute effort and increases M_C^*. On the other hand, the larger are H and M_C, the smaller the *net* bribe, $\hat{b}$, received by the politician.

Finally, we assume that the bureaucrat will play the game only if it gives them a positive utility:

$$U_B^{NC}(M_{NC}^*) \geq 0 \quad \text{and,}$$

[6]We treat b as exogenous to our model. In practice, b would be constrained by the value of the outside option for the bureaucrat—that is the maximum bribe that the politician could feasibly extract should be defined by $\overline{w} - b \leq V$, where V is the value of the outside option for the bureaucrat. We normalize V to zero, resulting in the restriction that $b < \overline{w}$. In principle, there is no *minimum* value for b, but specific cultural or institutional factors outside the scope of our model could constrain b to be some value $\tilde{b} < \overline{w}$. I.e., in a setting with strong anti-bribery norms, b may be close to zero.

[7]We assume that the probability of being caught and punished is exogenous to the game.

[8]Perhaps by improving the possibility of the politician's reelection.

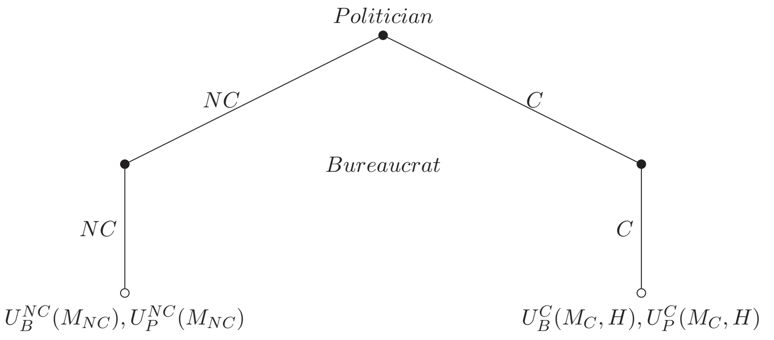

FIGURE 1 Extensive form of the game

TABLE 1 Definitions of model parameters

Symbol	Definition
$\overline{w}$	Wage of the bureaucrat
T	Infrastructure threshold
β	Climate uncertainty
θ	Marginal cost of effort to the bureaucrat
σ	Probability of corruption not being detected
b	Maximum feasible bribe

$$U_B^C(M_C^*, H^*) \geq 0$$

This assumption represents the individual rationality constraint for the bureaucrat. That is, if the utility is negative, the bureaucrat can break their contract with the politician for an outside opportunity. Therefore, the politician chooses a contract that maximizes their expected utility, subject to the bureaucrat's participation constraint.

2.3 | Solving the game

The structure of the game is as follows. In the first stage, the politician chooses between corrupt (C) and non-corrupt (NC) strategies. The corrupt contract includes the bribe parameter H. In the second stage, the bureaucrat chooses their level of effort (M) based on the politician's strategy. Figure 1 presents the structure of the game in extensive form and Table 1 summarizes the definitions all the model parameters.

The game has two potential subgame perfect Nash equilibria: corruption and non-corruption. Because the politician chooses the terms of remuneration (i.e., whether there will be a bribe and how it will be structured), the bureaucrat's only choice is to form a best response to the contract presented by the politician. Of course, the politician anticipates this best response when selecting a strategy. We solve the game by backward induction.[9] First, we characterize the optimal choice of the bureaucrat in the second stage under either contract. Second, we assume that the politician correctly anticipates the

[9]Refer to Appendices A and B for the derivations of solutions.

best response of the bureaucrat when choosing which contract to offer and what level of H to require.

2.3.1 | Non-corrupt solution

To begin, we substitute the uniform CDF into the non-corrupt bureaucrat's utility function from expression 1 and solve for optimal maintenance effort under the non-corrupt contract (see Appendix A).

$$U_B^{NC}(M_{NC}) = \max_{M_{NC}} \overline{w}Pr(M_{NC} + \epsilon > T) - \frac{\theta M_{NC}^2}{2}$$

$$U_B^{NC}(M_{NC}) = \max_{M_{NC}} \frac{\overline{w}}{2} - \frac{\overline{w}T}{\beta} + \frac{\overline{w}M_{NC}}{\beta} - \frac{\theta M_{NC}^2}{2} \tag{5}$$

$$FOC: \frac{\overline{w}}{\beta} - \theta M_{NC} = 0$$

$$\Rightarrow M_{NC}^*(\overline{w}, \theta, \beta) = \frac{\overline{w}}{\theta\beta} \tag{6}$$

Substituting expression 6 into expression 5, the non-corrupt bureaucrat's maximized utility may then be derived as below.

$$U_B^{NC}(M_{NC}^*) = \overline{w}\left[\frac{1}{2} - \frac{T}{\beta} + \frac{\overline{w}}{2\theta\beta^2}\right]$$

Knowing that $M_{NC}^* = \frac{\overline{w}}{\theta\beta}$, the non-corrupt politician's maximized utility is:

$$U_P^{NC}(M_{NC}^*) = \overline{w}\left[\frac{1}{\theta\beta} - \frac{1}{2} + \frac{T}{\beta}\right] - \frac{\overline{w}^2}{\theta\beta^2} \tag{7}$$

2.3.2 | Corrupt solution

Next, we characterize the optimal choice of M and H under the corrupt contract and derive the resulting payoffs (see Appendix B). The bureaucrat's choice of M, taking H as given is:

$$U_B^C(M_C, H) = \max_{M_C} \mathbb{E}\left[\sigma(\overline{w} - b + Hq) - \frac{\theta M_C^2}{2}\right]$$

$$FOC: \sigma H - \theta M_C = 0$$

$$\Rightarrow M_C = \frac{\sigma H}{\theta} \tag{8}$$

The politician chooses H to maximize her utility, anticipating the bureaucrat's choice of M_C:

$$U_P^C(M_C, H) = \max_H \mathbb{E}[\sigma(q + b - Hq - \overline{w})]$$

$$= \max_H \mathbb{E}[\sigma(M_C + \epsilon + b - HM_C - H\epsilon - \overline{w})]$$

$$= \max_H \mathbb{E}\left[\sigma\left(\frac{\sigma H}{\theta} + \epsilon + b - H\frac{\sigma H}{\theta} - H\epsilon - \overline{w}\right)\right]$$

$$= \max_H \sigma\left(\frac{\sigma H}{\theta} + b - H\frac{\sigma H}{\theta} - \overline{w}\right)$$

$$FOC: \frac{\sigma^2}{\theta} - \frac{2H\sigma^2}{\theta} = 0$$

$$\Rightarrow H^* = \frac{1}{2} \tag{9}$$

$$M_C^*(\sigma, \theta) = \frac{\sigma}{2\theta} \tag{10}$$

H^* and M_C^* can then be used to derive the maximized utility functions of the corrupt bureaucrat and politician:

$$U_B^C(M_C^*, H^*) = \sigma[\overline{w} - b] + \frac{\sigma^2}{8\theta} \tag{11}$$

$$U_P^C(M_C^*, H^*) = \frac{\sigma^2}{4\theta} + \sigma[b - \overline{w}] \tag{12}$$

3 | INCENTIVES FOR CORRUPTION AND IMPLICATIONS FOR INFRASTRUCTURE

The game is solvable by backward induction and has a unique subgame perfect Nash equilibrium (e.g., corruption or non-corruption) for each set of parameter values. This section examines the conditions under which the politician will choose to engage in corruption and discusses the resulting implications for infrastructure provision. First, we highlight the payoffs and infrastructure outcomes under each equilibrium. Next, we conduct comparative statics to characterize how each parameter affects both incentive to be corrupt (defined below) and infrastructure provision. Finally, we examine the conditions under which corruption improves or worsens infrastructure provision and the implications for anticorruption efforts.

3.1 | Comparative statics for corruption

In order to examine the conditions under which the politician chooses corruption, we define I_C as the politician's incentive to be corrupt. This is simply the difference between the utility of being corrupt and the utility obtained by being non-corrupt and is given by:

$$I_C = U_P^C(M_C^*, H^*) - U_P^{NC}(M_{NC}^*)$$

$$= \sigma\left[\frac{\sigma}{4\theta} + b - \overline{w}\right] - \overline{w}\left[\frac{1}{\theta\beta} - \frac{1}{2} + \frac{T}{\beta} - \frac{\overline{w}}{\theta\beta^2}\right] \tag{13}$$

If $I_C > 0$, the politician chooses the corrupt contract; otherwise, the politician chooses the non-corrupt contract. Either way, the bureaucrat responds accordingly. We conduct comparative statics over three parameters: climate uncertainty (β), the probability of detection ($1-\sigma$), and the fixed bureaucratic wage ($\overline{w}$).[10] The change in the incentive to be corrupt with respect to uncertainty about possible weather events β—referred to here as climate uncertainty—is given by:

$$\frac{\partial I_C}{\partial \beta} = \frac{\overline{w}}{\theta\beta^2} + \frac{\overline{w}T}{\beta^2} - \frac{2\overline{w}^2}{\theta\beta^3} \tag{14}$$

The relative magnitudes of $\overline{w}, \beta, T,$ and θ determine whether expression 14 is positive. We depict how these parameters interact to determine outcomes in the next section.

The change in the incentive to be corrupt with respect to the probability of detection is given by[11]:

$$\frac{\partial I_C}{\partial \sigma} = \frac{\sigma}{2\theta} + b - \overline{w} \tag{15}$$

Equation 15 shows that probability of detection has an ambiguous effect on the incentive to be corrupt—it depends on the value of the fixed bureaucratic wage, $\overline{w}$, relative to the probability of detection, $(1-\sigma)$, and the bureaucrat's cost of effort, θ. Specifically, if $\sigma < 2\theta(\overline{w} - b)$, the incentive to be corrupt decreases as the probability of detection increases.[12] This result follows directly from the fact that the probability of detection reduces the politician's net earnings in the corrupt contract.

The change in the incentive to be corrupt with respect to the bureaucratic wage, $\overline{w}$, is given by:

$$\frac{\partial I_C}{\partial \overline{w}} = \frac{2\overline{w}}{\theta\beta^2} + \frac{1}{2} - \left[\sigma + \frac{1}{\theta\beta} + \frac{T}{\beta}\right] \tag{16}$$

The sign of 16 is ambiguous and depends on the degree of climate uncertainty and probability of detection relative to the wage.

[11]Recall that the probability of being caught and punished in our model is $(1-\sigma)$. Therefore, σ is the probability of not being detected.

