Essays on the Performance of Manufacturing Firms in Developing Countries

by

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A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Economics

in the

Graduate Division

of the

University of California, Berkeley

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Spring 2010

Abstract

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This dissertation provides a theoretical and empirical investigation of the role of two under-explored factors in the performance of industrial firms in developing countries – one external to the firm in source, electricity service quality, and one internal to the firm, management practices.

The first chapter lays out a theoretical framework that illustrates how poor electricity service quality can have particularly negative impacts on industrial productivity, including unexpected consequences like increased market concentration and oligopolistic behavior. The key idea here is that, because firms can produce their own electricity using private generators when the public grid is down, unreliable central power systems translate the substantial economies of scale in where relatively small producers are otherwise cost-competitive. As a result, larger firms can more easily dominate markets, potentially resulting in lower output and slower productivity growth.

The second chapter turns to state- and firm-level data from India over the period 1979-2005, providing econometric estimates of the impacts of increases in electricity generation capacity on aggregate manufacturing output, employment and productivity, as well as suggestive evidence on the relationship between electricity shortages and the firm size distribution. The headline result is that a 1% increase in public sector electricity generation capacity is associated with a 0.13-0.26% increase in manufacturing output, about half of which comes from increased employment in the manufacturing sector and the remainder from increased productivity. These results put the present value of investments in public sector electricity generation capacity at roughly 2-4 times their cost.

The third chapter turns to management practices, a similarly under-studied determinant of firm performance that lies primarily internal to the firm. Using data from an experiment on the randomized provision of management consulting services to textile manufacturing firms in India, this chapter provides a detailed methodology for measuring management practices on the shop-floor as well as econometric estimates of the impact of improved management practices on firm-level productivity, quality and profitability. The econometric results confirm the commonly held suspicion among businesspeople that the quality of management matters for firm performance; the improvements in management practices induced by the treatment increased the average plant's productivity by about 15% and its profitability by about 24% per year. The chapter also offers some suggestive evidence on why firms do not necessarily rapidly adopt modern management practices despite their benefits for productivity, focusing on the notion of management as a technology which diffuses slowly via knowledge transfer.

Together, these three chapters provide a complex picture of the performance of firms in developing countries. External obstacles like poor electricity service quality broadly hinder economic growth and require improvements in state capacity, regulatory quality and the market environment to overcome. However, firms nonetheless can potentially make large gains in productivity and profitability from improving their internal systems and processes, including management practices. This story is consistent with the evidence of great competitive difficulties felt by many Indian firms struggling to compete with Chinese imports on the one hand, and the rise of great Indian multinationals like Tata and Reliance from humble beginnings as family businesses on the other.

Chapter 1

Electricity and Industrial Development

Evidence from India, 1979-2005

1. Introduction

Physical infrastructure is often cited as a bottleneck for industrial development in low-income countries. Because sectors like electricity, transportation and communications provide key inputs used by all other sectors of an economy, they may play an important catalyst role in determining aggregate productivity. The frequent power outages and voltage fluctuations that plague firms in many low-income countries result in machine downtime, damage to raw materials and capital equipment, and expensive small-scale private power generation, raising production costs for basic manufactures and rendering continuous-process manufacturing techniques and sensitive electronics unusable. The economies of scale inherent in self-provision of infrastructure services (for example, the use of private generators) creates particular cost disadvantages for small firms and may reduce competitive pressure and creative destruction. Hence the quality of public power systems may plausibly affect the average productivity and factor utilization of manufacturing firms as well as the distribution of productivity among firms.

Market forces do not necessarily deliver the socially efficient quality of infrastructure services. Infrastructure investments are characterized by enormous scale economies and high levels of systematic risk, so markets are often dominated by government or highly regulated entities and are imperfectly competitive at best. To give a high-profile example, India's electricity system as a whole has faced an average power supply deficit of 8% relative to demand over 1992-2005. This translates directly into rolling blackouts and forced outages; for example, in the summer of 2008 the dedicated manufacturing zones outside of Mumbai had no public power 1-2 days per week and faced intermittent power outages regularly. The World Bank's Enterprise Surveys suggest that manufacturing firms in India and many African countries faced upwards of 30-40 major power outages per year on average during the mid-2000s. While high costs and poor service quality have provided impetus for power sector reform programs in many developing countries, effective regulation appears to be crucial to the success of privatization and restructuring (Pollitt 1997, Zhang et al 2007).

