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Operations Research and Control Systems
Institute of Mathematical Methods in Economics
Vienna University of Technology

Research Unit ORCOS
Argentinierstraße 8/E105-4,
1040 Vienna, Austria
E-mail: orcos@eos.tuwien.ac.at

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Abstract

We present a novel model of corruption dynamics in the form of a nonlinear optimal dynamic control problem. It has a tipping point, but one whose origins and character are distinct from that in the classic Schelling (1978) model. The decision maker choosing a level of corruption is the chief or leader who presides over a bureaucracy whose state of corruption is influenced by the leader's actions, and whose state in turn influences the pay-off for the leader. The policy interpretation is somewhat more optimistic than in other tipping models, and there are some surprising implications, notably that reforming the bureaucracy may be of limited value if it takes its cues from a corrupt leader.

1 Introduction

There is a long tradition of and continuing interest in economic modeling of corruption (e.g., Rose-Ackerman, 2010). A recurrent theme is endogenous feedback or social interaction creating tipping points that separate multiple stable equilibria involving lower and higher levels of corruption. Multiple equilibrium models are appealing because they can explain two stylized facts without recourse to semi-tautological arguments about differences in culture or institutions, namely, there is (1) great heterogeneity across jurisdictions in the level of corruption and (2) stability over time in the level of corruption in any given jurisdiction (Dawid and Feichtinger, 1996; Andvig and Moene, 1990; Mishra, 2006).

Schelling (1978) offered what is perhaps the most famous such model, and thereby pioneered the idea of frequency-dependent equilibria in which individual incentives are a function of the aggregate level of corruption. There are other approaches. For example, Blackburn et al. (2006) model how corruption can harm economic development and low-levels of development can in turn promote greater corruption, and Mishra (2006) considers how corruption can develop via an evolutionary game. Nevertheless, we take Schelling's (1978) model as a point of departure both because it is so well known and because it was what inspired our thinking. In particular, we began by asking what a dynamic version of Schelling's model might look like.

The contribution of this paper is simply to suggest a somewhat different mechanism for producing multiple equilibria, one which has some different policy implications. We make no attempt to review empirical evidence concerning which tipping point mechanism accords best with the evidence. Nor do we suggest that the mechanism described here is in any way better than others or even that the various mechanisms are mutually exclusive. Perhaps several mechanisms play a role. Rather, we seek only to provide a concise description of this alternative mechanism.

The next section explains our model. The model takes the form of a linear-quadratic optimal dynamic control problem, so its qualitative solution structure can be derived analytically, as seen in Section 3. Section 4 concludes with the model's implications for a higher-level social planner or reformer who prefers for society to be in a low-corruption state. The social planner could be a Constitutional Convention designing the framework for a new system of government or an altruistic individual or agency that acts to monitor and respond to institutional corruption. In general, the present model offers somewhat greater optimism about the potential for a corrupt society to be pulled back to a low-corruption state.

2 The Model

Schelling's model posits many decision makers who are essentially peers, each of whom rationally makes a binary choice about whether to be corrupt or not. In our model the masses are not so strategic; they just emulate norms set by high-level leadership. Rather, in our model there is just one individual whose decision calculus is modeled in detail, namely the head or chief executive of the organization (e.g., the head of state of a country). Furthermore that decision maker's choice is not binary (be corrupt or not) but continuous (how aggressively corrupt to be, e.g., how frequently one accepts bribes).

We refer to the decision maker as the "leader" not in a Stackelberg game theoretic sense but rather just in the ordinary sense of the word. We refer to the mass of people who take their cue concerning the acceptability of corruption from the leader as the "bureaucracy".

The leader can change his/her level of corruption instantaneously; it is a control variable, u. In contrast, the culture of corruption within the bureaucracy has a certain inertia, so it is represented by the state variable, x. Corruption grows under corrupt leadership and declines under a reformer in a manner we will describe shortly.

We have in mind incorporating and contrasting two particular corruption dynamics. The first is simply that that the leader's own corrupt acts bring a direct benefit to the leader. The greater degree of his or her own corruption, u, the greater is the benefit. This could be thought of as high-level or grand corruption.

