The Quality of Public Investment*

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Abstract

Macro-level estimates of the productivity of public capital are typically larger than micro-level estimates. The evidence also shows large cross-country differences in the quality of public capital. A general equilibrium growth model is introduced to explain both facts. The productivity of firms specializing in differentiated intermediate inputs depends on public capital whose provision is subject to bureaucratic corruption. Higher corruption lowers the quality of public capital, discourages specialization and development. Persistent differences in this quality results from multiple equilibrium levels of corruption. Simple numerical calculations show that (i) relatively small micro-level productivity effects of public capital can generate large macro-level effects, and (ii) quality differences in public capital can substantially account for the income gap between rich and poor nations.

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1 Introduction

Conventional wisdom holds that public infrastructure capital in the form of power, transport and telecommunications, allows access to additional productive opportunities and enhances growth. At the same time, differences in the endowment of such capital are often seen as contributing to the large output and productivity differences observed across countries. Since the seminal work by Aschauer (1989), a large number of empirical studies have found support for a positive and significant contribution of public investment to the level and growth of aggregate output. The magnitudes of these contributions, however, vary considerably from one study to another because of differences in econometric methodology, measurement of physical capital, and the level of data aggregation (see Straub, 2007, 2008; Romp and de Haan, 2007, and references therein). Studies at the industry, regional, and sectoral level find much lower estimates for the elasticity of public infrastructure capital to growth as compared to macro-level studies.

In general, studies that use public investment flows (or their cumulative assets) tend to find ambiguous and negligible growth effects of public infrastructure investment, particularly for low-income countries (Easterly and Rebelo, 1993; Pritchett, 2000). The likely reason for this is that investment spending is a poor proxy for the accumulation of productive assets.[1] Poor infrastructure and ineffective use of public capital have been blamed for the differential growth performance across countries and productive investment by firms (see for example Hulten 1996; Calderon and Serven 2007; Reinnikka and Svensson 2002).[2]

It is also well known that many low-income countries are characterized by weak institutions. Several recent empirical studies suggest that deficiencies in public capital provision and its growth effects may be particularly linked to the existence of inefficient or corrupt bureaucracies (Esfahani and Ramirez, 2003; Dal Bo and Rossi, 2007).[3] This can also be seen in Figure 1, which shows a

[1] In an extensive survey of the literature, Straub (2007) finds that empirical studies that use physical indicators of infrastructure generally find a significant positive output or growth contribution of infrastructure. However, less than half of the empirical studies using expenditure-based infrastructure measures find significant positive growth effects.

[2] Hulten (1996) finds that differences in the effective use of infrastructure resources explain one-quarter of the growth differential between Africa and East Asia, and more than 40 percent of the growth differential between low- and high-growth countries. Calderon and Serven (2008) find evidence that an improved quality of infrastructure services can have a positive effect on long-run growth in Sub-Saharan African. Using firm-level data for Uganda, Reinnikka and Svensson (2002) show that poor provision of public infrastructure services significantly reduces investment in the productive capacity of firms.

[3] Esfahani and Ramirez (2003) show that the growth effects of infrastructure depend upon the strength of a country's institutions, such as contract enforcement and bureaucratic efficiency. Dal Bo and Rossi (2007) find that greater corruption is significantly associated with lower efficiency of electricity distribution.

clear negative correlation between an aggregate index of infrastructure quality and a country-wide index of the control of corruption.

This paper presents a simple framework that reconciles the contradictory empirical results mentioned above and highlights the importance of public infrastructure in creating an income gap between countries. We develop a model in which inefficient and corrupt bureaucracies interact with the provision of public investment services in their effect on the productivity of private capital and growth.

In the model, public investment reduces costs of producing differentiated intermediate inputs, thereby fostering specialization. But in the presence of corruption, the extent of specialization and private investment depend on the availability of complementary public oversight and enforcement. We argue that government oversight of bureaucrats is less effective when corruption is entrenched. Lower oversight, and the resulting higher corruption, reduces the effectiveness of government spending and leads to much lower growth than would be the case in the absence of specialization.[4] This feature of our model provides a potential explanation for reconciling the varying estimates of the elasticity of public infrastructure capital to growth found in macro-level studies as well as the smaller magnitudes found in sectoral and micro-studies.

A key feature of our framework is that the extent of corruption, the quality of public infrastructure and growth are all jointly determined. In particular, this implies that public investment is more efficient in developed relative to poorer countries. We also show that the quality of public investment can account for significant income gaps between rich and poor countries in the presence of endogenous specialization. Moreover, given that the quality of monitoring and bureaucratic oversight play a key role in the realization of investment returns in the model, our analysis has important policy implications. It implies that any scaling-up of public investment needs to be accompanied by improvements in screening, monitoring and overseeing investment decisions.

We extend Romer's (1987) framework of product specialization by introducing infrastructure as a publicly provided good that raises the productivity of intermediate inputs as in Glomm and Ravikumar (1994). Since final output is increasing in the number of intermediate inputs, public infrastructure fosters economic growth by promoting specialization. However, as in Sarte (2001), the precise growth effects of public investment and its efficiency are linked to an agency problem between the government and its bureaucracy. Public infrastructure is provided by bureaucrats, but bureaucratic malfeasance lowers the quality of public expenditures. Moreover,

[4] This is consistent with Duggal *et al.* (2007) who show that public capital, through a combination of its direct productivity effect, as well as its indirect effect through efficiency-enhancing externalities, has the potential to generate increasing returns to scale at the aggregate level.

bureaucratic decision-making entails strategic interactions that give rise to multiple, frequency-dependent equilibria associated with different incidences of corruption, quality of public infrastructure, and growth.[5]

The paper proceeds as follows. Section 2 specifies the basic model and Section 3 examines the properties of equilibrium. In section 4, we discuss the implications of our model. We conclude in Section 5 by proposing future extensions.

2 The Environment

We start by constructing a simple general equilibrium model of corruption and public capital. Time is discrete and indexed by $t = 0, \ldots, \infty$. There is a constant population of two-period lived agents belonging to overlapping generations of families. Individuals work for a unit time in youth and consume only in old age.[6] The measure of agents born every period is unity.

Households either work for firms producing specialized goods or work as bureaucrats. This is decided by a lottery before households enter the labor market. At any point in time a constant measure $m < 1$ of public works projects are in operation. Each project $j \in [0, m]$ is managed by a single official so that m also denotes the proportion of the workforce engaged in the public sector. Production of output is undertaken by firms of which there is a continuum of unit mass. Firms hire labor and rent capital from households.