The existing empirical literature finds strong correlations between infrastructure investment and aggregate productivity. Most developing countries experiencing rapid industrial growth in recent decades had roads, railways and power grids that worked relatively well. However, pinning down causality in cross-country work is difficult, as infrastructure investment is the endogenous outcome of a policymaking process that both depends on and influences many other economic factors, and few robust econometric approaches have been offered. In addition, no work of which the author is aware has empirically investigated the potential impact of infrastructure quality on the relative productivity of firms of different sizes or on the overall size distribution of firms.

This study uses state-level aggregated panel data and firm-level repeated cross-sections from the Indian Annual Survey of Industries (ASI), together with state-level panel data on the Indian power system from the Central Electricity Agency (CEA) over 1979-2005, to investigate the impact of electricity generation and distribution infrastructure on industrial development. It focuses primarily on electricity generation capacity of utilities (in megawatts), as insufficient electricity supply is a chronic problem in India, though it also looks at distribution-system variables like the length of the network of power lines (in kilometers) and the capacity of the network of distribution transformers (in megawatts). These infrastructure variables change over time and across states in relatively lumpy fashion as major infrastructure projects are completed. I also attempt to more directly study the impact of electricity shortages at the state level, but the data on the power supply position only covers 1992-2005.

More specifically, this study addresses two related questions:

1. What is the average impact of improvements in public power infrastructure on output, investment, employment and productivity in the Indian manufacturing sector?

2. How does the impact of public power infrastructure vary with firm size? Is there any evidence that public power infrastructure influences the firm size distribution over the medium run?

The Indian electricity system is regulated and administered at the state level, which is the relevant level of aggregation for the infrastructure and power supply data, so the first question can be addressed using the state-level manufacturing data which covers 1979-2005. The basic results suggest a link between new electricity generation capacity and increases in aggregate manufacturing output at the state level. A 1% increase in public sector electricity generation capacity is associated with roughly a 0.13-0.26% increase in manufacturing output, which arises primarily from increased labor use in the manufacturing sector and increased productivity. Attempts to link aggregate manufacturing output more directly to the shortage of electricity (or the power supply balance) using changes in generation capacity as an instrument were less successful, in part due to the much smaller dataset covering only 1992-2005.

The ideal analysis for the second question, studying whether small firms grow faster than large firms over various time horizons after improvements in the power system, is unfortunately ruled out because the firm identifiers in the Annual Survey of Industries firm-level dataset are scrambled. That is, the data are a repeated cross-section, not a true panel.[1] This also unfortunately means I cannot decompose any of the aggregate impacts above into the growth of existing firms versus the entry of new firms, which is a critical distinction for policy.

With the available data, I attempt three exercises. First, I regress firm-level productivity on an interaction between firm size (measured via inputs) and state-level electricity generation capacity, controlling for state and year fixed effects. This can be interpreted as checking whether the relative productivity of small firms versus large firms increases in states which experience more rapid increases in electricity generation capacity. I find some suggestive results along these lines with a measure of productivity based on Hsieh and Klenow (2009).

[1] To be more precise, the ASI covers the universe of registered firms above a time-varying size threshold -- currently 50 employees with power or 100 employees without power – and a sample of the smaller firms.

The estimated coefficients suggest that a 10% increase in generation capacity are associated with a 0.65-0.83% increase in TFP for very small firms, with a significant interaction term on (firm size * generation capacity) that implies the impact is 25% smaller for 150-employee firms and 50% smaller for 22,500-employee firms. However, this result is not robust to alternative measures of productivity and firm size, so the overall picture is mixed. This weak resultis not entirely unexpected, as discussed above, because smaller firms in electricity-poor environments may use technologies that are less sensitive to the quality of the power supply (e.g. Eifert 2010), and can only adjust to improvements in the power supply over the medium to long run.

Second, I split the sample of states into those which experienced significant improvements in power supply balance over 1992-2005, those which experienced significant deteriorations, and those which were relatively unchanged. I then compare the evolution of the firm-size distributions among these three groups, and find some evidence that, relative to the deteriorating-electricity states, the improving-electricity states saw an increase in density at the middle of the firm size distribution and a reduction in the thickness of the tails of the distribution. I also track the percentage of manufacturing output accounted for by the largest 1% of firms among these three groups of states, and find that this share decreased by about 10% in the improving-electricity states relative to the deteriorating-electricity states over 1992-2005. One interpretation of these findings is that the long-run improvement in the electricity supply leveled the playing field, allowing more mobility through the firm size distribution and challenging the dominance of large firms. However, this interpretation is tentative because larger states are more likely to be in the "deteriorated-electricity" sample, raising questions about what other dynamics might be at work here. This highlights the importance for future research of being able to link firms across years in large, census-style firm datasets in developing countries.