[12]We assume that the bureaucrat's fixed wage is greater than the maximum bribe paid to the politician, i.e., $\overline{w} > b$

[10]Refer to Appendix C for comparative statics on the general functional form.

3.2 | Comparative statics for infrastructure provision

We examine the effect of model parameters on the bureaucrat's maintenance effort under each of the two contracts before characterizing the conditions under which effort is higher under the corrupt contract.[13] Visual inspection of expression 10 shows that the infrastructure provision under the corrupt regime increases as the probability of detection, $(1 - \sigma)$, and the unit cost-of-effort, (θ), decrease.

Expression 10 also shows that infrastructure provision under the corrupt contract is unaffected by climate uncertainty. Due to the linearity of the corrupt contract and the risk neutrality assumption, the bureaucrat responds only to the mean shock, which is assumed to be zero.

On the other hand, the infrastructure provision effort under the non-corrupt equilibrium given by Equation 6 *does* depend on β. Expression 6 shows that the infrastructure provision effort under the non-corrupt regime increases with the wage of the bureaucrat. Under the non-corrupt contract, the bureaucrat's effort increases the probability that they earn a wage. Therefore, an increase in wage results in an increase in their incentive to supply effort.

Expression 6 also shows that the infrastructure provision under the non-corrupt equilibrium is strictly decreasing in climate uncertainty (β). This is because an increase in the range of possible weather events reduces the marginal productivity of effort toward ensuring that the minimum threshold T is met.

3.3 | Infrastructure provision and system outcomes

Thus far, we have characterized how model parameters affect provision of infrastructure *within* a given contract. Now, we compare infrastructure provision effort *across* both corrupt and non-corrupt regimes. Define ΔM to be the difference between the levels of infrastructure provision by the bureaucrat under the corrupt and non-corrupt regimes:

$$\Delta M = M_C^*(\sigma, \theta) - M_{NC}^*(\overline{w}, \theta, \beta)$$

$$= \frac{\sigma}{2\theta} - \frac{\overline{w}}{\theta\beta} \tag{17}$$

The provision of infrastructure is greater under the corrupt regime if $\Delta M > 0$ and greater under the non-corrupt regime if $\Delta M < 0$.

Based on expressions for I_C in eq 13 and ΔM in eq 17, there are four possible outcomes for corruption and infrastructure provision, summarized in Table 2. In the remainder of our discussion, we will focus on how the incentives for corruption interact with the condition for $\Delta M > 0$ to derive implications for policy approaches to improving infrastructure outcomes. Our discussion above highlights that the gains to corruption and infrastructure provision both depend on the policy controls (the probability of detection and the wage) and state of the world (climate uncertainty).

All four scenarios described in Table 2 are feasible outcomes of the game. There is a unique equilibrium for each constellation of parameter values, but the equilibrium outcome varies—in some cases, there is a corrupt equilibrium, and in other cases, there is a non-corrupt equilibrium. For any given set of values, the subgame perfect Nash equilibrium is a unique point for each exogenous parameter set. We are interested in the level of infrastructure provision associated with each equilibrium.

[13]Refer to Appendix C for comparative statics on the general functional form.

TABLE 2 Possible outcomes for corruption and infrastructure provision

	Politician is non-corrupt	Politician is corrupt
Corruption Improves Infrastructure	$I_C < 0$ $\Delta M > 0$	$I_C > 0$ $\Delta M > 0$
Corruption Degrades Infrastructure	$I_C < 0$ $\Delta M < 0$	$I_C > 0$ $\Delta M < 0$

It is possible for infrastructure provision under the corrupt contract to be better or worse than under the non-corrupt contract. Hence, changes in one of the policy controls, such as the wage or the probability of detection, can have complex effects on infrastructure provision because they alter the incentives for provision *within* a contract, but can also force a transition to a different contract by affecting the incentive to be corrupt.

These compound effects are what make it difficult to sign the comparative statics for each parameter. To gain traction, our approach below is to depict these dynamics separately for each of the two key policy controls (σ and $\overline{w}$), taking the other as given. To do so, we plot infrastructure provision against model parameters after accounting for switching between equilibria that can occur as parameter values change. This approach helps shed light on how the parameters interact to shape the model outcomes.

We derive the following condition for the corrupt equilibrium from the I_C in eq 13:

$$\sigma\left[\frac{\sigma}{4\theta}+b-\overline{w}\right]>\overline{w}\left[\frac{1}{\theta\beta}-\frac{1}{2}+\frac{T}{\beta}-\frac{\overline{w}}{\theta\beta^{2}}\right] \tag{18}$$

We also derive a condition for when the infrastructure provision effort is greater under the corrupt regime ($\Delta M > 0$):

$$\frac{\sigma}{2\theta}-\frac{\overline{w}}{\theta\beta}>0$$

$$\sigma>\frac{2\overline{w}}{\beta} \tag{19}$$

Together, equations 18 and 19 define the conditions for a corrupt equilibrium that results in better infrastructure provision. To depict the intuition for how wages, monitoring, and climate uncertainty interact to determine outcomes, in the next section we plot these conditions as a function each of the key variables of interest, holding the other variables constant at "high" and "low" values.[14] We first explore how changes in the probability of detection are likely to affect outcomes when wages and climate uncertainty are low vs. high, allowing us to characterize how anticorruption measures can be expected to perform if other factors are held fixed. Next, we consider how changes in the wage affect outcomes for high vs. low levels of monitoring. Finally, we characterize the effect of climate uncertainty for different levels of monitoring. Taken jointly, these examples provide intuition for how climate uncertainty shapes the complementarity of wage-based and monitoring-based strategies to improve outcomes.

[14]To recap, we assume players' beliefs over possible shocks as diffuse prior with a uniform distribution with zero mean between the limits $[-\beta/2, \beta/2]$. Refer to Appendix E for corruption and infrastructure outcomes when players' beliefs are normally distributed with zero mean and variance β.

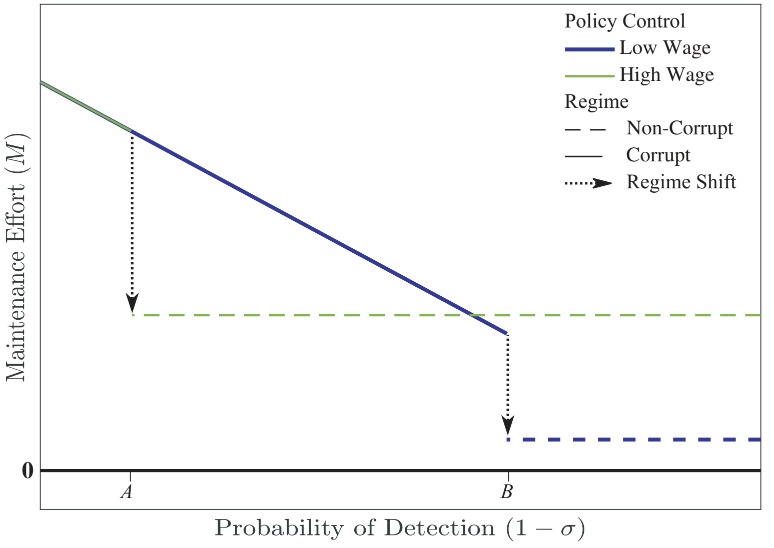

FIGURE 2 The infrastructure provision effort as a function of probability of detection in a state of high climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates low fixed bureaucratic wages, and green line indicates high fixed wages

3.4 | The probability of detection

Figure 2 illustrates infrastructure provision effort as a function of the probability of detection for high (green line) and low (blue line) values of wages, in a state of high climate uncertainty.[15] The figure also depicts the critical values of $(1-\sigma)$ where the equilibrium outcome switches from the corrupt contract (solid lines) to the non-corrupt contract (dashed lines). Hence, for values of $(1-\sigma) < A$, the outcome is the corrupt contract, regardless of the wage. For $A < (1-\sigma) < B$, the high-wage outcome is the non-corrupt contract, but the low-wage outcome is the corrupt contract. Finally, for $(1-\sigma) > B$, the non-corrupt contract is the outcome with either wage.

The graph demonstrates that allowing corruption actually yields greater infrastructure provision when climate uncertainty is high. This result follows our discussion on the comparative statics of M_C^* (expression 10) and M_{NC}^* (expression 6): under high climate uncertainty: an increase in $(1-\sigma)$ reduces M_C^* within the corrupt contract and has no effect on M_{NC}^*. If $(1-\sigma)$ increases enough to push the equilibrium into the non-corrupt contract, doing so causes a discrete reduction infrastructure provision because $M_C^* > M_{NC}^*$ in the neighborhood where the contract switch occurs (point A for high wages and point B for low wages).

Next, we examine the outcomes for ΔM and I_C in a state of low climate uncertainty. Figure 3 illustrates infrastructure provision effort as a function of the probability of detection for high and low wages, in a state of low climate uncertainty.[16] In this setting, increasing the probability of detection makes the non-corrupt equilibrium more likely, but whether this improves infrastructure provision effort depends on the wage. With a low wage, the equilibrium outcome is the non-corrupt contract unless $(1-\sigma) < A'$. At the same time, M_C^* is strictly greater than M_{NC}^* when the wage is low. Hence,

[15]Refer to Figure D1 for corruption and infrastructure outcomes under different bribe thresholds.

[16]Refer to Figure D2 for corruption and infrastructure outcomes under different bribe thresholds.

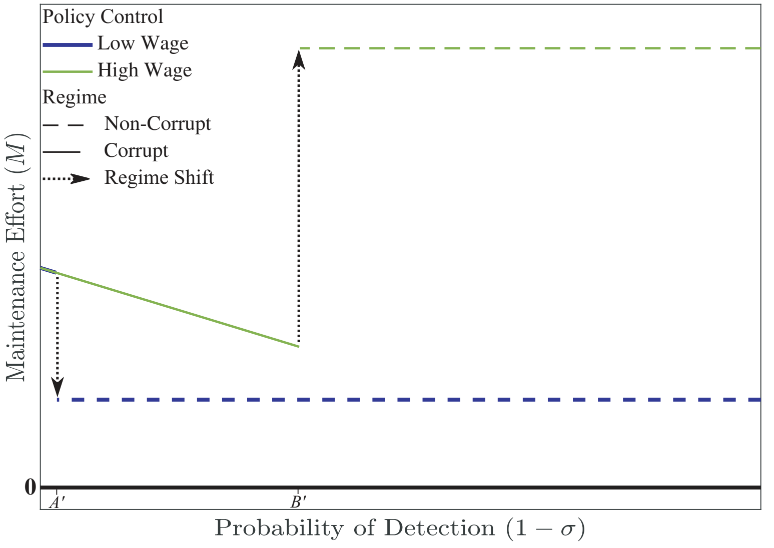

FIGURE 3 The provision of infrastructure as a function of probability of detection in a state of low climate uncertainty (low β). The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates low bureaucratic wages, and green line indicates high wages

with low wages and low climate uncertainty, infrastructure provision is highest when monitoring effort is kept low.