2.1 Production

Economic production is undertaken in two stages (sectors). A monopolistically competitive industry first manufactures differentiated intermediate inputs that are then sold to the final goods sector. The setup of this sector closely follows Ethier (1982) and Romer (1987).

Final Goods Producers

The competitive final goods sector produces a unique consumption good using the available varieties of intermediate goods that we denote by x. The range of intermediate goods, n, is

[5] These strategic interactions have been incorporated into several models of corruption, for example, Andvig and Moene (1990). Mauro (2004) relies on strategic complementarities similar to the ones considered in our paper to explain the persistence of corruption and low growth in some countries. But he does not examine the macroeconomic implications of the quality of public investment spending and bureaucratic oversight.

[6] The assumption that all first period income is saved is made for convenience. Non-trivial saving decisions will affect steady-state income levels, but not income ratios or the productivity of public investment.

endogenous and evolves over time. At any date t, for a given n_t, the aggregate technology that combines intermediate goods into final output is constant returns to scale

$$Y_t = \left[\int_0^{n_t} x_{it}^{1-\sigma} di \right]^{1/(1-\sigma)}. \tag{1}$$

The elasticity of substitution between every pair of intermediate inputs is constant and equal to $1/\sigma$ where $\sigma \in [0, 1]$.

In the symmetric equilibrium that we will study shortly, $x_{it} = x_t$ for all t, using which final output can be written as

$$Y_t = n_t^{1/(1-\sigma)} x_t. \tag{2}$$

Consider now input demands. A perfectly competitive firm in this sector purchases $\{x_{it}\}_{i=0}^{n_t}$ at prices $\{p_{it}\}_{i=0}^{n_t}$ to maximize profits

$$\left[\int_0^{n_t} x_{it}^{1-\sigma} di \right]^{1/(1-\sigma)} - \int_0^{n_t} p_{it} x_{it} di$$

where the price of the final good has been normalized to 1. The demand for the i–th intermediate input is

$$x_{it} = p_{it}^{-\sigma} Y_t \tag{3}$$

with a price elasticity of demand of σ.

Intermediate Goods Producers

The intermediate goods sector consists of a continuum of small firms each of which manufactures a unique intermediate input. This sector is monopolistically competitive and firm entry and exit determines, in equilibrium, the range of intermediate inputs that are available for the final goods sector.

Operating a particular intermediate goods firm requires a fixed cost of φ units of the final good every period. This cost encompasses technological requirements as well as regulatory restrictions on firm entry. The production process itself is constant returns to scale in private inputs, capital (k) and labor (l):

$$x_{it} = A g_t^{\theta} k_{it}^{\alpha} l_{it}^{1-\alpha}, \; A > 0, \; \alpha, \theta \in (0, 1). \tag{4}$$

The firm's effective productivity Ag_t^{θ} depends on the technology-specific term A and on public capital externalities. Here g denotes the aggregate public capital stock adjusted for the scale of economic activity, that is, $g_t = G_t/Y_t$. In this we follow Glomm and Ravikumar (1994) to take into account congestion externalities.[7]

In any period (we temporarily drop time subscripts), a price setting intermediate goods firm hires labor and capital at the competitively determined wage rate w and rental rate r respectively to maximize operating profits

$$\Pi_i = p_i x_i - (w l_i + r k_i)$$

subject to (3) and (4). The optimality conditions

$$(1-\sigma)(1-\alpha)\frac{p_i x_i}{l_i} = w \text{ and } (1-\sigma)\alpha\frac{p_i x_i}{k_i} = r$$

imply that input costs are a $(1-\sigma)$ proportion of revenues and hence, operating profits are

$$\Pi_i^* = \sigma p_i x_i$$

at the optimum. Free entry into the i–th intermediate input sector ensures that these profits are dissipated by entry costs in equilibrium. That is

$$\sigma p_i x_i = \varphi \text{ for all } i. \tag{5}$$

It follows that

$$p_{it} = n_t^{\sigma/(1-\sigma)} \text{ and } \ x_{it} = \left(\frac{\varphi}{\sigma}\right) n_t^{-\sigma/(1-\sigma)} \text{ for all } i,$$

and that aggregate output is linear in input variety

$$Y_t = \left(\frac{\varphi}{\sigma}\right) n_t. \tag{6}$$

Going forward, it will help to keep in mind how the role of public capital departs from the existing literature. First, what matters is not investment in public infrastructure but its quality (see below). Secondly, even if each intermediate goods firm benefits only modestly from access to better infrastructure (that is, θ is relatively small), the cumulative macro impact can be large in principle. This is particularly so if the elasticity of demand for the intermediate input is relatively low and the inputs are strong complements. In that case the introduction of newer intermediate goods expands the demand for existing inputs. Higher profitability, in turn, encourages firm entry, supply of a wider range of specialized inputs and, ultimately, spurs development.

In a symmetric equilibrium where the aggregate labor supply is $1-m$ and the aggregate capital stock K, each intermediate goods firm's input demands are

$$l_{it} = \frac{L_t}{n_t} = \frac{1-m}{n_t}, \quad k_{it} = \frac{K_t}{n_t} \text{ for all } i$$

[7] That is public goods are not pure private goods, being subject to some rivalry as in Barro (1990).

using which the output of each intermediate goods firm becomes

$$x_{it} = A(1-m)^{1-\alpha} g_t^{\theta} \frac{K_t^{\alpha}}{n_t}. \tag{7}$$

Finally, anticipating the general equilibrium analysis below, note that the results above establish that wages are proportional to the degree of specialization,

$$w_t = \lambda n_t, \tag{8}$$

where $\lambda \equiv [(1-\sigma)(1-\alpha)\varphi]/[\sigma(1-m)]$.

2.2 The Government

A benevolent government collects taxes from households and allocates them towards public investment and law enforcement.

Specifically, the government hires m bureaucrats each at the market wage w to oversee the construction and management of public works projects. A bureaucrat can engage in corruption, that is, mismanage public funds by diverting some of it towards private ends. As in Blackburn *et al.* (2006), a bureaucrat who is willing to accept a salary lower than w is expected to receive compensation through malfeasance and can be immediately identified as corrupt. As a result, the government can minimize its labor costs while ensuring bureaucratic participation by setting the salaries of all bureaucrats equal to the wage paid to households.[8]

If apprehended, a corrupt bureaucrat is fined an amount equal to his salary, or equivalently, dismissed without pay. In addition, to go after the bureaucrat's appropriated funds requires legal cost that is proportional to the theft amount. In other words, an additional cost of corruption is the deadweight loss from having to spend additional resources to uncover infractions and expose them to legal proceedings. To contain the problem, the government investigates bureaucratic behavior through a costly and imprecise monitoring technology described below.