Section 2 links this study to the broader theoretical and applied literatures on macroeconomics and development, illustrating why one would expect the electricity sector to play a particularly important role in influencing aggregate productivity. Section 3 introduces the econometric methodology. Section 4 presents the primary results. Section 5 discusses costs and benefits of public investments in power generation capacity in India and briefly reviews the evidence on the potential of regulatory reform to facilitate private investment. Section 6 concludes.

2. Theoretical Background

Understanding the sources of the enormous disparities across countries in output per worker is one of the most high-profile research topics in economics. The dominant approach has been to write down a one-sector, two-factor model and hypothesize about the sources of large differences in total factor productivity, the model's residual. Leading candidate explanations include variation in economic policies and institutions, termed "social infrastructure" by Hall & Jones (1999). These explanations are powerful, but require economic mechanisms that translate institutional failings into large differences in aggregate productivity. This study provides one such mechanism.

Specifically, the cost and quality of intermediate inputs plays an important role in the productivity of firms and industries as typically measured by economists. Sectors which produce hard-to-substitute inputs used throughout the economy therefore have an outsized impact on aggregate productivity. Infrastructure sectors like electricity provide a leading example. Furthermore, because these sectors tend to be characterized by huge economies of scale and are heavily regulated or dominated by the public sector, market forces do not ensure socially efficient levels of quality. Rather, the quality of public sector institutions and regulations play a major role. Hence the economic importance of infrastructure provides one plausible channel for the much-discussed impact of institutions.

2.1 Intermediate inputs and substitution possibilities

The approach taken by Jones (2007, 2009) provides a nice theoretical framework for understanding why infrastructure sectors like electricity may play an outsized role in determining aggregate productivity. While most macroeconomic models include only labor and capital as factors of production, around half of real-world firms' costs are associated with intermediate inputs and services produced by other firms, creating the potential for upstream-downstream linkages among sectors. For example, a wide range of industries use steel as an intermediate input in production, so the presence of a high-quality, low-cost steel industry reduces the costs of downstream industries.[2] This is true in large part because of technological complementarities: the auto industry cannot readily substitute other inputs for steel when producing cars. Intermediate input linkages generate multiplier effects in aggregate productivity. Jones (2009) gives the example that low productivity in the power sector increases costs in banking and construction, which in turn increases the costs of building dams and power plants, further increasing costs in electric power.

Upstream-downstream linkages driven by technological complementarities represent an important type of interdependency among firms, one which channels resources and income growth towards areas with already-vibrant industries.[3] Put another way, there may be cheap labor in rural Africa, but the sparseness of local industries means that cheap labor is combined with high-cost, low-quality inputs and services, and the output is inevitably high-cost and low-quality. Many industries require specialized raw material and service inputs or workers with very specific skills, and cannot easily shift towards other inputs when prices change (Kremer, 1993). Infrastructure services like electricity and transportation are required by most or all industries and are not very substitutable for other factors of production.

The issue of complementarities in production extends to the *quality* of inputs as well as the quantity. In a manufacturing value chain with just-in-time input-output management, sub-

[2] Many intermediate inputs are sold on competitive global markets, which in a frictionless world would eliminate complementarities and linkages as a source of cross-country income differences. However, transport costs, trade restrictions, bureaucratic import procedures and search costs keep those markets from equalizing access to inputs for firms in different countries. Other key inputs and services are inherently non-traded, like transport.

[3] This is one channel for the agglomeration externalities and density effects emphasized in Ciccone and Hall (1996) and Krugman (1991).

standard quality of a shipment of key inputs needed for an intermediate processing task can put most of the firm's downstream activities on hold. A plant operating a continuous-process technology cannot make up for the lack of power during half of the day by buying more electricity during the other half of the day. Delays at the local port make a firm unable to meet overseas orders reliably and quickly, reducing the effective quality of its products. In all these examples, lower quality of key inputs reduces the marginal returns to other factors of production in a way that cannot easily be avoided by reshuffling the input mix.

One subtle issue here is the difference between substitution possibilities in the short run and the long run. A firm with an installed capital base, production technology and management structure may have very limited ability to change its input mix in the short run, but over some years it could redesign its production processes, bring in new technology and equipment and retrain its workforce. It could also alter the design of its main product line or move into other product lines in similar industries in such a way as to economize on "problem" inputs.

Such possibilities may diminish, but certainly not eliminate, the importance of cross-sector linkages. It is not always easy to find appropriate new technologies. If steel prices skyrocket, automobile manufacturers can research new composite materials to use in place of steel, but this process is long, costly, uncertain and rife with externalities. Using alternative technologies may also have dramatic implications for productivity and product mix. Technologies which are relatively insensitive to the quality of electricity inputs (e.g. hand-powered and basic mechanical techniques without sensitive machinery or electronics) tend to be associated with lower productivity. They also tend not to be associated with high-value-added industries and products; for example, manufacturing semiconductors or high-value chemicals requires a level of precision and quality control attainable only through the use of computer-controlled equipment.