In contrast, when wages are high and climate uncertainty is low, M_C^* is strictly less than M_{NC}^*. This leads to a non-monotonic relationship between $(1-\sigma)$ and M_C^* because $\frac{\partial M_C^*}{\partial(1-\sigma)} < 0$ (expression 10). Hence, increases in monitoring effort when $(1-\sigma) < B'$ will result in worse infrastructure provision effort. However, a large enough increase in monitoring such that $(1-\sigma) < B'$ would result in a large improvement of infrastructure maintenance effort. Put differently, when wages are high and climate uncertainty is low, expressions 18 and 19 are not satisfied.

3.5 | The bureaucratic wage

Having characterized the effect of monitoring effort conditional on wages, we now turn to an examination of the effect of wages at high vs. low levels of monitoring effort. Recalling the condition for the corrupt equilibrium from the expression for I_C in eq 13:

$$\sigma\left[\frac{\sigma}{4\theta}+b-\overline{w}\right] > \overline{w}\left[\frac{1}{\theta\beta}-\frac{1}{2}+\frac{T}{\beta}-\frac{\overline{w}}{\theta\beta^2}\right] \tag{20}$$

We can rewrite the condition for when the infrastructure provision effort is greater under the corrupt regime ($\Delta M > 0$) as:

$$\frac{\sigma}{2\theta}-\frac{\overline{w}}{\theta\beta} > 0$$

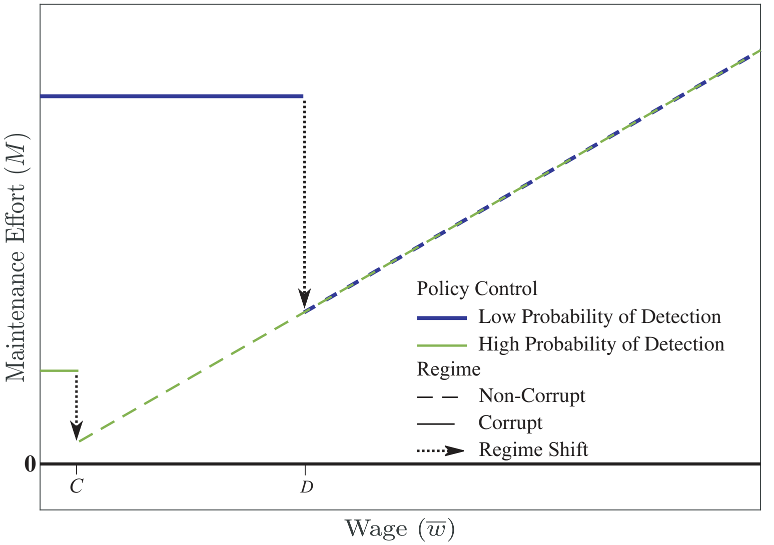

FIGURE 4 The provision of infrastructure as a function of wages in a state of high climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates weak monitoring mechanisms, and green line indicates strong monitoring mechanisms

$$\Rightarrow \overline{w} < \frac{\beta\sigma}{2} \tag{21}$$

We know from expression 6 that as wages increase, infrastructure provision is strictly increasing under the non-corrupt regime. However, expression 16 shows that the regime shift to non-corrupt equilibrium ($I_C < 0$) depends on the state of climate uncertainty. Hence, we analyze the effect of the wage separate for high vs. low climate uncertainty.

Figure 4 illustrates infrastructure provision effort as a function of the fixed wage for a high and low probability of detection, in a state of high climate uncertainty.[17] As the figure depicts, the politician's incentive to be corrupt decreases as the wage increases, causing a shift to the non-corrupt regime at point C (D) when monitoring effort is high (low). This is because the politician's benefit from infrastructure provision in the non-corrupt contract exceeds their benefit in the corrupt contract (expression 13). Hence, small increases in the wage around point C or D will lead to worse infrastructure provision because $M^*_{NC} < M^*_C$ in that neighborhood.

However, sufficiently large increases in the wage can improve infrastructure because infrastructure provision is strictly increasing in wages within the non-corrupt equilibrium (expression 6). Finally, the figure indicates an inverse relationship between the probability of detection and the wage. That is, a high probability of detection requires a small increase in wage to shift the system into the non-corrupt regime (point C).

Figure 5 illustrates infrastructure provision effort, as a function of the wage for high and low probability of detection, in a state of low climate uncertainty.[18] When climate uncertainty is low, increases

[17] Refer to Figure D3 for corruption and infrastructure outcomes under different bribe thresholds.

[18] Refer to Figure D4 for corruption and infrastructure outcomes under different bribe thresholds.

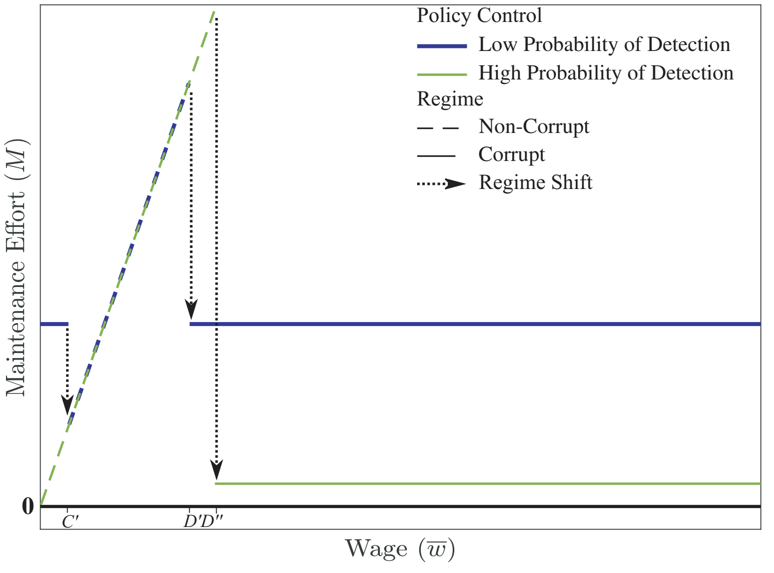

FIGURE 5 The provision of infrastructure as a function of wages in a state of low climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates weak monitoring mechanisms, and green line indicates strong monitoring mechanisms

in the wage can cause two shifts between equilibria. We know from expression 6 that infrastructure provision effort in the non-corrupt regime is strictly increasing in the wage. At low wages, the system shifts from a corrupt to a non-corrupt regime at C'. This is because the politician's benefit from infrastructure provision effort in the non-corrupt regime is higher than the corrupt regime (expression 13). However, as wages increase, the system shifts back to the corrupt regime with a lower level of infrastructure provision at point D' (low monitoring) or D'' (high monitoring). This is because the politician's cost of paying wages to the bureaucrat far exceed their benefit from infrastructure provision in the non-corrupt regime (expression 13). Figure 5 shows that as wages increase, the condition in expression 19 fails and the system shifts to corrupt equilibrium ($\Delta M < 0$ and $I_C > 0$) where infrastructure provision falls. Hence, the effect of changes in the wage on infrastructure provision can only be expected to improve infrastructure within a relatively small window (C' to D' or D'') when climate uncertainty is low.

3.6 | Climate uncertainty

In the final part of our analysis, we examine the effect of climate uncertainty on the corrupt equilibrium and on infrastructure provision effort. This discussion focuses on uniformly distributed beliefs, but Appendix E shows that the results are unchanged when players' beliefs are normally distributed with zero mean and variance β.

We can rewrite the condition for when the provision of infrastructure is greater under the corrupt regime ($\Delta M > 0$) as:

$$\Delta M > 0 \Rightarrow \frac{\sigma}{2} > \frac{\overline{w}}{\beta}$$

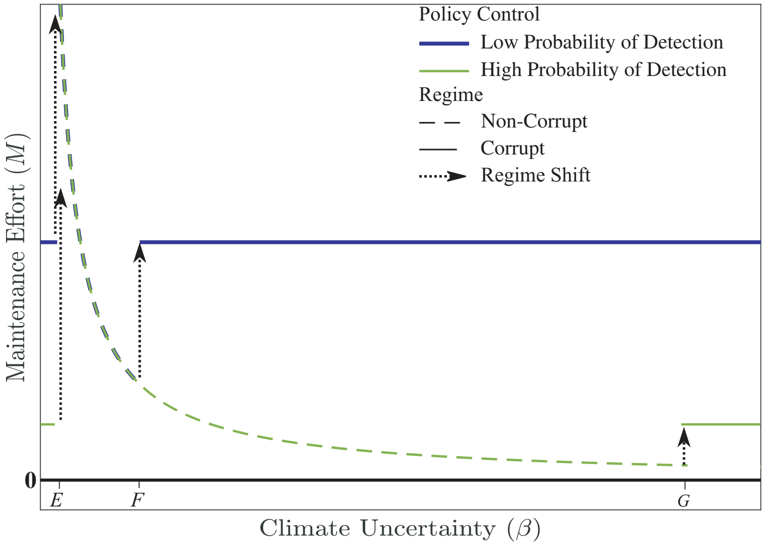

FIGURE 6 The provision of infrastructure as a function of climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates weak monitoring mechanisms, and green line indicates strong monitoring mechanisms

$$\Rightarrow \beta > \frac{2\overline{w}}{\sigma} \tag{22}$$

Figure 6 illustrates infrastructure provision effort as a function of climate uncertainty for a high and low probability of detection.[19] The figure shows that corruption becomes more likely as climate uncertainty increases, except at very low levels of uncertainty ($\beta < E$). This result follows our discussion in the comparative statics for I_C (expression 14) and M_{NC} (expression 6). We know from expression 14 that at low climate uncertainty, I_C is negative even though it is increasing at the margin ($I_C < 0$ but $\frac{\partial I_C}{\partial \beta} > 0$). This result is represented by the first regime shift in Figure 6 at point E.

Within the non-corrupt regime, increases in uncertainty lead to worse infrastructure provision ($\frac{\partial M^*_{NC}}{\partial \beta} < 0$). However, for high enough uncertainty, I_C becomes positive. This is represented by the second regime shift at points F (low monitoring) and G (high monitoring) in Figure 6. For large enough β, the conditions in expressions 22 and 20 are both satisfied, and the corrupt equilibrium yields greater infrastructure provision ($\Delta M > 0$ and $I_C > 0$).