However, the high-level leader does not accept petty bribes from everyday people directly. Rather, it is bureaucrats who extract bribes from the citizenry (e.g., to overlook infractions or to approve building or other licenses). Still, a corrupt leader will expect the bureaucrats to pass along a proportion of that bribe money. These payments could be thought of as a "franchise fee" or as "protection payments" purchasing protection from the enforcement powers vested in the leader's inner circle and entourage.

Hence, the leader's revenue from corruption has two terms, one that is driven just by u and another that is an increasing function of both u and the bureaucracy's total amount of corrupt revenue (proportional to x). The latter has an interaction that makes the cross partial derivative positive, so the function is not simply additive. The simplest function that captures this is to assume this 2nd component of the leader's corrupt revenue is proportional to the product of u and x.

Both the leader's own individual corruption and the bureaucracy's corruption are costly for the leader. Participating in corrupt practices directly (u) is costly because of the risk of being caught. Presiding over a corrupt bureaucracy (x) is costly in terms of political popularity; the citizenry will blame the political leader if they are oppressed by pervasive extortion by government officials. Plausibly both costs are convex, and for simplicity we model them as being quadratic. In order to avoid the problem of specifying salvage values after some finite term of office, we abstractly imagine the decision maker has an infinite time horizon but discounted at some (possibly fairly large) discount rate r, so the objective is

$$\max_u \int_0^\infty e^{-rt}\left(\alpha ux + \beta u - \frac{1}{2}u^2 - Cx - \frac{G}{2}x^2\right) dt.$$

All of the parameters are positive except perhaps β. Parameter β is really the difference between two effects, the component of the leader's corrupt revenue that comes from bribes paid directly to the leader, not indirectly via the bureaucracy, minus the linear part of the cost of corruption (e.g., from enforcement risk). In a society whose institutions make it difficult for the leader to collect payoffs directly, so indirect collections from bureaucrats dominate, the parameter β could be negative.

The state dynamics should reflect the idea that when the leader demands a large share of the bribe revenue, that will tend to increase corruption in the bureaucracy. This could be so for multiple reasons, including simple economic necessity (need to take more bribes to have enough money to pass along), practical factors (corrupt leaders have less incentive and ability to root out corrupt bureaucrats), and moral/sociological considerations (corrupt leaders signal a culture of permissiveness with respect to corruption). Conversely, if the leader is honest, the level of bureaucratic corruption will tend to decline, but not instantaneously. If we let δ denote the rate at which corruption ebbs under a completely honest regime, this suggests the degree of corruption in the bureaucracy might obey the simple dynamic:

$$\dot{x} = u - \delta x.$$

As a matter of realism and mathematical convenience, we presume there is a limit to how corrupt the leader can be, and scale that upper bound to 1.0. So we impose a control limit $u \leq 1.0$ which, given the state dynamics, also bounds the state variable. Naturally both the state and control must be non-negative.

3 Solution

3.1 Analysis

We are considering a linear-quadratic infinite time nonlinear optimal control problem:

$$\begin{array}{ll} \max_{u} & \int_0^\infty e^{-rt}\left(\alpha ux+\beta u-\frac{1}{2}u^2-Cx-\frac{G}{2}x^2\right)dt \\ \text{subject to} & \\ & \begin{array}{rcl} \dot{x} & = & u-\delta x \\ u & \geq & 0 \\ u & \leq & 1.0, \end{array} \end{array}$$

with x the state and u the control. The current value Hamiltonian is

$$H=\alpha ux+\beta u-\frac{1}{2}u^2-Cx-\frac{G}{2}x^2+\lambda\left(u-\delta x\right),$$

so that the necessary optimality conditions become

$$\begin{array}{l} H_u=\alpha x+\beta-u+\lambda=0, \\ \dot{\lambda}=\left(r+\delta\right)\lambda-\alpha u+C+Gx, \end{array}$$

from which we derive that

$$\begin{array}{rcl} \dot{u} & = & \alpha\dot{x}+\dot{\lambda} \\ & = & \alpha\left(u-\delta x\right)+\left(r+\delta\right)\lambda-\alpha u+C+Gx \\ & = & \alpha\left(u-\delta x\right)+\left(r+\delta\right)\left(-\alpha x-\beta+u\right)-\alpha u+C+Gx, \\ & = & \left(r+\delta\right)u-\left(r+2\delta\right)\alpha x+Gx-\left(r+\delta\right)\beta+C. \end{array}$$