The government runs a balanced budget every period. A fraction μ of tax revenues T_t goes toward public capital projects, the remaining $1-\mu$ towards auditing bureaucrats (law enforcement). Since bureaucrats are paid w_t and m of them are recruited to manage as many projects, public capital outlays are $\mu T_t - m w_t$ with each project getting an equal share

$$q_t^j = \frac{\mu}{m} T_t - w_t, \quad j \in [0, m] \tag{9}$$

[8] This can be interpreted as an "allocation of talent" condition: the government induces potential bureaucrats to take up public office only by paying them what they could earn elsewhere (Acemoglu and Verdier, 1998).

Anticipating leakages due to corruption (see below), each project yields a quality-adjusted public capital of

$$G_t^j = \varepsilon_t q_t^j$$

where $\varepsilon_t \in [0,1]$. Since all bureaucrats face the same problem (see below), the efficiency index is same across various public works projects. The aggregate public capital stock is then

$$G_t = \int_0^m G_t^j dj = \varepsilon_t q_t \tag{10}$$

where $q_t \equiv \int_0^m q_t^j dj = \mu T_t - m w_t$.

Taxes are levied on the labor income of both workers and bureaucrats. Bureaucrats pay taxes on their legitimate labor earnings but not on misappropriated government funds because they hide such income to avoid easy detection.[9] Hence,

$$T_t = \tau w_t = \lambda \tau n_t. \tag{11}$$

Combining these relationships we get

$$G_t^j = \lambda \left(\frac{\mu \tau}{m} - 1 \right) \varepsilon_t n_t \tag{12}$$

and

$$g_t = \frac{G_t}{Y_t} = \zeta \varepsilon_t \tag{13}$$

where $\zeta \equiv \lambda \sigma (\mu \tau - m)/\varphi$.

2.3 Households

Workers

Since all households consume in the second period of life, they save their entire first period post-tax income. Workers earn only wage income so that their savings is given by

$$s_t^w = (1-\tau) w_t. \tag{14}$$

[9] Bureaucrats are also responsible for tax collection which could be subject to bribery and tax evasion (Blackburn *et al.*, 2006). But this does not arise in our model as all households have the same income and are subject to the same tax liability.

Bureaucrats

Consider next the behavior of a bureaucrat. The bureaucrat's problem here is a quite a bit simpler than Sarte (2001) or Blackburn *et al.* (2006), two papers that explicitly model bureaucratic corruption in the context of public expenditure and revenues respectively. Our objective is to parsimoniously establish that persistent differences in the quality of public capital can occur due to multiple equilibrium levels of corruption rather than extrinsic technological differences across countries.

Public works projects yield either high- or low-quality public capital, an outcome that partially depends on a bureaucrat's input. Given q funds at his disposal, the bureaucrat can invest the full amount or a portion $(1-\nu)q$ of it, where $\nu \in [0, \hat{\nu}]$ and[10] $\hat{\nu} < 1$. If he does the latter (and pockets νq), his project may yield low quality public capital. Such corruption can manifest in either of two ways. Funds earmarked for public infrastructure projects could directly end up in private pockets or revenues for public investment may be diverted to projects where bribes are easier to collect, implying a bias in the spending composition towards low-productivity projects.

In particular, for an investment of $(1-\nu)q$, the quality-adjusted public capital is

$$g = \begin{cases} \delta_H q, & \text{with prob. } 1-\pi(\nu) \\ \delta_L q, & \text{with prob. } \pi(\nu) \end{cases} \tag{15}$$

where $\pi : [0, \hat{\nu}] \to [\pi_0, 1]$, $\pi_0 \geqslant 0$, $\pi \in C^2$ with $\pi'(\nu) > 0$ and $\delta_H > \delta_L$. The expected quality of the project is $\delta_H - \pi(\nu)(\delta_H - \delta_L)$, decreasing in the theft level ν.

The quality of public capital mediated by any bureaucrat is observed only at the end of each period. The bureaucrat faces a trade-off since appropriating more funds lowers the expected quality of his public capital and, thus, raises the prospect of detection and subsequent dismissal from government service.

The government uses a simple rule-of-thumb in auditing a project whenever it is of low quality. This means $\pi(\nu)$ also denotes the bureaucrat's probability of being audited. But not all audits are successful the probability of which is ϕ. An apprehended bureaucrat is dismissed and the government's legal expenses exhaust the entire appropriated funds (νq). To avoid easy detection of illegal income even before a project is audited, a corrupt bureaucrat spends additional resources to cover his tracks. These costs are proportional to the amount of illegal income, c being the average hiding cost, and constitute yet another kind of deadweight loss due to corruption (Shleifer

[10]For instance, because there is a natural upper bound to how much the bureaucrat can keep diverting before the theft becomes obvious. This assumption ensures that some public investment occurs even when bureaucratic rapacity is at its worst.

and Vishny, 1993). Once the bureaucrat pays these costs, he is able to earn the same return r on his illegal income as on his legitimate earnings. The bureaucrat's expected income at the end of t is, therefore, given by

$$[1 - \phi\pi(v)]\,[w + (1 - c)vq]$$

which he maximizes by his choice of $v \in [0, 1]$. The associated first order condition in an interior optimum

$$1 - \phi\pi(v) = \phi\pi'(v)\left[\frac{w}{(1 - c)q} + v\right]$$

implicitly defines the bureaucratic theft level as

$$v = V\left(\phi, \frac{w}{q}, c\right)$$

which is decreasing in the probability of a successful audit and with wage compensation relative to potential rents from managing the public works project, but decreasing in the cost of hiding illegal income. For example, when the probability function takes the linear form $\pi(v) = \pi_0 + (1 - \pi_0)(v/\hat{v})$, optimal theft

$$v = \frac{\hat{v}}{2(1 - \pi_0)}\left[\frac{1}{\phi} - \left(\frac{1 - \pi_0}{\hat{v}}\right)\frac{w}{(1 - c)q} - \pi_0\right]$$

is decreasing in both ϕ and $w/\{(1-c)q\}$ and lies in $[0, \hat{v}]$ under appropriate parametric restrictions.

2.4 Corruption in Partial Equilibrium

While a bureaucrat takes the probability ϕ of being successfully audited as exogenous to his decisions, it is endogenously determined in any period. We assume that ϕ depends on two factors. It depends negatively on the average level of theft $\bar{v}$ among public officials. When other bureaucrats engage in large-scale theft of public funds, it becomes harder for auditors to detect and apprehend a particular bureaucrat (see Lui, 1986, and Dabla-Norris and Freeman, 2004).