Another relatively subtle issue is that in some cases firms can in principle respond to the high price and low quality of a key input by producing that input themselves. In most cases in-sourcing is not a useful way to deal with major shortcomings in input availability. If a garment firm's textile inputs are expensive and low quality, it is probably so in part because the key inputs for textile production are also expensive and low quality, so the garment firm is unlikely to be able to run an upstream textile plant much more efficiently than the existing textile firms. In other cases firms can potentially improve on the status quo, for instance by using a portable generator or hiring a contractor to fix a road. In these examples firms incur an up-front cost in order to change the effective prices and qualities of the inputs available to them. Sometimes externalities make in-sourcing impractical: a firm might pay to fill in potholes on nearby roads, but will not contribute to a fund to fix highways because it internalizes too small a share of the benefits. In other cases, especially in infrastructure services, in-sourcing may be practical but is associated with large economies of scale. From a small 2-kW diesel generator to a large 2,000-kW unit, fuel efficiency of generators varies by a factor of two and the purchase price per kW of capacity varies by a factor of six, creating dramatic economies of scale in self-generation of electricity. This implies that poor-quality public power supply may slant the industrial playing field towards larger firms which can more cost-effectively supply their own electricity, even in industries where otherwise economies of scale are minimal (Eifert, 2010).

Firms can collaborate to produce key inputs in cases where externalities or scale economies are present. The aforementioned highway fund might be run by a well-organized consortium that can monitor and enforce such contributions from many firms. Firms might buy large generators and sell electricity to large blocks of their neighbors; such competition with the public power utility is often prohibited by law in poor countries, but small firms may still find ways to share generators with their neighbors and reduce their costs. However, collective action problems are often difficult to overcome in the volatile environments with weak contracting institutions, and practical levels of collaboration among firms still may not be able to achieve the scale necessary for low-cost self-provision of important inputs. In the end, empirical research is the only way to evaluate the magnitude of the cost burdens and productivity shortfalls imposed on firms by weaknesses in upstream sectors.

This logic is particularly important with respect to sectors whose output is utilized as inputs throughout the economy, sometimes referred to as *general purpose technologies* (GPT). The depth and breadth of the downstream linkages created by GPT sectors like electricity, telecom and IT cause them to play important catalyst roles: a price increase in the electricity sector raises costs and prices in many sectors, and eventually raising the prices of inputs used in the electricity sector, spurring on a vicious cycle. The intensive use of GPTs like electricity and IT in modern technologies and high-value industries implies that the quality and price of these key inputs may play an important role in technology diffusion.

2.2 Electricity in developing countries

The implications of these dynamics for economic development are strong. Infrastructure sectors often have the characteristics of natural monopoly and hence are dominated by government monopolies or heavily regulated private firms. The lack of market discipline puts a premium on the capacity and willingness of governments and bureaucracies to implement high-quality regulation and oversight, which is too often lacking in poor countries. Infrastructure sectors are also generally non-tradable; firms cannot import their electricity or transport services from countries where power grids work and roads are repaired, so they are stuck with the quality of locally available inputs.

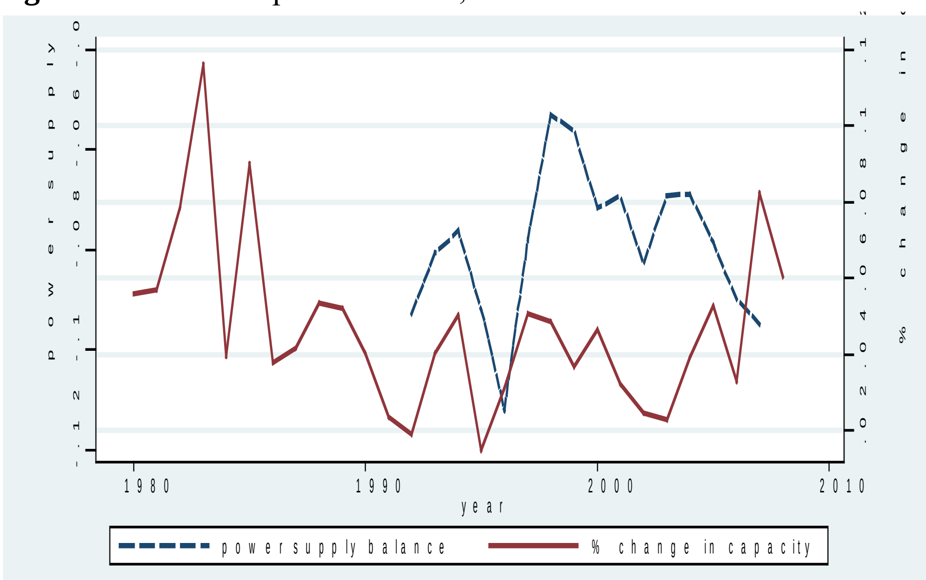
The low quality and high costs associated with key infrastructure sectors in many poor countries provides a plausible explanation for large shortfalls in aggregate productivity. Dysfunctional electricity grids and communication systems, roads full of potholes, unreliable railways and inefficient ports dramatically raise the costs of industrial firms, directly as well as indirectly through effects on upstream sectors. If a power monopoly fails to invest enough in generation capacity and the rate of power outages increases, the costs of a large range of industrial sectors rise, which in turn raises the price of the inputs produced in those sectors, which in turn raises costs throughout the economy. The poor availability of key GPT inputs may also help explain why modern production technologies are slow to diffuse into poor countries; without a reliable electricity supply many continuous-process or electronics-using technologies may be simply unusable. Via these mechanisms, the political economy dynamics emphasized by studies of policies and institutions can generate large differences in per capita income across countries.