This gives for the $\dot{u}=0-$isocline:

$$u=\left(\frac{\left(r+2\delta\right)\alpha-G}{r+\delta}\right)x+\beta-\frac{C}{r+\delta}, \tag{1}$$

The slope is greater than δ, so the $\dot{u}=0-$isocline is steeper than the $\dot{x}=0-$isocline iff

$$\alpha>\frac{\delta\left(r+\delta\right)+G}{r+2\delta}.$$

We can find that the Hamiltonian is jointly concave in state and control iff $\alpha^2<G$.

To calculate the interior steady state $\hat{x}$ we observe that

$$\dot{x}=u-\delta x=0\Rightarrow\hat{u}=\delta\hat{x},$$

which can be substituted into (1) to obtain

$$\begin{array}{l} \left(r+\delta\right)\delta\hat{x}-\left(r+2\delta\right)\alpha\hat{x}+G\hat{x}-\left(r+\delta\right)\beta+C=0, \\ \frac{\hat{u}}{\delta}=\hat{x}=\frac{C-\left(r+\delta\right)\beta}{\left(r+2\delta\right)\alpha-\delta\left(r+\delta\right)-G}. \end{array}$$

We find that this steady state is only admissible iff

$$\beta \leq C/(r+\delta),$$
$$\alpha \leq \frac{\delta(r+\delta)}{r+2\delta} + \frac{G}{r+2\delta} + \frac{\delta\left[C-(r+\delta)\beta\right]}{r+2\delta}.$$

The Jacobian is

$$\det\begin{pmatrix} -\delta & 1 \\ G-(r+2\delta)\,\alpha & r+\delta \end{pmatrix} = -\delta\,(r+\delta) + (r+2\delta)\,\alpha - G.$$

We have instability iff

$$\alpha > \frac{\delta\,(r+\delta)+G}{r+2\delta}.$$

Hence, instability occurs if and only if the $\dot{u}=0$-isocline is steeper than the $\dot{x}=0$-isocline.
Remark. Note that this threshold is independent of the parameter β. This linear term in the cost function has therefore no influence on the stability of a steady state, although - of course - it does influence the steady state's location (and existence in the relevant region). ■

The eigenvalues are

$$\begin{aligned} \epsilon_1 &= \frac{1}{2}r + \frac{1}{2}\sqrt{(r+2\delta)\,(r-4\alpha+2\delta)+4G} \text{ and} \\ \epsilon_2 &= \frac{1}{2}r - \frac{1}{2}\sqrt{(r+2\delta)\,(r-4\alpha+2\delta)+4G}. \end{aligned}$$

We have an unstable node if

$$\frac{\delta\,(r+\delta)}{r+2\delta} + \frac{G}{r+2\delta} < \alpha < \frac{r+2\delta}{4} + \frac{G}{r+2\delta},$$

and an unstable focus if

$$\alpha > \frac{r+2\delta}{4} + \frac{G}{r+2\delta}.$$

By using the Lagrangian function

$$L = H + \nu_1 u + \nu_2(1-u),$$

where the Lagrange multipliers ν_1, ν_2 can be determined to be

$$\nu_1 = -\alpha x - \beta - \lambda \text{ and}$$
$$\nu_2 = \alpha x + \beta + \lambda - 1,$$

we can find the following steady states with active control constraints

$$\hat{x}_0 = 0, \qquad \hat{u}_0 = 0, \qquad \hat{\lambda}_0 = -\frac{C}{r+\delta}, \qquad \hat{\nu}_{01} = -\beta + \frac{C}{r+\delta}, \qquad \hat{\nu}_{02} = 0 \text{ and}$$
$$\hat{x}_1 = \frac{1}{\delta}, \qquad \hat{u}_1 = 1, \qquad \hat{\lambda}_1 = \frac{\alpha - C - G/\delta}{r+\delta}, \qquad \hat{\nu}_{11} = 0, \qquad \hat{\nu}_{12} = \frac{\alpha}{\delta} + \beta - 1 + \frac{\alpha - C - G/\delta}{r+\delta}.$$

The first of the two steady states is admissible if $\hat{\nu}_{01} > 0$ and the second if $\hat{\nu}_{12} > 0$. Both steady states are stable saddle points as the eigenvalues of the Jacobian are $(-\delta, r+\delta)$.