Secondly, ϕ is influenced by the quality of law enforcement e, resources devoted towards project audits relative to their size. Recall that $(1 - \mu)T$ is allocated for law enforcement every period. Since total investment in public projects is $(\mu T - mw)$, enforcement quality is simply

$$e = \frac{(1 - \mu)\tau}{\mu\tau - m} \tag{16}$$

for all t.

Based on these we specify the probability of a successful audit as

$$\phi_t = \phi(\bar{v}_t, e_t) \tag{17}$$

where $\phi_1 < 0$ and $\phi_2 > 0$. Moreover, we require that $\phi(0, e_t) = 1$ so that in the absence of any theft, deviation by a particular bureaucrat is detected for sure if he is audited. One functional form that satisfies these properties is

$$\phi(\bar{\nu}, e) = 1 - \frac{\beta \bar{\nu}^{\theta}}{e}, \quad \theta \geqslant 1$$

We can now characterize the (partial) equilibrium level of corruption. Note first that a bureaucrat's optimal choice of ν is increasing in $\bar{\nu}$ due to a strategic complementarity. Each bureaucrat's expected returns from corruption depends on the choices made by other bureaucrats: when others engage in theft of public resources, the probability of being detected is small for a particular bureaucrat and, consequently, his incentives for corrupt activities are high. Not surprisingly this can give rise to multiple equilibrium levels of corruption.

Figure 2(a) illustrates this possibility using the functional specifications from above to construct the bureaucrat's best response function $\nu(\bar{\nu})$, given choices made by other bureaucrats, that is $\bar{\nu}$. Equilibrium levels of corruption are identified as the three Nash equilibria, $\{\nu_L, \nu_M, \hat{\nu}\}$.

As in many other models of corruption, it is straightforward to establish that the intermediate equilibrium ν_M is not "stable" under small unilateral deviations by a bureaucrat. For example, Figure 2(b) presents the bureaucrat's net marginal benefit from corruption (in partial equilibrium) for the same functional specifications. At the intermediate equilibrium, a small unilateral increase in the bureaucrat's theft level actually raises his net marginal benefit and keeps doing so all the way to the upper bound $\hat{\nu}$. It is then unreasonable to expect ν_M will be observed as an equilibrium outcome. The two extreme levels of theft $\{\nu_L, \hat{\nu}\}$ are, in contrast, robust to such deviations. Accordingly we entertain only these values as feasible equilibrium outcomes.

The exact values of the two corruption equilibria depend, of course, on functional choices. But the outcome, when there are multiple levels of corruption, is two different qualities of public capital, high and low, corresponding to $\varepsilon \in \{\nu_L, \hat{\nu}\}$. The exact equilibrium quality depends on bureaucratic expectations of corruption in government service. But it depends also on the government through its choice of μ.

In fact, conditional on multiple equilibria in corruption, an increase in the share of resources devoted to law enforcement (that is, lower μ) can eliminate both ν_M and $\hat{\nu}$. In Figure 2(a), a decrease in μ shifts down and flattens the best response function. When μ is low enough, the best response function intersects the 45^{o} line only once, at a lower ν_L. Of course reducing μ may entail an economic cost as public investment goes down, but it does not have to. If a crackdown on corruption is effective enough to switch the economy to the ν_L equilibrium, the quality of public capital may well increase even though less is budgeted for each project.

3 General Equilibrium

3.1 The Quality of Public Capital

Given the equilibrium level of corruption/theft $\nu \in \{\nu_L, \hat{\nu}\}$, we now turn to the general equilibrium analysis. For either of these two values of ν, a fraction $1-\pi(\nu)$ of projects will be of good quality since there is a continuum of these projects. From (10), the average quality of public investment

$$G_t = \lambda(\mu\tau - m)\left[\delta_H - \pi(\nu)(\delta_H - \delta_L)\right] n_t$$

leads to

$$g_t \equiv \frac{G_t}{Y_t} = \gamma\left[\delta_H - \pi(\nu)(\delta_H - \delta_L)\right],$$

via equation (6) where $\gamma \equiv \lambda\sigma(\mu\tau - m)/\varphi$. Quality-adjusted public capital is higher for lower levels of corruption and takes either of two values $g \in \{g_H, g_L\}$ given by

$$g_H = \gamma\left[\delta_H - \pi(\nu_L)(\delta_H - \delta_L)\right], \quad g_L = \gamma\left[\delta_H - \pi(\hat{\nu})(\delta_H - \delta_L)\right],$$

depending on the corruption equilibrium the economy is in.

The previous section established that it is possible to have multiple equilibria in corruption for a given pair of (w_t, q_t), both of which are endogenously determined in general equilibrium. What is relevant for a bureaucrat's incentives to be corrupt is the ratio w_t/q_t

$$\frac{w_t}{q_t} = \frac{m w_t}{(\mu\tau - m)w_t} = \frac{m}{\mu\tau - m}$$

which depends only on model parameters and is time invariant. This keeps the bureaucrat's incentives independent of time. We assume then the economy remains in either of the two corruption equilibrium every period (that is, there are no exogenous shifts in expectations from one period to another). Public capital g is time-invariant as a result and, in particular, does not co-evolve with private capital accumulation.

To determine the dynamic behavior of the economy, we express the range of intermediate goods in terms of the aggregate capital stock using (7) as

$$n_t = a g^{\frac{\theta(1-\sigma)}{1-2\sigma}} K_t^{\frac{\alpha(1-\sigma)}{1-2\sigma}} \tag{18}$$

where $a \equiv \left[\sigma A(1-m)^{1-\alpha}/\varphi\right]^{(1-\sigma)/(1-2\sigma)}$, and aggregate output as

$$Y_t = \frac{\varphi}{\sigma} n_t = \left(\frac{\varphi a}{\sigma}\right) g^{\frac{\theta(1-\sigma)}{1-2\sigma}} K_t^{\frac{\alpha(1-\sigma)}{1-2\sigma}} \tag{19}$$

A key feature of this equilibrium relationship is that the effective output elasticity of public investment $\theta(1-\sigma)/(1-2\sigma)$ exceeds θ. Recall that the direct productivity effect of quality-adjusted public capita g on a firm's output is θ. That productivity effect has a bearing on firms' decisions to enter the market for specialized inputs. Productive public investment generates a higher profit flow in the intermediate goods industry and promotes entry of newer types of goods. This specialization effect appears as the $(1-\sigma)/(1-2\sigma)$ term in the exponent of g and is increasing in σ. Since the elasticity of substitution across intermediate goods is $1/\sigma$, this implies that the effect of market entry is larger the more complementary are various intermediate goods in final goods production. We show below this specialization channel is capable of generating a significant gap between the micro- and macro-estimates on public capital.