India provides a stark example of a large developing country with a chronic electricity problem. The India-wide power supply balance, or electricity supply deficit relative to demand, averaged about -8.5% between 1992 and 2007, with a brief improvement in the late 1990s followed by a steady deterioration since. This corresponds to a similar average rate of load-shedding (rolling blackouts). A recent study by the Manufacturers' Association for Information Technology and Emerson Power estimated that Indian businesses lost Rs 43,205 crore (about 1% of GDP) in FY09.[4]

Frank Wolak (2008) describes the bleak situation of the Indian power system as follows:

> "It is difficult to imagine more adverse initial conditions. Tariffs are set significantly below the average cost of supplying power for all customer classes […] Technical line losses are among the highest in the world and theft of power is rampant […] The transmission network has limited transfer capacity across regions of the country, which can often leave significant excess generation capacity in some parts of the country that cannot be used to meet demand in other parts of the country […] Private sector participation by foreign and domestic firms has declined substantially because of the much-publicized difficulties the SEBs have in fulfilling their payment obligations under long-term power purchase agreements […] Commercial losses to the Indian electricity supply industry during 2001-02 were estimated to be equivalent to 1.5 percent of India's GDP."

Figure 1. India-wide power balance, 1992-2007



[4] Study available at http://www.mait.com/admin/press_images/press27may09.htm

2.3 Existing empirical evidence

There is a literature that uses aggregate data across countries or states to study the effect of infrastructure or public investment on macroeconomic outcomes; see Munnell (1992) and Grammlich (1994) for surveys. Early studies found large returns on public infrastructure investments, e.g. Aschauer (1989a, 1989b, 1989c), but suffered from omitted variables and simultaneity problems like the broader cross-country literature on economic growth. Subsequent work allowed for state and time fixed effects and spatial correlation, recognized various scale and homogeneity properties and dynamics, and used more disaggregated data, finding smaller but more robust returns to public sector investments. Morrison and Schwartz (1996) find significant returns to infrastructure investment in state-level panel data from the United States for 1970-87. Cohen and Paul (2004) estimate a structural model which characterizes private cost savings and underlying input demand effects from public infrastructure investment, using state-level US data on prices and quantities of aggregate output and inputs and finding that cross-state spillovers from infrastructure investment result in substantially increased estimates of cost savings. Recent research also looks at effects of the growth of specific infrastructure sectors, including telecommunications (Roller and Waverman, 2001) and information technology (Greenstein and Spiller, 1996), finding positive impacts on aggregate productivity.

There is relatively little research on infrastructure and development. Esfahani and Ramirez (2003) study the relationship between infrastructure investment and economic growth across a large cross-section of countries, finding substantial impacts of power and telecommunications sectors, but leveraging a structural model heavily for identification. Fedderke, Perkins and Luiz (2009) provide a VAR time-series analysis of the relationship between infrastructure investment and economic growth in South Africa over 1875-2001, finding the public stock of infrastructure generally and electricity generation specifically to increase GDP growth.

Several recent papers study the impacts of policies on economic performance across Indian states, mostly focusing on labor market regulation, industrial de-licensing and trade liberalization. Besley and Burgess (2004) show that Indian states with more pro-worker labor market regulations experienced slower growth of output and employment in manufacturing over 1958-1992. Aghion et al (2008) show that the effects on manufacturing output of dismantling the extensive system of licensing was greater in states with pro-employer labor market regulations. Sharma (2008) find that Indian manufacturing firms which benefitted from industrial de-licensing in the 1980s performed better after trade liberalization in the 1990s.