<table>
<tr><th>Potential for leader to exploit bureaucracy's corruption</th><th></th><th colspan="2">Direct net effect of leader's corruption on leader's welfare</th></tr>
<tr><td></td><td></td><td>Negative or modest, $\beta < C/(r+\delta)$</td><td>Very favorable, $\beta > C/(r+\delta)$</td></tr>
<tr><td>Low, $\alpha < \frac{\delta(r+\delta)}{r+2\delta} + \frac{G}{r+2\delta} + \frac{\delta[C-(r+\delta)\beta]}{r+2\delta}$</td><td></td><td>No corruption in steady state</td><td>Stable saddle
See Figure 1</td></tr>
<tr><td rowspan="2">High, $\alpha > \frac{\delta(r+\delta)}{r+2\delta} + \frac{G}{r+2\delta} + \frac{\delta[C-(r+\delta)\beta]}{r+2\delta}$</td><td>Intermediate, $\alpha < \frac{r+2\delta}{4} + \frac{G}{r+2\delta}$</td><td>3 admissible steady states: interior steady state is unstable node
See Figure 3</td><td rowspan="2">Maximal corruption in steady state
See Figure 4</td></tr>
<tr><td>High, $\alpha > \frac{r+2\delta}{4} + \frac{G}{r+2\delta}$</td><td>3 admissible steady states: interior steady state is unstable focus
See Figure 2</td></tr>
</table>

Table 1: Qualitative Behavior of Solution Depends on Parameters α and β

3.2 Characterization of Solution

This analysis implies that the qualitative structure of the solution can be completely characterized by cross-tabulating the levels of parameters α and β, distinguishing two ranges for α and two for β. Parameter α does not appear in the threshold for β. Hence, the full characterization essentially reduces to a simple 2 X 2 table, as indicated in Table 1, although the lower left hand cell is itself divided to distinguish intermediate from high values of α.

As a reminder, the interpretation of these two parameters is: (1) potential for a corrupt political leader to profit from petty bribes collected by the bureaucracy (α) and (2) the direct net benefit to the leader of being corrupt, meaning the benefit of bribes paid directly to the leader less associated enforcement risk (β).

For the numerical calculations we use the parameter values $r = 0.1$, $\delta = 0.2$, $C = 1$, and $G = 1$ and vary the parameters α and β.

We omit the picture for the upper left condition (small α, small β), where corruption essentially does not pay off. We note only that if the bureaucracy starts out sufficiently corrupt (x very large), the leader may initially pursue some corrupt activities (u is initially positive), but that occurs only in the transient; neither the leader nor the bureaucracy is corrupt in steady state.

Figure 1 shows the solution for the case where the leader does not profit so much from a corrupt bureaucracy, buth where the direct benefit from being corrupt is large (small α (=2.1), large β (=3.4)). Then a saddle point solution arises so that the dynamics are simple. For the most part, the leader chooses a level of corruption that optimizes direct considerations (net benefit of personal corruption, β, relative to costs C and G). The bureaucracy then imitates that level of corruption (x converges to the level indicated by the leader's u). There is some feedback. If the bureaucracy starts out honest, that softens