3.2 Market Clearing

In equilibrium, a fraction $\phi(\nu)\pi(\nu)$of bureaucrats are apprehended and earn zero net income. Those not apprehended invest their earnings, both legal and illegal, in the loanable funds market. Total savings for bureaucrats is then simply the post-tax income of non-apprehended bureaucrats

$$\begin{aligned} z_t^B &= (1-\phi\pi)\left[(1-\tau)w_t+\nu(1-c)q_t\right] \\ &= \frac{1}{m}(1-\phi\pi)\left[(1-\tau)m+\nu(1-c)(\mu\tau-m)\right]w_t \end{aligned}$$

where the last equality follows from (9).

Aggregate saving comprising those of workers and bureaucrats is hence

$$z_t = \left[(1-\phi\pi)\left\{1-\tau+\nu(1-c)(\mu\tau-m)\right\}\right]w_t \equiv \Gamma(\nu)w_t.$$

Note here that corruption increases bureaucrats' saving flowing through the loanable funds market. At the same time, corruption affects the equilibrium probability that a bureaucrat is apprehended. It can be shown that this probability is decreasing in the level of theft in the high corruption equilibrium, and increasing in the low corruption one.

Finally from (8) and (18), $w_t = \lambda a g^{\theta(1-\sigma)/(1-2\sigma)}K_t^{\alpha(1-\sigma)/(1-2\sigma)}$ and the asset market clearing condition becomes

$$k_{t+1} = \lambda a\Gamma(\nu)g^{\frac{\theta(1-\sigma)}{1-2\sigma}}k_t^{\frac{\alpha(1-\sigma)}{1-2\sigma}} \tag{20}$$

by defining k as the aggregate capital stock per young household. Given an initial capital stock $k_0 > 0$ owned by the initial old, equation (20) completely characterizes the dynamic equilibria of this economy. A unique asymptotically stable steady-state capital stock exists as long as the exponent on K_t on the right hand side is less than one, that is, as long as $\alpha(1-\sigma)/(1-2\sigma) < 1$, or equivalently,

$$\sigma < \frac{1-\alpha}{2-\alpha}$$

the right-hand side of which does not exceed 1/2. We shall maintain this parametric restriction and note that since it implies $\sigma < 1/2$ it also ensures that the exponent on g in equation (20) is positive.

Substituting the steady-state capital stock into the production function for final goods leads to the following expression for steady-state output per worker

$$\bar{y} = \Phi(\nu) g^{\frac{\theta(1-\sigma)}{1-2\sigma-\alpha(1-\sigma)}} \tag{21}$$

where the constant $\Phi(\nu) \equiv \{\varphi/(\sigma(1-m)^{\alpha})\} [\lambda a \Gamma(\nu)]^{\alpha(1-2\sigma)/\{1-2\sigma-\alpha(1-\sigma)\}}$ is a function of the corruption level ν.

Corruption affects steady-state output per worker through g and $\Gamma(\nu)$. It lowers the quality of public capital, discourages specialization and thereby lowers steady-state output. Through the term $\Gamma(\nu)$, it also affects the flow of investment in private capital. But this effect is ambiguous. Recall that

$$\Gamma(\nu) \equiv [1 - \phi(\nu)\pi(\nu)] [\{(1-\tau) + \nu(1-c)(\mu\tau - m)\}] .$$

One the one hand, higher degrees of corruption mean bureaucrats appropriate more of public investment outlays which, through their saving, raises investment. On the other hand, higher corruption entails a larger deadweight loss through the $\pi(\nu)\phi(\nu)$ term which negatively affects capital accumulation. It is unclear then what the net effect of corruption would be on the Γ term. Shleifer and Vishny (1991) argue that the deadweight loss from corruption is especially large, which suggests the net effect on Γ is more likely than not to be negative.

4 Discussion

4.1 Micro versus Macro Evidence

There is a wealth of evidence to suggest that public infrastructure contributes significantly to growth of output, reduction in costs, and increase in profitability (Straub, 2007, 2008). Macro-estimates of the output elasticity of public capital tend to be larger, often substantially so, than the few micro-estimates that are available. Early estimates (Ashauer, 1989, and others) based on aggregate production function analyses report output elasticities of public capital ranging from

0.31 to 0.54. But more carefully done empirical studies point to a lower elasticity of about 0.20 to 0.30 at the national level and possibly lower at the regional level.

Estimates based on state and metropolitan level data suggest elasticities of approximately 0.06 to 0.20 (Haughwout, 2002, Romp and de Haan, 2007, Straub, 2008). Studies at the industry level are generally confined to the manufacturing sector or a specific subset of this sector. Here again, like the macro studies, estimates are relatively high. For instance, using state manufacturing data from the US over 1970-1987, Morrison and Schwartz (1996) obtain a rate of return of $20-30$ percent in the manufacturing sector. Pineda and Rodriguez (2006) use data for Venezuela to estimate the effect of public infrastructure investment on the productivity of manufacturing firms. Their finding is similar: a 1 percent increase in the allocation to public expenditures generates an increase in productivity of the manufacturing sector of between 0.2 and 0.35.

In this paper, public capital has been modeled as directly contributing to a firm's productivity. The model offers a simple intuitive reconciliation of relatively lower micro estimates of this productivity effect with relatively higher macro estimates.[11] To frame our discussion it is instructive to start with a simpler specification of public capital than in the model. The paradigm adopted by a large literature on public investment and economic growth (for example, Barro, 1990, Glomm and Ravikumar, 1994, 1999, Fisher and Turnovsky, 1998, among others) does not allow for firm entry, specifying a direct productivity effect on aggregate output.[12] In terms of our model, this is tantamount to fixing the range of intermediate goods and starting with a reduced-form aggregate technology based on equations (2) and (4):

$$Y_t = n^{1/(1-\sigma)} x_t = B g^{\theta} K_t^{\alpha} \tag{22}$$

where $B \equiv An.^{\sigma/(1-\sigma)}$ A quick comparison with the equilibrium relationship (19) shows, not surprisingly, that public capital has a larger impact under endogenous specialization. This is, of course, not surprising but it does provide a rationale for different estimates in the micro- and macro-empirical literature.