Intuitively, the shift back to the corrupt regime comes much later when monitoring is high. Perhaps counterintuitively, this leads to much worse infrastructure provision when monitoring is high. The reason is that increases in the range of possible weather shocks affect the incentives for provision in the non-corrupt contract (expression 6), but not the corrupt contract (expression 10). The upshot is that corruption may be efficient (in the sense of yielding better infrastructure provision) for sufficiently high climate uncertainty.

[19]Refer to Figure D5 for corruption and infrastructure outcomes under different bribe thresholds.

4 | DISCUSSION AND CONCLUSION

This paper uses a principal–agent model to examine the impact of corruption on the provision of public infrastructure. Previous literature has focused either on public goods provision but not corruption (e.g., Niskanen (1971, 1975); Breton and Wintrobe (1975); Tullock (1965); Shepsle and Weingast (1984)) or on bribery in a regulatory context that lacks public goods provision (e.g., Rose-Ackerman (1975, 1999, 1978); Shleifer and Vishny (1993)). We extend both literatures by analyzing how bribes between government officials affect a principal's ability to incentivize public goods provision more effectively by her agent. Such arrangements are common in the developing world, where provision of infrastructure is crucial for smoothing out weather variability (Burton, 2010).

The non-corrupt contract in our model mimics the employment terms facing many bureaucrats: They earn a fixed wage if their performance is above some minimum threshold, but they are fired if it is not. This contract exposes the agent to the risk associated with shocks that affect infrastructure performance. The corrupt contract removes the threat of firing but includes a bribe that varies in proportion to the level of infrastructure provision. Hence, the corrupt contract mimics an efficient linear contract.

We find that there is no unique equilibrium: Both corruption and non-corruption can be supported as outcomes of the game for certain parameter values. Crucially, we also find that the efficient linear contract associated with the corrupt outcome can lead to better infrastructure provision for some parameter values. We partition the set of possible outcomes into four scenarios: (a) the politician chooses to be corrupt, with negative consequences for infrastructure provision; (b) the politician chooses to be corrupt, with positive consequences for infrastructure provision; (c) the politician chooses to be non-corrupt, with negative consequences for infrastructure provision; and (d) the politician chooses to be non-corrupt, with positive consequences for infrastructure provision.

By exploring the conditions under which each scenario occurs, we derive implications and testable predictions for when policies aimed at curbing corruption or bolstering wages can be expected to improve infrastructure provision. Our discussion focuses on three parameters: the probability of detection $(1-\sigma)$, the fixed wage $\overline{w}$, and the degree of climate uncertainty β, and the effects of changes in one parameter must be analyzed conditional on the others. There are several important predictions that follow from our analysis.

The first key result of our model is that in a state of high climate uncertainty, increases in monitoring effort to curb corruption will actually lead to worse infrastructure provision (Figure 2). For sufficiently high climate uncertainty, infrastructure provision is greater in the corrupt contract. In this setting, increasing monitoring effort reduces maintenance effort within the corrupt contract while also making a shift to the less productive non-corrupt contract more likely.

Second, we find a more nuanced relationship between wages and infrastructure provision when climate uncertainty is high. An increase in the wage tends to make the non-corrupt contract more likely and also to improve maintenance effort within the non-corrupt contract itself. Whether infrastructure provision is higher in the non-corrupt contract depends on the value of the wage, but our results in Figure 4 suggest that increases in the wage are more likely to improve outcomes if (a) those increases are relatively large and (b) the probability of detecting corrupt activity is high.

Third, when climate uncertainty is low, we find that the effect of monitoring effort depends crucially on the wage. For low wages, increasing monitoring effort is expected to reduce infrastructure provision. For high wages, an increase in monitoring effort can improve infrastructure provision if it is large enough to cause a shift to the non-corrupt equilibrium (Figure 3). Finally, we find that as climate uncertainty increases, a high level of monitoring is associated with a non-corrupt equilibrium that yields lower infrastructure provision than the corrupt equilibrium that would prevail with lower monitoring (Figure 6).

Our findings are consistent with existing literature that suggests crackdowns on bureaucratic corruption may not restore efficiency in the economy, but can instead lead to worse economic outcomes, particularly in the context of developing countries (Chen et al., 2020; Dreher & Gassebner, 2013; Fisman & Svensson, 2007; Leff, 1964; Shleifer & Vishny, 1993). Our findings are also consistent with relatively mixed findings in the literature regarding the importance of adequate wages in relation to curbing corruption (Becker & Stigler, 1974; Di Tella & Schargrodsky, 2003; Myrdal, 1972; Shapiro & Stiglitz, 1984). For example, "shirking models" of Shapiro and Stiglitz (1984) and Becker and Stigler (1974) predict that a higher wage is necessary to eliminate corruption when the probability of detection is low. Our model nests this finding as a special case when climate uncertainty is high (Figure 4). In such cases, infrastructure provision may improve in the non-corrupt regime only if the wages are very high.

Improving the efficiency of irrigation infrastructure is arguably a high priority for several developing countries. Yet, empirical evidence shows that the condition of irrigation infrastructure continues to decline in countries like India due to political and bureaucratic corruption (Suhardiman & Giordano, 2014). In spite of strong monitoring procedures, the high-ranked bureaucrats in the irrigation bureau continue to conceal their receipt and passing on of illicit funds. The fact that the exchange of illicit funds is encouraged and is often demanded, by the politician reduces the effectiveness of these monitoring mechanisms (Wade, 1982). Intuition suggests that corruption distorts the allocation of resources and reduces provision of public goods (De Soto, 1989). But, in spite of research showing the negative effects of corruption on irrigation performance in government-managed irrigation systems (Rinaudo, 2002), few studies have examined this issue in connection with the agency literature. To make matters worse, there is little to no understanding of the role of corruption in the context of climate uncertainty, which looms large in irrigation systems in the developing world.

The model developed in this paper reveals a non-monotonic relationship between corruption and infrastructure provision and shows that there is not a one-size-fits-all "panacea" approach for improving infrastructure provision. Anticipating institutional responses to climate change is especially critical for managers of infrastructure in developing countries. However, it is important to understand the nexus of climate uncertainty, remuneration in corrupt and non-corrupt systems, and monitoring effectiveness before making policy recommendations.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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REFERENCES

BBC (2012). *India's bureaucracy is 'worst in Asia'*. BBC. https://www.bbc.com/news/world-asia-india-16523672

Becker, G. S. (1983). A theory of competition among pressure groups for political influence. *The Quarterly Journal of Economics*, *98*(3), 371–400. https://doi.org/10.2307/1886017

Becker, G. S., & Stigler, G. J. (1974). Law enforcement, malfeasance, and compensation of enforcers. *The Journal of Legal Studies*, *3*(1), 1–18. https://doi.org/10.1086/467507

Borooah, V. K. (2016). Deconstructing corruption: A study of cash for favours in rural India. *Journal of South Asian Development*, *11*(1), 1–37. https://doi.org/10.1177/0973174115624773

Breton, A., & Wintrobe, R. (1975). The equilibrium size of a budget-maximizing bureau: A note on Niskanen's theory of bureaucracy. *Journal of Political Economy*, *83*(1), 195–207. https://doi.org/10.1086/260313

Burguet, R., & Che, Y.-K. (2004). Competitive procurement with corruption. *RAND Journal of Economics*, 50–68. https://doi.org/10.2307/1593729

Burton, M. (2010). *Irrigation management: Principles and practices*. Cabi.

Cawthorne, A. (2014). *Overpass collapses in World Cup city, crushes vehicles*. Reuters. https://www.reuters.com/article/us-brazilworldcup-accident/overpass-collapses-in-world-cup-city-crushes-vehicles-idUSKBN0F82A220140703

Chen, H., Liu, S., Liu, Q., Shi, X., Wei, W., Han, R., & Küfeoğlu, S. (2021). Estimating the impacts of climate change on electricity supply infrastructure: A case study of china. *Energy Policy*, *150*, 112119. https://doi.org/10.1016/j.enpol.2020.112119

Chen, Z., Jin, X., & Xu, X. (2020). Is a corruption crackdown really good for the economy? Firm-level evidence from China. *Journal of Law, Economics, and Organization*, *1*, 1–44. https://doi.org/10.1093/jleo/ewaa014

Cheung, S. N. et al. (1969). *The theory of share tenancy. The Theory of Share Tenancy, With Special Application to Asian Agriculture and the First Phase of Taiwan Land Reform* (pp. 175–182). University of Chicago Press.

Corruption Perceptions Index. (2018). *Transparency international*. Retrieved from https://www.transparency.org/files/content/pages/2018_CPI_ExecutiveSummary.pdf

Dastidar, K. G. (2017). *Oligopoly, auctions and market quality, economics, law, and institutions in Asia Pacific*, 1, 1(1–189). Springer, Tokyo. https://doi.org/10.1007/978-4-431-55396-0

De Soto, H. (1989). *The invisible revolution in the third world*. The Other Path, Harper and.

Di Tella, R., & Schargrodsky, E. (2003). The role of wages and auditing during a crackdown on corruption in the city of Buenos Aires. *The Journal of Law and Economics*, *46*(1), 269–292. https://doi.org/10.1086/345578

Dreher, A., & Gassebner, M. (2013). Greasing the wheels? The impact of regulations and corruption on firm entry. *Public Choice*, *155*(3–4), 413–432. https://doi.org/10.1007/s11127-011-9871-2

Elliott, J., Deryng, D., Müller, C., Frieler, K., Konzmann, M., Gerten, D., Glotter, M., Flörke, M., Wada, Y., Best, N., Eisner, S., Fekete, B. M., Folberth, C., Foster, I., Gosling, S. N., Haddeland, I., Khabarov, N., Ludwig, F., Masaki, Y., … Wisser, D. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change. *Proceedings of the National Academy of Sciences*, *111*(9), 3239–3244. https://doi.org/10.1073/pnas.1222474110

Fisman, R., & Svensson, J. (2007). Are corruption and taxation really harmful to growth? Firm level evidence. *Journal of Development Economics*, *83*(1), 63–75. https://doi.org/10.1016/j.jdeveco.2005.09.009

Gerlak, A. K., Saguier, M., Mills-Novoa, M., Fearnside, P. M., & Albrecht, T. R. (2020). Dams, Chinese investments, and EIAs: A race to the bottom in South America? *Ambio*, *49*(1), 156–164. https://doi.org/10.1007/s13280-018-01145-y

Heckman, J., Heinrich, C., & Smith, J. (1997). Assessing the performance of performance standards in public bureaucracies. *The American Economic Review*, *87*(2), 389–395.