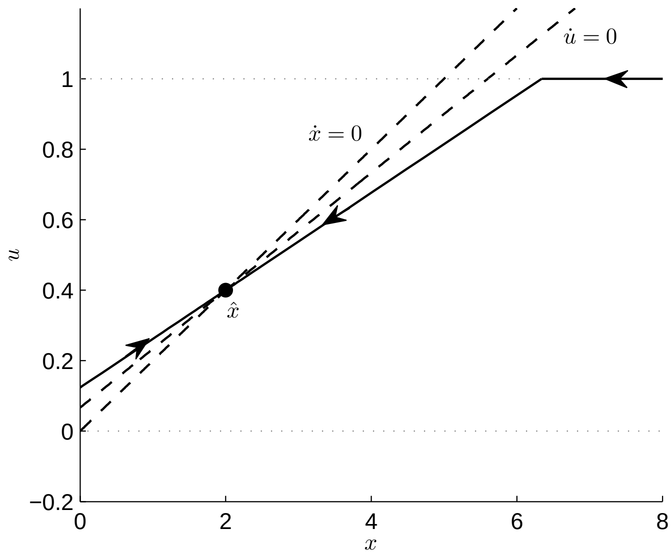

Figure 1: **Low** potential to exploit bureaucracy corruption, but leader's own corruption is profitable: saddle point equilibrium; (small α (=2.1), large β (=3.4); $r = 0.1$, $\delta = 0.2$, $C = 1$, $G = 1$)

the leader's initial degree of corruption, so u as well as x increase over time.

Both 2 and Figure 3 have a history dependent solution. Figure 2 shows a typical Skiba threshold solution for a large α(=2.18) and small β(=3). For initial conditions just to the left or right of the Skiba point, $\bar{x}$, the leader employs a level of corruption that is low or high, respectively, and the system approaches the low or maximum steady state, respectively. If one starts exactly on the Skiba point, one is indifferent between pursuing a policy that moves toward the lower or upper equilibrium. Note, however, that in this lower left case in Table 1 a Skiba point does not necessarily have to occur just because there are three admissible steady states. It might very well be that depending on the parameters it is optimal to always either go to the high or low steady state.

In contrast with Figure 2, in Figure 3 (intermediate α (=2.122) and small β (=3.32)) the (weak) Skiba point falls exactly on the steady state. In that case, the policy function is continuous, and the optimal policy when starting exactly at that point is technically to remain there forever. However, if there were the slightest perturbation to either side, it would be optimal to diverge in that direction as far as possible, not to return to the steady state.

In Figure 1 the leader's interests drove the bureaucracy's response. Here, one could say that the bureaucracy's initial state drives the leader's behavior - unless the initial level of bureaucratic corruption is exactly at the Skiba point.

The location of the Skiba point depends in expected ways on the parameters. Larger benefits of corruption (i.e., larger α (=2.18) and β (=3.4)) and/or smaller costs (i.e., smaller C and G) push the Skiba point to the left, meaning that for a broader range of initial conditions it is optimal for the leader to pull the society even further into corruption.

The role of C is interesting, though, because it does not pertain directly to the leader's

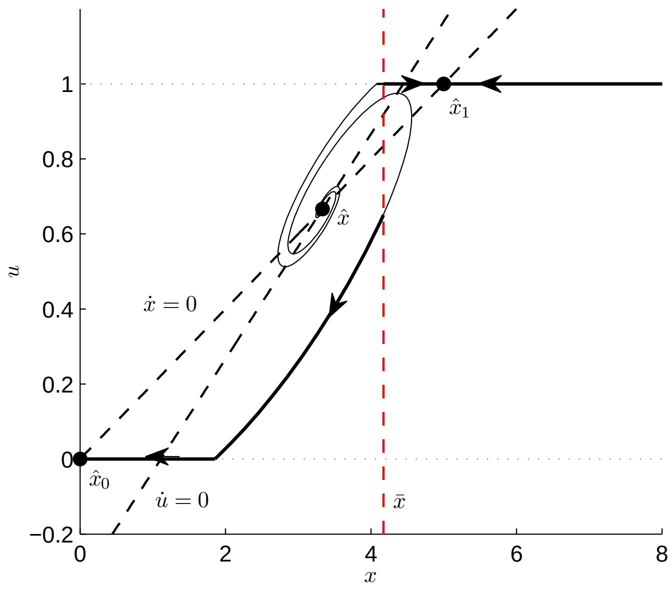

Figure 2: **Medium** potential to exploit bureaucracy's corruption and lower benefits from own corruption: interior unstable focus with Skiba point at $\bar{x}$; (large α (=2.18), small β (=3); $r = 0.1$, $\delta = 0.2$, $C = 1$, $G = 1$)