Even if the direct productivity effect of public capital is relatively small, as micro-estimates find, the macro-effects can be magnified via the effect of quality-adjusted public investment on intermediate goods specialization. The more complementary intermediate goods are, the greater this magnification effect. For instance, Hulten *et al.* (2006) using data for Indian states, find a substantial externality effect from the states' infrastructure to manufacturing productivity. For the period 1972 to 1992, they find that the growth of road and electricity-generating capacity

[11] The high estimates found in the macro literature are also likely to be driven by econometric issues, particularly endogeneity. Micro studies, on the other hand, do not pick up externalities.

[12] Few of these papers explicitly consider corruption or inefficiencies in public investment provision.

Table 1: Effective Output Elasticity of Public Capital

	$\sigma = 0.1$	$\sigma = 0.2$	$\sigma = 0.3$	$\sigma = 0.4$
$\theta = 0.05$	0.06	0.07	0.09	0.15
$\theta = 0.10$	0.11	0.13	0.18	0.30
$\theta = 0.15$	0.17	0.20	0.26	0.45
$\theta = 0.20$	0.23	0.27	0.35	0.60

accounted for nearly half the growth of the productivity residual of India's registered manufacturing.

From equation (22) above, the macroeconomic elasticity of aggregate output with respect to quality-adjusted public investment is $\theta(1-\sigma)/(1-2\sigma)$. Table 1 reports numerical values of this elasticity for various combinations of the elasticity of firm output with respect to public capital (θ) and complementarity of intermediate goods (σ). While we have some evidence on what reasonable values of θ are, empirical evidence for σ is scant. One exception is Acemoglu and Ventura (2002), who report an estimate of 2.6 for the elasticity of substitution among intermediate goods. This implies a point estimate of $\sigma = 0.38$.

Table 1 demonstrates that public capital can be quite productive in the presence of significant complementarities across intermediate goods. Even a conservative estimate of the micro-elasticity $\theta = 0.10$ implies a macro elasticity of about 0.30 for $\sigma = 0.4$, in line with some of the macro studies on the productivity of public capital.

4.2 Accounting for Income Gaps

The distinction of micro- and macro-effects of public capital has implications for income gaps. For example, embedding the simpler technology of equation (22) in an OLG economy similar to ours leads to a steady-state output per worker of

$$\bar{y} = \tilde{B} g^{\frac{\theta}{1-\alpha}}, \tag{23}$$

where the constant $\tilde{B}$ depends on B and other parameters. Compare again this equation to (21): the steady-state elasticity of public capital on income levels is higher in (21) as long as $\sigma > 0$. What this implies is that differences in the *quality* of public investment yield a larger steady-state output gap when specialization is endogenous.

We examine this issue more closely. Recall from our discussion above that two equilibrium levels of corruption in public capital provision are possible. In one equilibrium, the level of corruption is low and most public capital outlays are converted into productive capital. High theft levels in the other equilibrium imply a very low quality of public capital. Suppose we interpret these two corruption and public capital equilibria as pertaining to rich (R) and poor (P) countries. That is, suppose $g^R \equiv g_H$, $g^P \equiv g_L$. Moreover, suppose that the average rich and poor countries differ only in corruption levels and, hence, in the quality of their public investment. The question we ask is to what extent such quality differences account for observed income gaps. From (23) above

$$\frac{\bar{y}^R}{\bar{y}^P} = \left[\frac{g^R}{g^P}\right]^{\frac{\theta(1-\sigma)}{1-2\sigma-\alpha(1-\sigma)}} \tag{24}$$

The difficulty in working with this expression is that we have no way of quantitatively pinning down corruption levels in the two countries. One way around this is to look at estimates of public capital quality or efficiency and impute them directly into equation (24) above with the caveat that public capital quality can differ for reasons besides corruption (for instance, technology gaps and other institutional failures).

Two studies notably estimate the quality of public capital across countries, results from which are reported in Table 2. Hulten (1996) defines the relationship between effective and actual public capital stocks as

$$g_e = \varepsilon g$$

where ε is a measure of the average level of public capital effectiveness. His dataset covers middle- and low-income countries over the period 1970-1990. The difference between public capital as a share of GDP in the top-third richest middle-income countries and bottom third is 12.4 percent versus 8.6 percent for similar categories in low income countries. The average efficiency index for top third countries is 0.65 as opposed to 0.45 for low income countries. This gives us a ratio of quality adjusted public capital in rich versus poor countries of about 1.45.

Calderon and Serven (2004) compile data on infrastructure quality stocks across both low-income and high-income countries. Using their dataset, we can again compute the average efficiency index of infrastructure quality stocks in rich and poor countries. This gives us a ratio of quality adjusted capital stock of around 3.3 percent (see Table 2).

Assuming a range for the quality adjusted public capital of 1.5 to 3 and $\alpha = 0.3$, we can obtain steady-state predictions for output gaps between rich and poor countries for different values of σ and θ in Table 3. As can be seen, small differences in the quality adjusted public investment can result in a large dispersion in steady-state output gaps between rich and poor countries for different values of intermediate goods complementarity (σ) and the direct productivity effect of public capital (θ).

Table 2: Ratio of Quality-Adjusted Public Capital

	Average Efficiency Index		g^R/g^P
	Rich	Poor	
Hulten (1996)*	0.65	0.45	1.45
Calderon and Sevren (2004)†	−0.274	−0.899	3.28

*46 low and middle-income countries. Information on infrastructure effectiveness sorted by quartiles, (values of 1 for top and 0.25 for bottom quartiles) and average for each infrastructure sector.

†39 low income and rich (excluding upper middle-income) countries. Index of (log) infrastructure quality based on waiting years for main lines, electricity T&D losses and the share of paved roads in total roads.

Table 3: Steady-State Predictions for Output Gaps

g^R/g^P		$\bar{y}^R/\bar{y}^P$	
	$\sigma = 0.10$	$\sigma = 0.25$	$\sigma = 0.40$
		$\theta = 0.05$	
1.5	1.04	1.06	1.84
2	1.06	1.10	2.83
3	1.10	1.16	5.20
		$\theta = 0.10$	
1.5	1.07	1.12	3.38
2	1.12	1.21	8
3	1.21	1.35	27
		$\theta = 0.15$	
1.5	1.11	1.18	6.20
2	1.19	1.33	22.63
3	1.32	1.57	140.30

Moreover, Table 3 shows that differences in the quality of public investment yield a larger steady-state output gap when specialization is endogenous. This suggests that the quality of public capital potentially has significant explanatory power in accounting for income gaps across rich and poor countries.