Heinrich, C. J. (1999). Do government bureaucrats make effective use of performance management information? *Journal of Public Administration Research and Theory*, *9*(3), 363–394. https://doi.org/10.1093/oxfordjournals.jpart.a024415

Holmstrom, B., & Milgrom, P. (1987). Aggregation and linearity in the provision of intertemporal incentives. *Econometrica: Journal of the Econometric Society*, 303–328.

Iyer, L., & Mani, A. (2012). Traveling agents: Political change and bureaucratic turnover in India. *Review of Economics and Statistics*, *94*(3), 723–739. https://doi.org/10.1162/REST_a_00183

Kenny, C. (2007). *Infrastructure governance and corruption: where next?*. The World Bank.

Klitgaard, R. (1988). *Controlling corruption*. Univ of California Press.

Leff, N. H. (1964). Economic development through bureaucratic corruption. *American Behavioral Scientist*, *8*(3), 8–14. https://doi.org/10.1177/000276426400800303

Lehne, J., Shapiro, J. N., & Eynde, O. V. (2018). Building connections: Political corruption and road construction in India. *Journal of Development Economics*, *131*, 62–78. https://doi.org/10.1016/j.jdeveco.2017.10.009

Lui, F. T. (1986). A dynamic model of corruption deterrence. *Journal of Public Economics*, *31*(2), 215–236. https://doi.org/10.1016/0047-2727(86)90019-8

Marjit, S., & Mukherjee, V. (2006). Poverty, utilization of foreign aid and corruption: the role of redistributive politics. In *Theory and practice of foreign aid*. Emerald Group Publishing Limited.

Matthews, P. (2016). *This is why construction is so corrupt*. World Economic Forum. https://www.weforum.org/agenda/2016/02/why-isthe-construction-industry-so-corrupt-and-what-can-we-do-about-it/

McCubbins, M. D., Noll, R. G., & Weingast, B. R. (1987). Administrative procedures as instruments of political control. *Journal of Law, Economics, & Organization*, *3*, 243.

Milly, P. C. D., Wetherald, R. T., Dunne, K., & Delworth, T. L. (2002). Increasing risk of great floods in a changing climate. *Nature*, *415*(6871), 514. https://doi.org/10.1038/415514a

Mollinga, P. P. (2001). Water and politics: Levels, rational choice and South Indian canal irrigation. *Futures*, *33*(8), 733–752. https://doi.org/10.1016/S0016-3287(01)00016-7

Mollinga, P. P. (2003). *On the waterfront: Water distribution, technology and agrarian change in a South Indian canal irrigation system*. Orient Blackswan.

Myrdal, G. (1972). *Asian drama; An inquiry into the poverty of nations* (Vol. *1*). Pantheon.

NDTV India (2016). *Bengal Suspends 2 Engineers, Arrests 3 Over Kolkata Flyover Collapse*. NDTV India. https://www.ndtv.com/cheat-sheet/24-dead-in-kolkata-flyover-collapse-90-pulled-out-in-all-night-rescue-10-developments-1292824

Niskanen, W. A. (1971). *Bureaucracy and representative government*. Aldine Atherton.

Niskanen, W. A. (1975). Bureaucrats and politicians. *The Journal of Law and Economics*, *18*(3), 617–643. https://doi.org/10.1086/466829

Niskanen, W. A. (2012). Gordon Tullock's contribution to bureaucracy. *Public Choice*, *152*(1–2), 97–101. https://doi.org/10.1007/s11127-011-9851-6

Ostrom, V., & Ostrom, E. (1991). Public goods and public choices: The emergence of public economies and industry structures. *The Meaning of American Federalism*, *1*, 163–197.

Quah, J. S. (2008). Curbing corruption in India: An impossible dream? *Asian Journal of Political Science*, *16*(3), 240–259. https://doi.org/10.1080/02185370802504266

Reuters (2015). *Government fires employee who skipped work for 24 years*. Reuters. https://www.reuters.com/article/indiasacking/government-fires-employee-who-skipped-work-for-24-years-idINKBN0KH0TW20150108

Rinaudo, J.-D. (2002). Corruption and allocation of water: The case of public irrigation in pakistan. *Water Policy*, *4*(5), 405–422. https://doi.org/10.1016/S1366-7017(02)00037-5

Rose-Ackerman, S. (1975). The economics of corruption. *Journal of Public Economics*, *4*(2), 187–203. https://doi.org/10.1016/0047-2727(75)90017-1

Rose-Ackerman, S. (1978). *Corruption: A study in political economy*. Academic Press.

Rose-Ackerman, S. (1999). *Corruption and government: Causes, consequences, and reform*. Cambridge University Press.

Rose-Ackerman, S., & Palifka, B. J. (2016). *Corruption and government: Causes, consequences, and reform*. Cambridge University Press.

Roy, A. (2013). Fighting construction fraud in India. *Grant Thornton Report*, *1*(1), 1–4. https://www.grantthornton.in/en/insights/articles/fighting-construction-fraud-in-india/

Salanié, B. (2005). *The economics of contracts: A primer*. MIT press.

Schweikert, A., Chinowsky, P., Espinet, X., & Tarbert, M. (2014). Climate change and infrastructure impacts: Comparing the impact on roads in ten countries through 2100. *Procedia Engineering*, *78*, 306–316. https://doi.org/10.1016/j.proeng.2014.07.072

Shapiro, C., & Stiglitz, J. E. (1984). Equilibrium unemployment as a worker discipline device. *The American Economic Review*, *74*(3), 433–444.

Shepsle, K. A., & Weingast, B. R. (1984). Uncovered sets and sophisticated voting outcomes with implications for agenda institutions. *American Journal of Political Science*, 49–74. https://doi.org/10.2307/2110787

Shleifer, A., & Vishny, R. W. (1993). Corruption. *The Quarterly Journal of Economics*, *108*(3), 599–617. https://doi.org/10.2307/2118402

Stiglitz, J. E. (1974). Incentives and risk sharing in sharecropping. *The Review of Economic Studies*, *41*(2), 219–255. https://doi.org/10.2307/2296714

Stott, P. (2016). How climate change affects extreme weather events. *Science*, *352*(6293), 1517–1518. https://doi.org/10.1126/science.aaf7271

Suhardiman, D., & Giordano, M. (2014). Is there an alternative for irrigation reform? *World Development*, *57*, 91–100. https://doi.org/10.1016/j.worlddev.2013.11.016

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., O'Regan, N., Rozenberg, J., Watkins, G., & Hall, J. W. (2019). Infrastructure for sustainable development. *Nature Sustainability*, *2*(4), 324–331. https://doi.org/10.1038/s41893-019-0256-8

The Hindu (2016). *The stained steel frame*. The Hindu. https://www.thehindu.com/opinion/lead/The-stained-steelframe/article14023107.ece

Tullock, G. (1965). *The politics of bureaucracy*. Public Affairs Press.

Wade, R. (1982). The system of administrative and political corruption: Canal irrigation in south India. *The Journal of Development Studies*, *18*(3), 287–328. https://doi.org/10.1080/00220388208421833

Weingast, B. R., & Moran, M. J. (1983). Bureaucratic discretion or congressional control? Regulatory policymaking by the federal trade commission. *Journal of Political Economy*, *91*(5), 765–800. https://doi.org/10.1086/261181

Weitzman, M. L. (1974). Prices vs. quantities. *The Review of Economic Studies*, *41*(4), 477–491.

How to cite this article: Vallury, S., & Leonard, B. (2021). Canals, climate, and corruption: The provisioning of public infrastructure under uncertainty. *Economics & Politics*, 00, 1–32. https://doi.org/10.1111/ecpo.12196

APPENDIX A

NON-CORRUPT SOLUTION

From equation 1, the bureaucrat's expected utility under the non-corrupt contract is given by:

$$U_B^{NC}(M_{NC}) = \max_{M_{NC}} [\overline{w}Pr(q > T) - \psi(M_{NC})]$$

$$= \overline{w}Pr(M_{NC} + \epsilon > T) - \frac{\theta M_{NC}^{\gamma}}{\gamma}$$

$$= \overline{w}Pr(\epsilon > T - M_{NC}) - \frac{\theta M_{NC}^{\gamma}}{\gamma}$$

$$= \overline{w}(1 - Pr(\epsilon < T - M_{NC})) - \frac{\theta M_{NC}^{\gamma}}{\gamma}$$

$$= \overline{w}(1 - F(T - M_{NC})) - \frac{\theta M_{NC}^{\gamma}}{\gamma}$$

$$\epsilon \sim U\left[\frac{-\beta}{2}, \frac{\beta}{2}\right]$$

$$= \overline{w}\left(1 - \frac{T - M_{NC} + \frac{\beta}{2}}{\beta}\right) - \frac{\theta M_{NC}^{\gamma}}{\gamma}$$

$$= \overline{w}\left(\frac{\frac{\beta}{2} - T + M_{NC}}{\beta}\right) - \frac{\theta M_{NC}^{\gamma}}{\gamma}$$

$$= \frac{\overline{w}}{2} - \frac{\overline{w}T}{\beta} + \frac{\overline{w}M_{NC}}{\beta} - \frac{\theta M_{NC}^{\gamma}}{\gamma} \tag{23}$$

$$FOC: \frac{\overline{w}}{\beta} - \frac{\theta\gamma M_{NC}^{(\gamma-1)}}{\gamma} = 0$$

$$\Rightarrow M_{NC}^{*}(\overline{w}, \theta, \beta, \gamma) = \left(\frac{\overline{w}}{\theta\beta}\right)^{\frac{1}{\gamma-1}} \tag{24}$$

Substituting 24 into equation 23, the bureaucrat's utility function may then be derived as:

$$U_B^{NC}(M_{NC}^{*}) = \frac{\overline{w}}{2} - \frac{\overline{w}T}{\beta} + \frac{\overline{w}}{\beta}.\left(\frac{\overline{w}}{\beta}\right)^{\frac{1}{\gamma-1}}.\left(\frac{1}{\theta}\right)^{\frac{1}{\gamma-1}} - \frac{\theta}{\gamma}\left(\frac{\overline{w}}{\theta\beta}\right)^{\frac{\gamma}{\gamma-1}}$$

$$= \frac{\overline{w}}{2} - \frac{\overline{w}T}{\beta} + \left(\frac{\overline{w}^{\gamma}}{\theta\beta^{\gamma}}\right)^{\frac{1}{\gamma-1}} - \frac{1}{\gamma}.\left(\frac{\overline{w}^{\gamma}}{\theta\beta^{\gamma}}\right)^{\frac{1}{\gamma-1}} \tag{25}$$