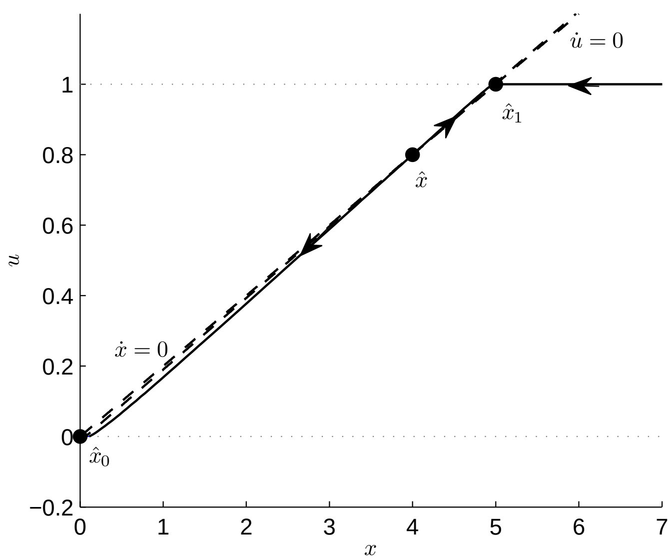

Figure 3: **Medium** potential to exploit bureaucracy's corruption but lower benefits from own corruption: interior unstable node and (weak) Skiba point coinciding with the steady state; (intermediate α (=2.122), small β (=3.32); $r = 0.1$, $\delta = 0.2$, $C = 1$, $G = 1$)

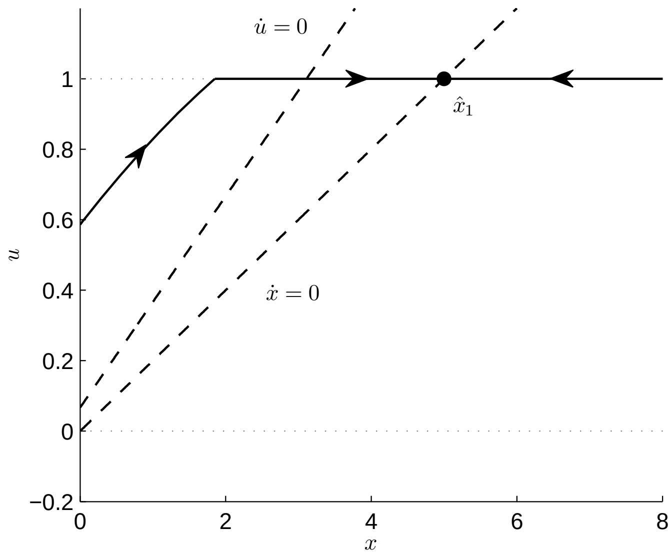

Figure 4: **High** potential to exploit bureaucracy's corruption and leader's own corruption is profitable: no interior steady state and maximum corruption; (large α (=2.18), large β (=3.4); $r = 0.1$, $\delta = 0.2$, $C = 1$, $G = 1$)

own corruption; it is the political price the leader pays for presiding over a corrupt bureaucracy. If the public can hold the political leader accountable for the bureaucracy's actions (high C), that reduces the leader's incentives for being corrupt, even if the public never detects or suffers from the high-level corruption the leader engages in directly. So within this model, one might expect democracies to be less corrupt than dictatorships.

Figure 4 shows an example of a solution for large α and large β where for all initial conditions it is optimal for the leader to be so corrupt that the system converges to the maximum level of corruption ($u = 1$, $x = 1$). The difference between Figure 4 and Figure 3 or 2's state dependence stems from the relative magnitude of β and $C/(r+\delta)$. The roles of β and C are clear. Higher benefits (β) or smaller costs (C) of corruption favor greater corruption. It is also not surprising that leaders who are more short-sighted (higher r) would be more tempted by corruption.