4.3 Further Thoughts

The model provides a qualitative idea how costly corruption can be for economic development. In each type of corruption equilibrium, a marginal increase in corruption lowers the quality of public capital.[13] This has a negative impact on steady-state output. Calculations in section 4.2 show that, if quality differences in public capital mainly arise from corruption, this effect can be sizable. In fact, there is good reason to think the effect may be larger than what our calculations show.

The Dixit-Stiglitz specification of product variety posits a constant elasticity of substitution across any pair of products. In the present context this may not accurately capture the cumulative effect of public capital. Consider for a moment how public capital, for example the provision of new roads, facilitates firm entry. Areas where little efficient transportation is available have a harder time connecting to markets. Providing a modern road in such an area will lower costs of accessing these markets and establishing production centers. That in turn will require and encourage the movement of workers and traders to these new centers. That leads to a demand for housing, local markets in a wide variety of goods and services, and facilities like schools and hospitals. The cumulative (elasticity) effect of establishing that road is, hence, likely to be larger in this case than in a developed and well-settled area where the road simply adds to an existing transport network.

A simple way to capture this is to specify $\sigma(n) \in [0, 0.5]$ as a decreasing function of the variety of specialized inputs n as in Blanchard and Giavazzi (2003). This reduced-form specification captures product substitutability in a Hotelling-type model where entering firms either choose product characteristic or market location: the more diverse the existing variety of intermediate inputs, the harder it becomes for an entrant to carve out a niche in the market. In equilibrium, n will be a function of the economy's stock of private capital and the quality of public capital through a version of equation (18).

The effective elasticity of output with respect to public capital $\theta(1-\sigma(n))/(1-2\sigma(n))$ is now decreasing in n. Hence how much corruption affects output depends on the level of development

[13] A marginal increase in μ, public investment allocation, raises corruption more in the worse equilibrium where the threat of detection is lower.

and product market specialization, that is, n. By lowering the quality of public capital, corruption will now tax economic activity and output at a higher rate in developing countries where $\sigma(n)$, and the return from expanding product variety (or markets), are higher.

Indeed this line of thought also cautions against imputing rate of return estimates for public capital from industrialized countries to design infrastructure policies for poorer countries. If the dynamic effect outlined above is the more substantive way through which public capital raises productivity, it is important for regression models that estimate the productivity of public capital to take into account non-linearities.

Finally, consider what the model says about sequencing infrastructure policies. Clearly pumping public resources into infrastructure investment mediated by a corruptible public sector will yield little return. Medium and long-term returns can be raised if those resources are instead devoted towards better law enforcement, that is, in systematically targeting and prosecuting corrupt public officials. In fact, diverting resources away from public investment (lowering μ, raising $1-\mu$) can be a sensible strategy as long as law enforcement is made more effective. In the first place, this will lower incentives for corruption as there is less to steal. Secondly, it can propel the economy from a high-corruption to a low-corruption equilibrium. The net effect on public capital will be positive if this channel is strong. In that case, sequencing law enforcement before public spending on infrastructure eliminates the economic trade-off between the two, and the equilibrium switch will generate extraordinarily large returns to infrastructure investment.

5 Conclusion

We presented a growth model with specialization where the impact of public capital on growth depends on the availability of complementary public oversight and enforcement. Many low-income countries are characterized by weak public sector institutions. To the extent that these weaknesses lower the productivity and efficiency of public investment, the end result is a lower rate of return to private investment, less specialization, and hence, lower growth.

This simple framework provides potential explanations for several issues raised in the empirical literature. In particular, we show that the varying estimates of the elasticity of public capital with respect to growth in the macro literature can be explained by inefficiencies in the provision of public investment and the lack of appropriate oversight. We also show that multiple corruption equilibria, rather than technology differences, can account for the observed differences in the quality of public capital across rich and poor countries. Finally we demonstrate that the quality of public investment can account for a significant portion of cross country income gaps.

From a policy perspective, our analysis suggests that public investment, by fostering specialization and enhancing the productivity of private capital, can have significant direct and indirect growth-enhancing effects. However, the link between investment and development outcomes depends critically on the quality and efficiency of public capital. This highlights the importance of going beyond discussions of spending levels and addressing issues of the broad institutional framework underpinning the provision of investment. In particular, given the interplay between bureaucratic oversight and infrastructure outlays presented in our model, our analysis suggests that simply increasing public spending on infrastructure can be highly inefficient. Therefore, in low-income countries with weak institutions but pressing infrastructure needs, improving the quality of monitoring and bureaucratic oversight is of paramount importance to ensure that public investment spending is not wasted.

There is a renewed push in policy circles to prioritize infrastructure investment in developing countries (see IMF, 2005, World Bank, 2009 for example). If research is to inform the design of better policy, much remains to be done. While we view our paper as a useful first step, a more thorough integration of micro-level empirical studies with macro-level quantitative models is required. For instance, we made no distinction between the productivity of existing firms and those that enter or exit the market when better quality infrastructure becomes available. It is not unreasonable to expect that as better roads facilitate the entry of new firms, the increased competition displaces less productive firms from the market. If this churning effect is empirically relevant, public capital would have an impact on aggregate productivity beyond the one we capture. The economic benefit from public capital will then depend on complementary product and labor market regulations.