3. A simple model

This short section aims to fix ideas and make more precise some of the statements above about impacts of public grid downtime on firm output and firms' ability to respond using private generators. Unfortunately a fully specified dynamic industry equilibrium model that included electricity service quality as an additional state variable would be quite intractable, as the industry state would be high-dimensional and non-stationary.

3.1 Static model with electricity

Consider a simple model of a firm responding to imperfect power supply. The key feature of this model is adherence to the physical reality that, in the case of electricity, quantity and quality are not substitutable at all in production. When a firm's production technology requires electricity as an input, if power from suppliers is unavailable over some time interval then the firm cannot produce during that interval unless it is generating its own power. This is not consistent with typical approaches to modeling input quality, e.g. via a production function of the form $Y(t) = f\left(K(t), L(t), Q(t)\cdot E(t)\right)$.

Rather, consider the following approach. Let *Q(t)* be an indicator function which is equal to 1 if public power is available at time *t* and 0 otherwise; let *G(t)* be an indicator function for whether the firm is operating a generator at time *t*. Consider a firm's output and costs over the time interval $[t_1, t_2]$:

(1) $$Y(t_1,t_2) = \int_{t_1}^{t_2} Q(t) f\left(A(t), K(t), L(t)\right) + \int_{t_1}^{t_2} G(t)(1-Q(t)) f\left(A(t), K(t), L(t)\right)$$

(2) $$C(t_1,t_2) = \int_{t_1}^{t_2} Q(t)\left(rK(t) + wL(t) + pE(t)\right) + G(t)(1-Q(t))\left(F + rK(t) + wL(t) + vE(t)\right) dt$$

Here p is the price of electricity from the public grid, $v > p$ is the marginal cost of private generation, and F is the per-unit-time fixed cost of a generator (e.g. rental).[5] If we assume that productivity, capital and generator ownership is fixed over the interval $[t_1, t_2]$ but that firms can adjust labor freely in response to power availability, then we can write these expressions in more convenient discrete time notation:

(3) $$Y(t) = Q\cdot f\left(A, K, L_1, E_1\right) + (1-Q)G\cdot f\left(A, K, L_0, E_0\right)$$

(4) $$C(t) = rK + Q\cdot\left(wL_1(t) + pE_1(t)\right) + (1-Q)G(t)\cdot\left(F + wL_0(t) + vE_0(t)\right)$$

$Q = \int Q(t)\, dt$ is the fraction of the time interval that public power is available, $\{L_1, E_1\}$ and $\{L_0, E_0\}$ denote the constant flow rate of labor and electricity per unit time when public power is available and not available respectively, and we have normalized the length of the period to 1.

In this model, when $Q < 1$, firms that do not use generators do not produce during the fraction *(1 - Q)* of time when public power is unavailable. To be conservative, here we assume they

[5] A more realistic model would involve firms purchasing generators of different capacities, where larger generators have lower purchase costs per kW of generation capacity and greater fuel efficiency.

can freely adjust labor, and hence not incur wage costs when the public grid is down[6], but capital stock is assumed to be fixed on this time horizon and user costs incurred. Without private generation, in order for a firm in a power-scarce environment to produce the same quantity as an otherwise identical firm in a $Q = 1$ environment, the former must own more capital which it operates less hours during the working week. This corresponds to the author's experience with medium-sized textile and garment manufacturing firms in Maharashtra, which are often shut one or two days a week on power rationing days.[7] Unexpected shutdowns are more deadly, potentially damaging machines and raw material, but we do not model the distinction here.

Firms which own generators can produce when the public grid is down, but incur higher costs, on the order of $(v-p)$ per unit of electricity. With increased marginal cost, firms with generators may alter their production activities when public power is unavailable, e.g. running only their less-power-intensive machinery. Letting P denote the price the firm receives for its output, in this simple model the firm's inputs of labor and electricity solve:

$$(5) \qquad f_L(A,K,L_1^*,E_1^*) = f_L(A,K,L_0^*,E_0^*) = w/P$$

$$(6) \qquad p = f_E(A,K,L_1^*,E_1^*) < f_E(A,K,L_0^*,E_0^*) = v/P$$

Condition (6) along with usual assumptions on the production function implies that the output loss for firms with generators is positive as firms cut production when running on their own higher-cost power. In practice, the extent to which this is true depends on the ability to adjust the input mix over a relatively short time horizon given their production technology. In industries where production processes are relatively rigid and all parts of the process must be run simultaneously, firms may be unable to adjust in this way, hence maintaining their output levels during power outages but incurring higher costs which may result in lower equilibrium output.