From equation 2, the politician's expected utility under the non-corrupt contract is given by

$$U_P^{NC}(M_{NC}) = \mathbb{E}[q - \overline{w}Pr(q > T)]$$

$$= \mathbb{E}[M_{NC} + \epsilon - \overline{w}Pr(M_{NC} + \epsilon > T)]$$

$$= M_{NC} + \mathbb{E}[\epsilon] - \overline{w}Pr(\epsilon > T - M_{NC})$$

$$= M_{NC} - \overline{w}(1 - Pr(\epsilon < T - M_{NC}))$$

$$= M_{NC} - \overline{w}(1 - F(T - M_{NC}))$$

$$\epsilon \sim U\left[\frac{-\beta}{2}, \frac{\beta}{2}\right]$$

$$= M_{NC} - \overline{w}\left(1 - \frac{T - M_{NC} + \frac{\beta}{2}}{\beta}\right)$$

$$= M_{NC} - \overline{w}\left(\frac{\frac{\beta}{2} - T + M_{NC}}{\beta}\right)$$

$$= M_{NC} - \frac{\overline{w}}{2} - \frac{\overline{w}T}{\beta} + \frac{\overline{w}M_{NC}}{\beta}$$

Substituting $M_{NC}^{*} = \left(\frac{\overline{w}}{\theta\beta}\right)^{\frac{1}{\gamma-1}}$, the non-corrupt politician's maximized utility may be derived as:

$$U_P^{NC}(M_{NC}^*) = \left(\frac{\overline{w}}{\theta\beta}\right)^{\frac{1}{\gamma-1}} - \frac{\overline{w}}{2} + \frac{\overline{w}T}{\beta} - \frac{\overline{w}}{\beta}.\left(\frac{\overline{w}}{\theta\beta}\right)^{\frac{1}{\gamma-1}}$$

$$= \overline{w}^{\frac{1}{\gamma-1}}\left[\left(\frac{1}{\theta\beta}\right)^{\frac{1}{\gamma-1}} - \frac{\overline{w}^{\frac{\gamma-2}{\gamma-1}}}{2} + \frac{T\overline{w}^{\frac{\gamma-2}{\gamma-1}}}{\beta}\right] - \left(\frac{\overline{w}^{\gamma}}{\theta\beta^{\gamma}}\right)^{\frac{1}{\gamma-1}} \tag{26}$$

Considering the specific case of $\gamma = 2$, the cost-of-effort has a quadratic functional form: $\frac{\theta M_{NC}^2}{2}$. The optimal maintenance effort, M_{NC}^* in eq 24 becomes: $M_{NC}^*(\overline{w}, \theta, \beta) = \frac{\overline{w}}{\theta\beta}$. Substituting $\gamma = 2$ in eq 25 and 26, the bureaucrat's and politician's maximized utilities under the non-corrupt contract may be derived as:

$$U_B^{NC}(M_{NC}^*) = \overline{w}\left[\frac{1}{2} - \frac{T}{\beta} + \frac{\overline{w}}{2\theta\beta^2}\right]$$

$$U_P^{NC}(M_{NC}^*) = \overline{w}\left[\frac{1}{\theta\beta} - \frac{1}{2} + \frac{T}{\beta}\right] - \frac{\overline{w}^2}{\theta\beta^2}$$

APPENDIX B

CORRUPT SOLUTION

From equation 3, the bureaucrat's expected utility under the corrupt contract is given by:

$$U_B^C\left(M_C, H\right) = \max_{M_C} \mathbb{E}\left[\sigma(\overline{w} - b + Hq) - \frac{\theta M_C^{\gamma}}{\gamma}\right]$$

$$= \mathbb{E}\left[\sigma(\overline{w} - b + HM_C + H\epsilon) - \frac{\theta M_C^{\gamma}}{\gamma}\right]$$

$$= \sigma(\overline{w} - b + HM_C) + \sigma H\mathbb{E}(\epsilon) - \frac{\theta M_C^{\gamma}}{\gamma}$$

$$= \sigma(\overline{w} - b + HM_C) - \frac{\theta M_C^{\gamma}}{\gamma} \tag{27}$$

$$FOC\colon \sigma H - \frac{\theta\gamma M_C^{\gamma-1}}{\gamma} = 0$$

$$\Rightarrow M_C^* = \left(\frac{\sigma H}{\theta}\right)^{\frac{1}{\gamma-1}} \tag{28}$$

The politician's problem is to choose a bribe, H, taking as given the bureaucrat's optimal choice of M_C for a given H:

$$U_P^C(M_C, H) = \max_H \mathbb{E}[\sigma(q + b - Hq - \overline{w})]$$

$$= \max_H \mathbb{E}[\sigma(M_C + \epsilon + b - HM_C - H\epsilon - \overline{w})]$$

$$= \sigma(M_C + b - HM_C - \overline{w}) + \mathbb{E}[\epsilon] - H\mathbb{E}[\epsilon]$$

$$= \sigma(M_C + b - HM_C - \overline{w})$$

$$\text{Substituting } M_C^* = \left(\frac{\sigma H}{\theta}\right)^{\frac{1}{\gamma-1}}$$

$$= \sigma\left(\frac{\sigma H}{\theta}\right)^{\frac{1}{\gamma-1}} + \sigma b - \sigma H\left(\frac{\sigma H}{\theta}\right)^{\frac{1}{\sigma-1}} - \sigma\overline{w}$$

$$= \gamma^{\frac{\gamma}{\gamma-1}}\left(\frac{H}{\theta}\right)^{\frac{1}{\gamma-1}} + \sigma b - \sigma^{\frac{\gamma}{\gamma-1}} H^{\frac{\gamma}{\gamma-1}}\left(\frac{1}{\theta}\right)^{\frac{1}{\gamma-1}} - \sigma\overline{w} \tag{29}$$

$$FOC: \frac{\sigma^{\frac{\gamma}{\gamma-1}}\left(\theta^{\frac{1}{\gamma-1}}\left(\frac{H}{\theta}\right)^{\frac{1}{\gamma-1}} - \gamma H^{\frac{\gamma}{\gamma-1}}\right)}{H(\gamma-1)\theta^{\frac{1}{\gamma-1}}} = 0$$

$$H^* = \frac{1}{\gamma} \Rightarrow M_C^*(\sigma, \theta, \gamma) = \left(\frac{\sigma}{\theta\gamma}\right)^{\frac{1}{\gamma-1}} \tag{30}$$

Substituting M_C^* and H^* into equation 27, the corrupt bureaucrat's maximized utility may be derived as:

$$U_B^C(M_C^*, H^*) = \sigma(\overline{w} - b + HM_C^*) - \frac{\theta {M_C^*}^{\gamma}}{\gamma}$$

$$= \sigma(\overline{w} - b) + \left[\frac{\sigma^\gamma}{\theta\gamma^\gamma}\right]^{\frac{1}{\gamma-1}} - \left[\frac{\sigma^\gamma}{\theta\gamma^{(2\gamma-1)}}\right]^{\frac{1}{\gamma-1}} \tag{31}$$

Substituting M_C^* and H^* into equation (29), the corrupt politician's maximized utility may be derived as:

$$U_P^C(M_C^*, H^*) = \gamma^{\frac{\gamma}{\gamma-1}}\left(\frac{H}{\theta}\right)^{\frac{1}{\gamma-1}} + \sigma b - \sigma^{\frac{\gamma}{\gamma-1}} H^{\frac{\gamma}{\gamma-1}}\left(\frac{1}{\theta}\right)^{\frac{1}{\gamma-1}} - \sigma\overline{w}$$

$$= \left(\frac{\sigma^\gamma}{\gamma\theta}\right)^{\frac{1}{\gamma-1}}\left[1 - \frac{1}{\gamma}\right] + \sigma(b - \overline{w}) \tag{32}$$

Considering the specific case of $\gamma = 2$, the optimal maintenance effort, M_C^* and bribe, H^* in eq 30 may be rewritten as: $H^* = \frac{1}{2}$ and $M_C^* = \frac{\sigma}{2\theta}$. Substituting $\gamma = 2$ in equations 31 and 32, the corrupt utilities may be rewritten as:

$$U_B^C(M_C^*, H^*) = \sigma[\overline{w} - b] + \frac{\sigma^2}{8\theta}$$

$$U_P^C(M_C^*, H^*) = \frac{\sigma^2}{4\theta} + \sigma[b - \overline{w}]$$

APPENDIX C

COMPARATIVE STATICS

The politician's incentive to be corrupt, I_C, which is the difference between the utility of being corrupt and the utility of being non-corrupt. The general form of I_C is given by:

$$I_C = U_P^C(M_C^*, H^*) - U_P^{NC}(M_{NC}^*)$$

$$= \left(\frac{\sigma^\gamma}{\gamma\theta}\right)^{\frac{1}{\gamma-1}} \left[1 - \frac{1}{\gamma}\right] + \sigma(b - \overline{w}) - \overline{w}^{\frac{1}{\gamma-1}} \left[\left(\frac{1}{\theta\beta}\right)^{\frac{1}{\gamma-1}} - \frac{\overline{w}^{\frac{\gamma-2}{\gamma-1}}}{2} + \frac{T\overline{w}^{\frac{\gamma-2}{\gamma-1}}}{\beta}\right] - \left(\frac{\overline{w}^\gamma}{\theta\beta^\gamma}\right)^{\frac{1}{\gamma-1}} \quad (33)$$

The change in the incentive to be corrupt with respect to uncertainty about possible weather events, β, is given by:

$$\frac{\partial I_C}{\partial \beta} = \frac{1}{(\gamma-1)}\left(\frac{\overline{w}}{\theta\beta^\gamma}\right)^{\frac{1}{\gamma-1}} + \frac{\overline{w}T}{\beta^2} - \frac{\gamma}{\beta^{1+\gamma}}\left(\frac{\overline{w}^\gamma}{\theta}\right)^{\frac{1}{\gamma-1}} \quad (34)$$

The relative magnitudes of $\overline{w}, \beta, T$, and θ determines whether equation 34 is positive.