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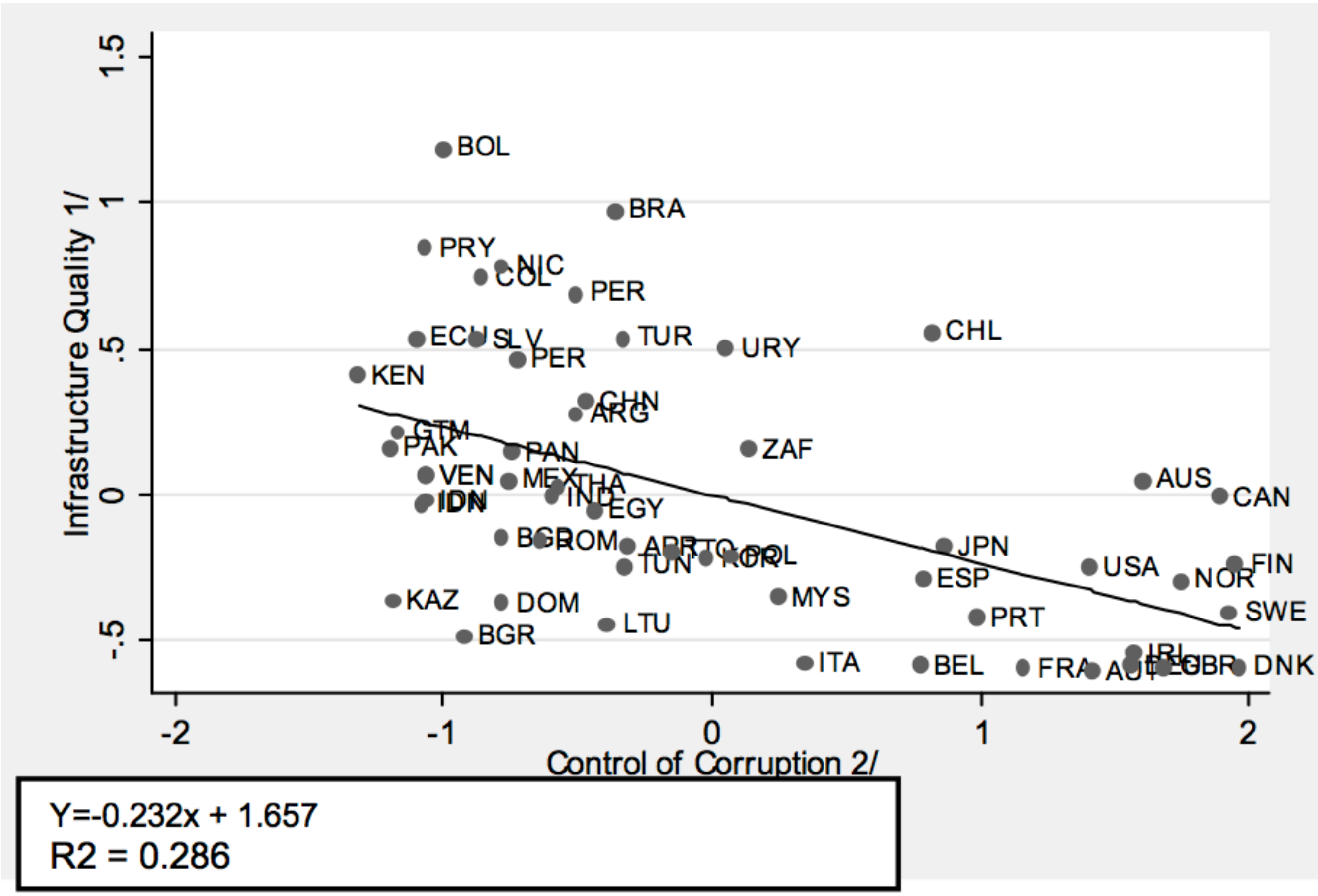

Figure 1: Infrastructure Quality versus Control of Corruption

[1]The index of Infrastructure Quality is compiled by Calderon and Serven (2004) by applying a principal component analysis to three indicators of telecommunications service quality. Higher values denote lower quality.

[2]The Control of Corruption indicator is from Kaufmann *et al* (2008) and measures the exercise of public power for private gain, including both petty and grand corruption and state capture. Higher values denote better control of corruption.

(a)

(b)

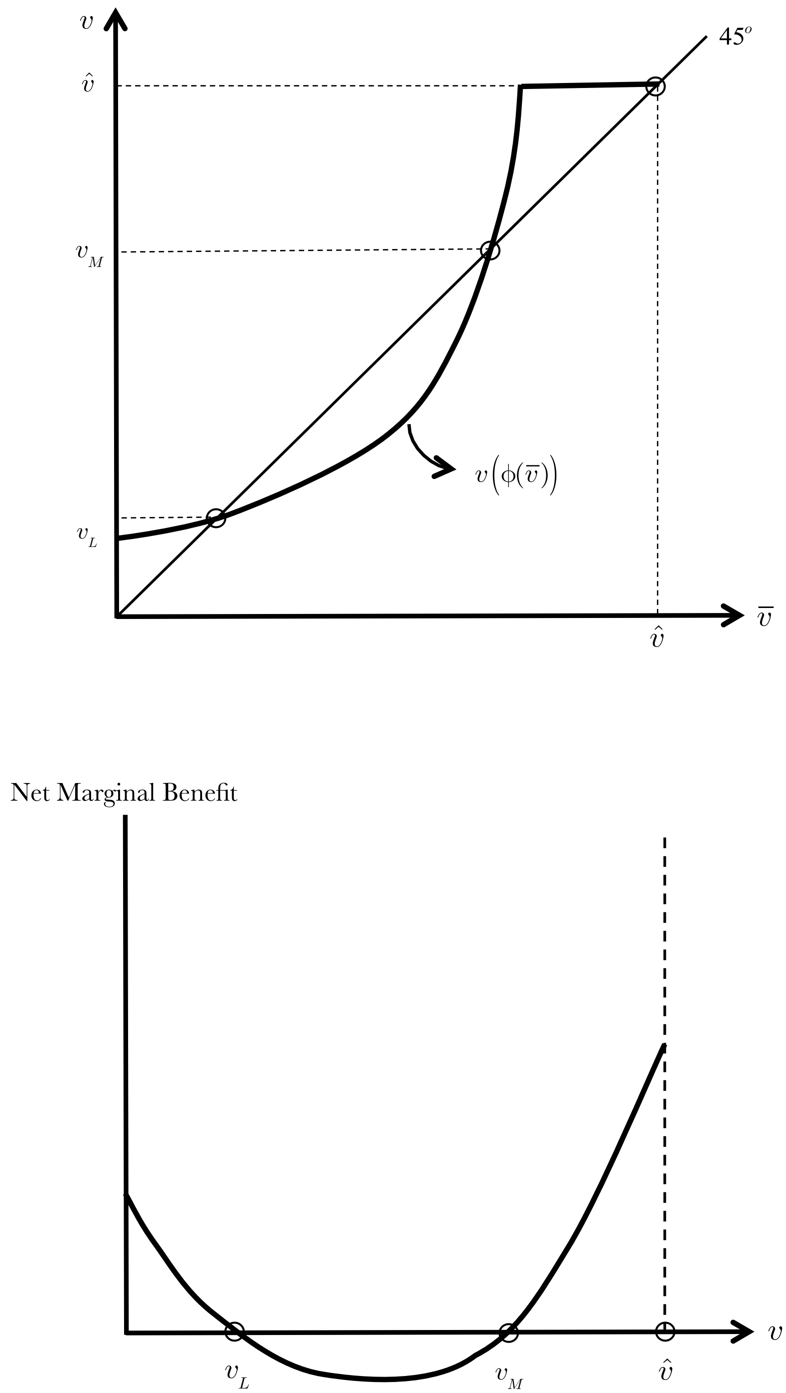

Figure 2: Multiple Equilibrium Levels of Corruption