Let π denotes profit and $\mathbf{X}_\mathbf{t}^*(G)$ the optimal choice of flexible inputs conditional on G. If firms can costlessly adjust their capital stocks and generator use period-by-period, then:

$$(7) \qquad Q \cdot f_K(A,K,L_1^*,E_1^*) + G(1-Q) \cdot f_K(A,K,L_0^*,E_0^*) = r/P$$

$$(8) \qquad G = 1 \Leftrightarrow \pi\left(\mathbf{X}_\mathbf{t}^* \mid G=1\right) > \pi\left(\mathbf{X}_\mathbf{t}^* \mid G=0\right)$$

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[6] This assumption is reasonable if power outages are regular and pre-scheduled, e.g. no power Saturdays between 8am and 6pm. However, areas with chronic power shortages also often have unexpected outages whose timing and length is not known a priori, so firms have a difficult time avoiding incurring labor costs via advance planning. If firms have limited ability to adjust labor during power outages, the cost impacts of poor-quality electricity supply will be greater, and the factor substitution effects (away from capital and towards labor) will be more muted.

[7] Anecdotal evidence and references in newspaper articles suggests this is common throughout India, though I have been unable to find more systematic data on .

Condition (7) implies that, all else equal, firms facing greater public power shortages will use less capital if they rely on the public grid because they incur the user costs of capital even when their plant lies idle without electricity. Condition (8) and the fixed cost *F* together imply that larger firms (e.g. in a model of monopolistic competition, those facing greater demand at a given price) will have a greater propensity to own generators because the extra *(1-Q)%* output they can produce outweigh the cost of the generator. Their average costs will also be lower than their smaller counterparts for the same level of productivity because of the economies of scale created by *F*; this result will be stronger the lower is *Q*.

To summarize, lower *Q* (a greater shortage of centrally supplied electricity) should reduce output and capital intensity, and possibly labor absorption depending on the substitutability of labor and capital.[8] This impact arises through a combination of a reduction in efficiency (machines sitting idle while the public grid is down) and higher marginal costs, and should be stronger for smaller firms because of scale economies in generator use.

3.2 Industry dynamics

In a more realistic dynamic model with adjustment costs for capital and generator ownership and imperfect financial markets, another interesting dynamic would arise. Small firms need retained profits in order to invest and grow, but if the availability of public power is poor enough, below a certain size threshold firms may be unprofitable due to the large amount of lost output if they do not use a generator and the high unit cost of electricity if they do use one. This may prevent small firms from growing to become large even if they are otherwise productive enough to compete at scale. A fully-specified dynamic equilibrium model that illustrates this point would not be very tractable[9], but I will briefly pursue the point for greater clarity.

Let $\pi^*(A,K,G) \equiv \max_{\{L,E\}}\{\pi(L,E \mid A,K,G)\}$ denote the profit a firm earns in equilibrium given optimal choice of labor and electricity inputs conditional on productivity, capital stock and generator ownership. Let $\chi^k(K,K')$ and $\chi^g(G,G')$ be adjustment cost functions which define the cost of expanding from capital stock *K* to *K'* and of going from generator ownership state *G* to *G'* respectively. Finally, let $\phi(K,G)$ be the scrap value of the firm. The Bellman equation for the firm's dynamic maximization problem is:

$$(9) \qquad V(A,K,G) = \max_{K',G'}\left\{\pi^*(A,K,G) - \chi^k(K,K') - \chi^g(G,G') + \beta E\left[V(A',K',G')\right]\right\}$$

[8] In general equilibrium labor use should increase due to shifts towards more labor-intensive technology.

[9] A dynamic industry model with heterogeneity in firm productivity and assets suffers from the curse of dimensionality. In particular, the state vector of the model includes the state of every firm in the industry, and with time-varying variables of interest (e.g. electricity service quality) the distribution of productivity and assets will be necessarily non-stationary. See Benkard, Weintraub and Van Roy (2009) for a detailed discussion of the issues involved.

The firm's optimal choice of capital investment, generator ownership and continued market participation implies the following three conditions:

(10) $$\chi_{k'}^{k}\left(K,K'\right)=\beta E\left[\pi_{k}^{*}\left(A',K',G'\right)-\chi_{k}^{k}\left(K',K''\right)\right]$$

(11) $$G'=1 \Leftrightarrow \chi^{g}(G,G'=1)+\beta E\left[\pi^{*}(A',K' \mid G')-\chi^{g}(G'=1,G'')\right]>0$$

(12) $$K'=G'=0 \quad \Leftrightarrow \quad V\left(A,K,G\right)<\phi(K,G)$$

Condition (10) says that the incremental cost of capital investment must equal the expected discounted profit generated by that investment next period plus the shadow value of owning the extra capital. Convex adjustment costs imply that the firm will limit the speed of its expansion, even if it would ideally like to be much larger given its productivity and demand. A similar dynamic arises with managerial span of control issues, financing constraints, and so forth. The point here is that potential entrants in a market often cannot instantaneously scale to a large size, but must build up their operations, production systems and organizational capabilities over time.