The change in the incentive to be corrupt with respect to the probability of detection is given by:

$$\frac{\partial I_C}{\partial \sigma} = (\gamma-1)\sigma^{\gamma-1}\left(\frac{1}{\gamma\theta}\right)^{\frac{1}{\gamma-1}} + b - \overline{w} \quad (35)$$

Equation 35 shows that the probability of detection has an ambiguous effect on the incentive to be corrupt. That is, it depends on the value of fixed bureaucratic wage relative to the probability of detection $(1-\sigma)$, bureaucrat's cost function parameters (θ and γ).

The change in the incentive to be corrupt with respect to the fixed bureaucratic wage is given by:

$$\frac{\partial I_C}{\partial \overline{w}} = \frac{\gamma}{\gamma-1}\left(\frac{\overline{w}}{\theta\beta^\gamma}\right)^{\frac{1}{\gamma-1}} + \frac{1}{2} - \left[\sigma + \frac{T}{\beta} + \frac{\overline{w}^{\frac{2-\gamma}{\gamma-1}}}{\gamma-1}\left(\frac{1}{\theta\beta}\right)^{\frac{1}{\gamma-1}}\right] \quad (36)$$

The sign of 36 is ambiguous and depends on the degree of climate uncertainty.

Expression 30 shows that the infrastructure provision under the corrupt contract is unaffected by climate uncertainty. Instead, it increases as the probability of detection, $(1-\sigma)$, and the cost-of-effort, θ, decrease. On the other hand, expression 24 shows that the infrastructure provision effort under the non-corrupt contract shows that the infrastructure provision effort under the non-corrupt contract is strictly decreasing in climate uncertainty and increases with the wage of the bureaucrat.

APPENDIX D

CORRUPTION AND INFRASTRUCTURE PROVISION OUTCOMES UNDER DIFFERENT BRIBES

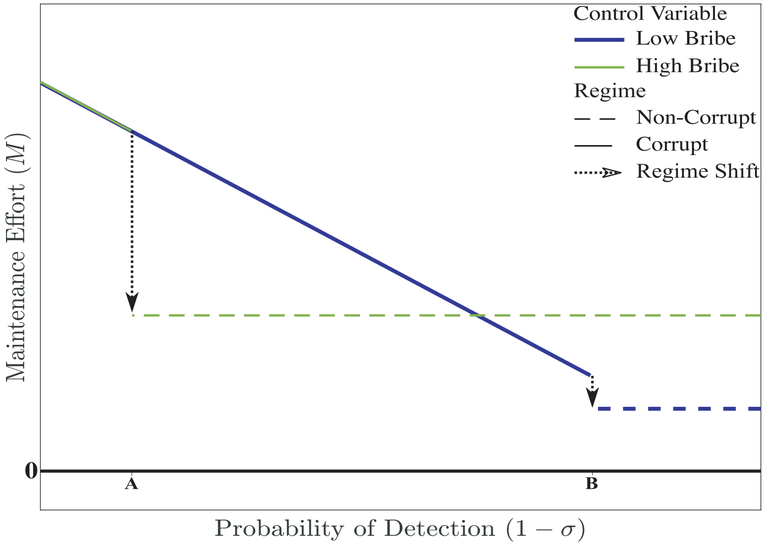

FIGURE D1 The infrastructure provision effort as a function of probability of detection in a state of high climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates low bribes and green line indicates high bribes

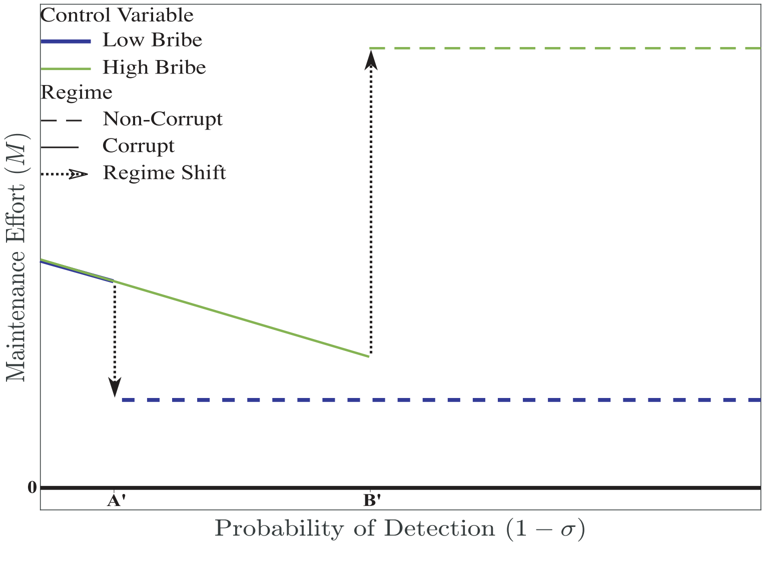

FIGURE D2 The provision of infrastructure as a function of probability of detection in a state of low climate uncertainty (low β). The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates low bribes, and green line indicates high bribes

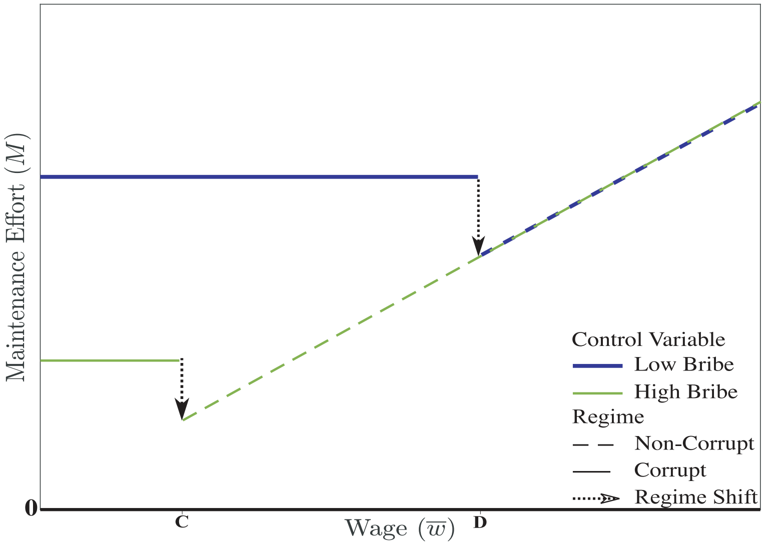

FIGURE D3 The provision of infrastructure as a function of wages in a state of high climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes respectively. The blue line indicates low bribes and green line indicates high bribes

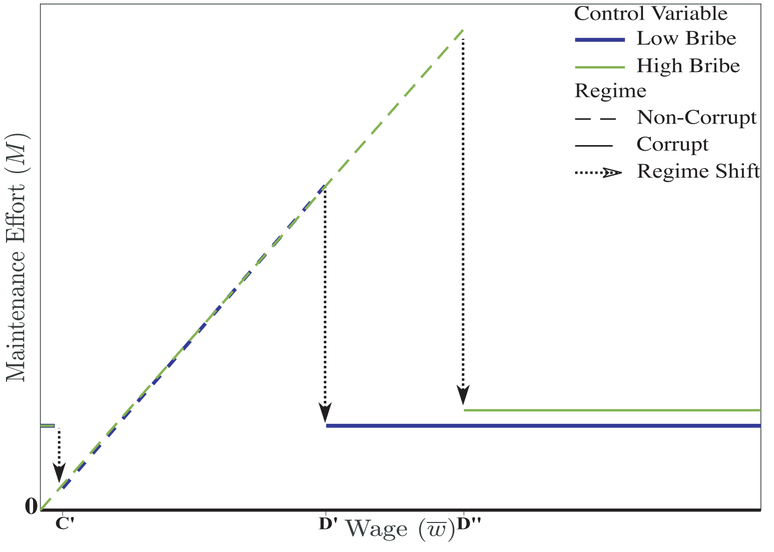

FIGURE D4 The provision of infrastructure as a function of wages in a state of low climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes respectively. The blue line indicates low bribes and green line indicates high bribes

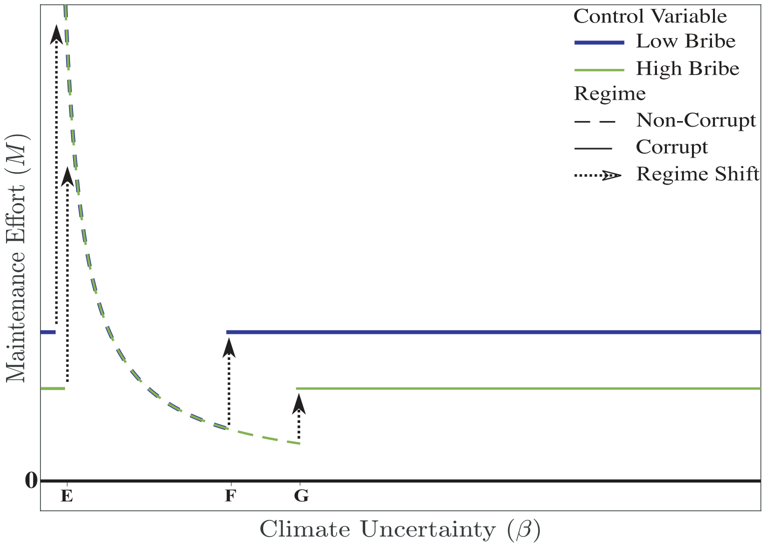

FIGURE D5 The provision of infrastructure as a function of climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates low bribes, and green line indicates high bribes

APPENDIX E

CORRUPTION AND INFRASTRUCTURE PROVISION OUTCOMES UNDER NORMALLY-DISTRIBUTED CLIMATE UNCERTAINTY

We characterize the players' beliefs over possible shocks as a diffuse prior with a normal distribution with zero mean and variance β. An increase in the value of β reflects a greater range of possible weather events so that a larger β reflects a more uncertain climate regime. This section shows the corruption and infrastructure provision outcomes for a normally distributed climate uncertainty.

Figure E1 illustrates infrastructure provision effort as a function of the probability of detection for high (green line) and low (blue line) values of wages, in a state of high climate uncertainty. Similar to the equilibrium outcomes under uniformly distributed climate uncertainty, the graph demonstrates that allowing corruption actually yields greater infrastructure provision when climate uncertainty is high. For values of $(1-\sigma) < A$, the outcome is the corrupt contract, regardless of the wage. For $A < (1-\sigma) < B$, the high-wage outcome is the non-corrupt contract, but the low-wage outcome is the corrupt contract. Finally, for $(1-\sigma) > B$, the non-corrupt contract is the outcome with either wage.