It is more surprising that a higher δ favors greater corruption inasmuch as δ is the natural rate of *desistance* from corruption among the bureaucracy (outflow rate from x). The reason, presumably, is that the leader can get away with a high level of corruption, u, without being punished as much or as long via the cost term Cx if $u's$ contribution to x decays quickly.

The striking implication of this observation is that when a society is corrupt at least in part because of synergistic interaction between corruption of the political leader and bureaucracy, reforming the bureaucracy may *not* be an effective reform strategy. Clearing out corrupt bureaucrats (increasing δ) may actually reinforce the strength of the high-corruption equilibrium. However, punishing the political leader for the bureaucracy's corruption (increasing C) or directly attacking the political leader's corruption (reducing β) could help.

4 Discussion

We considered a corruption model inspired by, but distinct from, Schelling's (1978) classic model. In our model the only optimizing decision maker is the senior political leader, and that leader receives two distinct types of benefits from corruption, that which depends directly and only on his or her own actions and those which are creamed from a bureaucracy that in turn collects bribes from the populace. Likewise, the leader suffers (convex) costs from both his or her own corruption and from the degree of corruption in the bureaucracy. The bureaucrats' decisions are not modeled explicitly; they take their cues from the senior leadership, adjusting the level of corruption over time to conform to the leader's example.

Structurally, four types of solutions are possible: (1) No corruption, (2) Maximum corruption, (3) An intermediate amount of corruption, and (4) Path dependency involving a Skiba point, reminiscent of the original Schelling (1978) model.

Path dependency occurs only when there is a synergistic interaction between the degree of corruption of the leader and that of the bureaucracy, such as when the leader extracts a share of the bribes collected by the corrupt bureaucracy. Path dependency, when it exists, takes the following form. If the level of corruption in the bureaucracy is initially below this critical level, then it is optimal for the leader to be relatively clean, and corruption will ebb toward zero. The decision maker may not be entirely honest; he or she might initially extract some bribes while the overall culture of corruption is still relatively high, but both the leader and bureaucracy become less corrupt over time, with the leader ceasing corrupt activity before the bureaucracy does. On the other hand, if initially the bureaucracy's level of corruption exceeds this Skiba threshold, then it is in the leader's self-interest to exploit the resulting income-generating possibility by also being corrupt, with the result that both the leader and the bureaucracy will become increasingly corrupt over time.

Schelling's model illustrated micro-motives and macro behavior, in which the collective action of many small decision makers fed back on those decision makers' private incentives. Schelling's decision makers were too small to influence the system individually, but if all such actors marched in lock step they could shape system behavior.

Here, in contrast, we model an "important" decision maker whose individual actions alone are sufficient to have macro effects. Those effects feed back on the decision maker's incentives. The result is threshold behavior and path dependency that would look from the outside very much like Schelling's model in its ability to explain great heterogeneity in corruption levels across societies at a given point of time, but persistence over time of both the lower- and higher-levels of corruption.

For any given leader, the policy conclusions are similar to those of Schelling's model. A society stuck in the high-corruption equilibrium will stay there unless and until there is some powerful change that pushes the system up and over the tipping point and down the other side. However, our model does not involve "enforcement swamping" (Kleiman, 1993, 2009), so the magnitude of the required surge may be less extreme.

Our model also admits a story of individual reformers. Suppose a reform minded individual wins political leadership, meaning someone for whom the private gains of corruption are not appealing (α and β small). If that person remains in power long enough for the bureaucracy's corruption to fall below the tipping point, then subsequent administrations may be corruption free even if they are led by people of average ethical character. Conversely, one particularly venal leader could, if in power long enough, have such a bad effect on an originally clean bureaucracy as to make high-levels of corruption a stable fixture of that society at least until an extraordinary reformer came on the scene.

So in some respects our model is slightly less pessimistic than Schelling's (1978) model regarding the prospects for pulling a corrupt society back to a low-corruption steady state. It does warn, though, that if the political leader sets the tone for the bureaucracy's level of corruption, then even if the bureaucracy's corruption synergistically enhances the leader's rewards from being corrupt, "draining the swamp" by expelling corrupt bureaucrats may not be effective. When corruption flows from the top, the reforms may need to target the top leadership.

Acknowledgments

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