Figure E2 illustrates infrastructure provision effort as a function of the probability of detection for high and low wages, in a state of low climate uncertainty. In this setting, increasing the probability of detection makes the non-corrupt equilibrium more likely, but the effect on infrastructure provision depends on the wage. With a low wage, the non-corrupt contract is the equilibrium unless $(1-\sigma) < B'$. The infrastructure provision is highest when the monitoring effort is low under this setting. In contrast, when wages are high and climate uncertainty is low, increases in monitoring when $(1-\sigma) < A'$ will result in worse infrastructure effort. However, a large enough increase in monitoring such that $(1-\sigma) > A'$ would result in a large improvement of infrastructure maintenance effort.

Figure E3 illustrates infrastructure provision effort as a function of bureaucratic wage for a high and low probability of detection, in a state of high climate uncertainty. As the figure depicts, the politician's incentive to be corrupt decreases as the wage increases, causing a shift to the non-corrupt regime at point C when monitoring effort is high (point D when monitoring effort is low). However, sufficiently large increases in the wage can improve infrastructure provision. The figure also indicates an inverse relationship between the probability of detection and the wage. That is, a high probability of detection requires a small increase in wage to shift the system into the non-corrupt regime (point C).

Figure E4 illustrates infrastructure provision effort, as a function of the wage for high and low probability of detection, in a state of low climate uncertainty. When climate uncertainty is low, increases in the wage can cause two shifts between equilibria. At low wages, the system shifts from corrupt to a non-corrupt regime at C'. However, as wages increase, the system shifts back to the corrupt regime with a lower level of infrastructure provision at point D' (low monitoring) or D'' (high monitoring). Figure E4 also shows that as wages increase, the system shifts to corrupt equilibrium ($\delta M < 0$ and $I_C > 0$) where infrastructure provision falls. Hence, the effect of changes in the wage on infrastructure provision can only be expected to improve infrastructure within a relatively small window (C' to D' or D'') when climate uncertainty is low.

Figure E5 illustrates infrastructure provision effort as a function of climate uncertainty for a high and low probability of detection. The figure shows that corruption becomes more likely at very low levels of uncertainty ($\beta < F$). Within the non-corrupt regime, increases in uncertainty can lead to either better or worse infrastructure provision based on the monitoring effort. However, for high enough uncertainty, infrastructure provision worsens under the non-corrupt equilibrium. Figure E5 shows that as climate uncertainty increases, the incentive to be corrupt becomes positive and infrastructure provision improves under the corrupt regime. This is represented by the second regime shift at points G (low monitoring) and H (high monitoring).

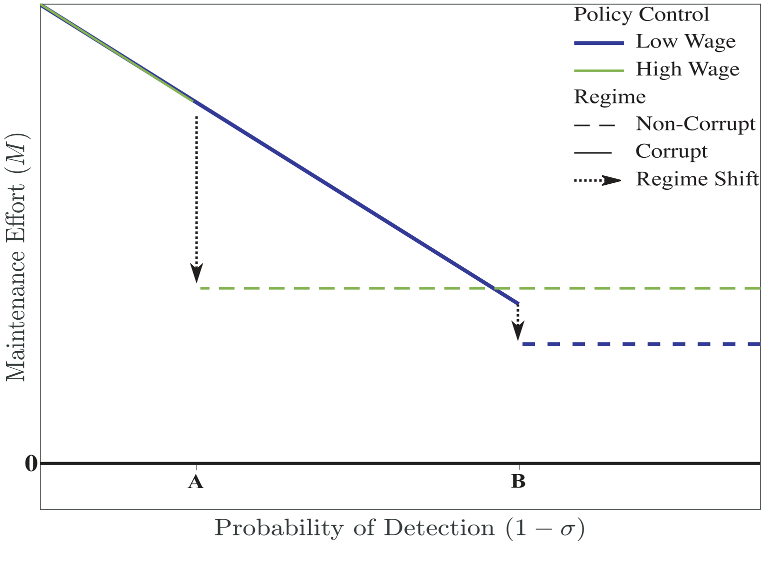

FIGURE E1 The infrastructure provision effort as a function of probability of detection in a state of high climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates low bureaucratic wages, and green line indicates high bureaucratic wages

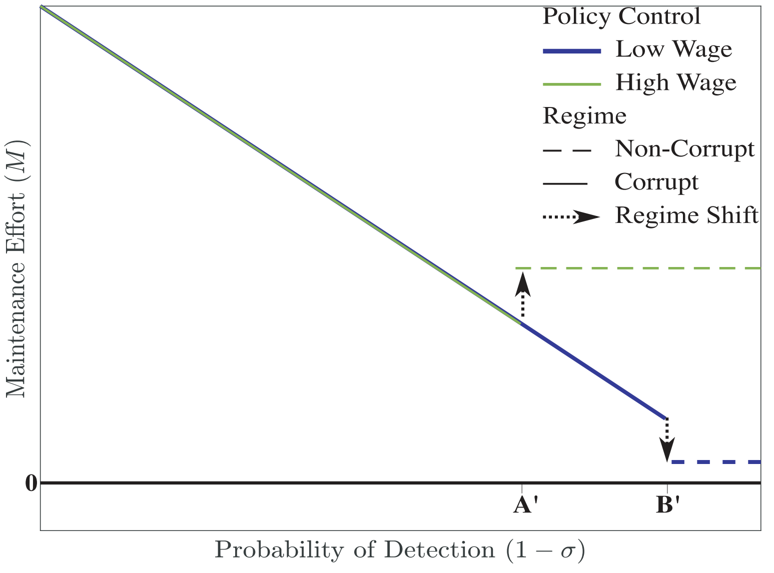

FIGURE E2 The provision of infrastructure as a function of probability of detection in a state of low climate uncertainty (low β). The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates low bureaucratic wages, and green line indicates high bureaucratic wages

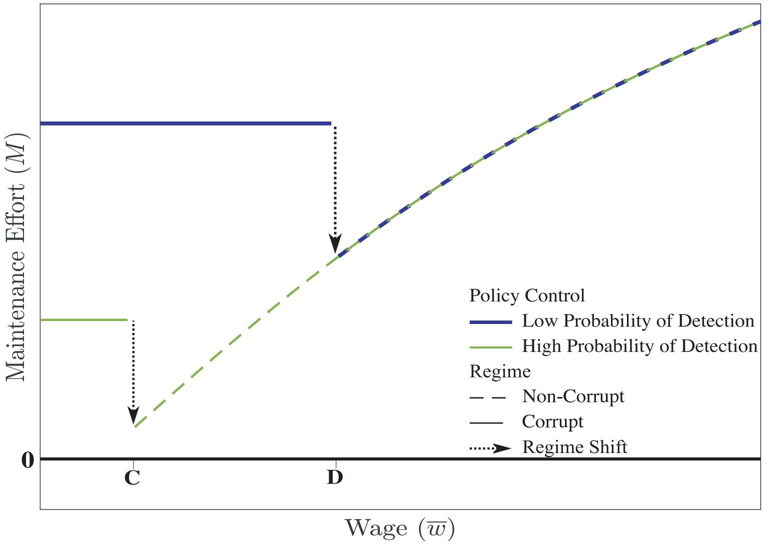

FIGURE E3 The provision of infrastructure as a function of wages in a state of high climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes respectively. The blue line indicates weak monitoring mechanisms bribes, and green line indicates strong monitoring mechanisms

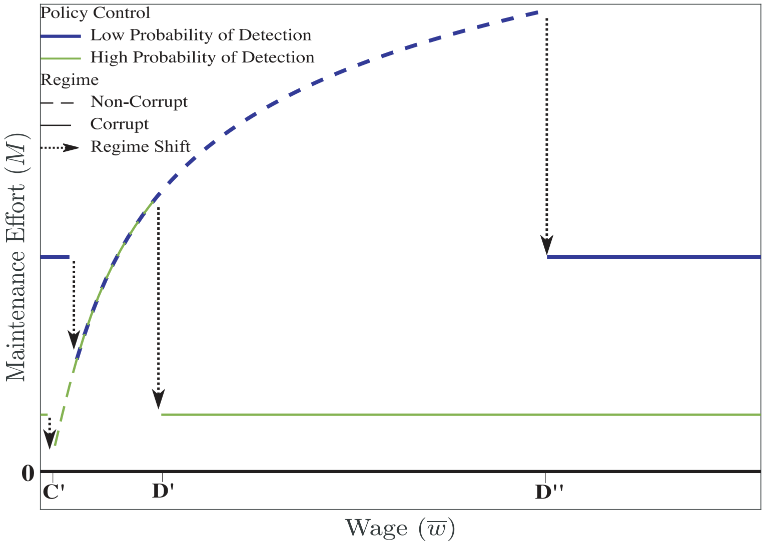

FIGURE E4 The provision of infrastructure as a function of wages in a state of low climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes respectively. The blue line indicates weak monitoring mechanisms bribes, and green line indicates strong monitoring mechanisms

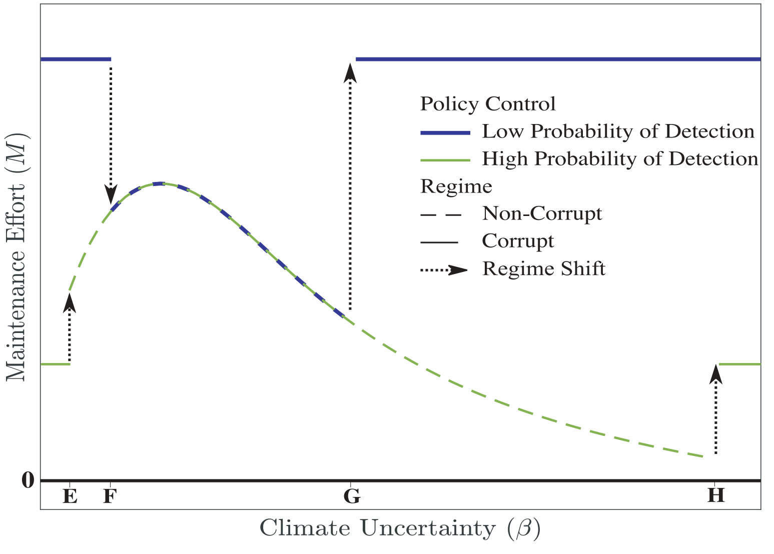

FIGURE E5 The provision of infrastructure as a function of climate uncertainty. The solid and dotted lines represent the corrupt and non-corrupt regimes, respectively. The blue line indicates weak monitoring mechanisms bribes, and green line indicates strong monitoring mechanisms