If adjustment costs for generators are modeled with a gap between purchase and sale prices, then condition (11) says that (i) firms will buy generators if the additional profit made in equilibrium when owning a generator plus the shadow value of generator ownership in the next period exceeds the cost of acquiring the generator, and (ii) firms that already own generators will keep them if the additional profit plus the shadow value of ownership exceeds the sale value. Because the key determinant of the profitability of generator ownership is a firm's size, it may not be cost-effective for a new entrant which has not yet built up a large capital stock due to the adjustment costs imposed by rapid growth.

Condition (12) says that a firm exits the market if its present value is otherwise below its scrap value. If Q is low enough, there may exist a capital stock level $\underline{K}$ such that $K<\underline{K} \Rightarrow \pi^{*}\left(A,K,G\right)<0$, e.g. the firm is unprofitable at its current size. This will likely occur where (11) is not satisfied and the firm is too small to cost-effectively use a generator. If financial markets are perfect and $V\left(A,K,G\right)>\phi(K,G)$, e.g. the firm is productive enough that the future discounted profits it generates once it reaches adequate scale overwhelm its current losses, then the firm will be able to acquire financing. However, with imperfect capital markets the firm may not be able to generate enough retained earnings to invest in order to grow to a profitable size. Meanwhile, large firms (e.g. those which have already accumulated a large capital stock) will be able to cost-effectively use generators and make profits. Depending on the nature of costs and demand, small entrants with higher productivity than some profitable incumbents may nonetheless be unable to generate enough retained earnings to reach a profitable scale, restricting the dynamics of aggregate productivity growth.

One implication of this story is slower growth of output and productivity as a result of power shortages. Another implication is that in equilibrium power shortages may skew the firm size distribution towards large firms which can produce their own electricity cost-effectively and micro firms which use non-electricity-dependent technologies. A third implication, which we unfortunately cannot pursue in the empirical work below given the lack of firm-level panel data, is a lower propensity of small firms to grow into medium-sized and large firms.

4. Empirical methods and data

The discussion above suggests two main lines of empirical investigation. First, are improvements in public power infrastructure associated with increases in aggregate output, factor accumulation and productivity at the state level? Second, is there any evidence that smaller firms benefit disproportionately from improvements in public infrastructure?

4.1 Data

The electricity data comes from the annual reports of the Indian Central Electricity Authority (CEA) for 1979-2005. The data is at the state-year level which corresponds to the administration of the Indian power system. The most important variables include public sector power generation capacity in megawatts; hydroelectric generation capacity in megawatts; and the power supply position in percent, which as per CEA methodology is measured by total power availability less estimated power requirement divided by power requirement (all in megawatts). Other variables which have spottier availability but are used in some places below include the total capacity of distribution transformers (in megawatts) and the total length of power lines (in kilometers).

The aggregate output, capital stock and labor force data comes from several sources in order to achieve coverage for the period 1979-2005. Specifically, we use aggregated ASI data available from Indiastat for 1992-2005; ASI and census of industries data from Besley and Burgess (2004) for the period 1979-1987; and firm-level ASI data for the period 1988-1991.

The firm-level data come from the Indian Annual Survey of Industries (ASI) and cover 1988-2004 with several missing years in between. The ASI is a census of all firms above a certain size threshold (typically 50-100 employees, but the threshold varies over time) and a representative sample of the rest. This data does not cover the large number of micro-firms in the informal manufacturing sector, which accounts for probably about 30% of manufacturing output (see Ministry of Statistics and Program Implementation 2006).[10] Because the smallest, informal firms in India (encompassing an estimated 15 million firms employing 30 million people) rarely use powered equipment, the short-run impacts of power infrastructure estimated in this paper are not likely to extend to this group.[11] However, the question of whether small firms using hand-powered technologies might respond to a reliable power

[10] More details, including the state-level dataset, are available upon request from the author. The firm-level data are available for purchase at http://www.mospi.nic.in/stat_act_t3.htm; they are covered by a strict confidentiality policy.

[11] See Nataraj 2010 for a detailed study merging data on registered and unregistered firms in India. She reports that about 5% of sole proprietorships and 30% of larger informal enterprises use electric power, compared to 93% of formal sector enterprises.

supply in the long run by adopting higher-productivity electricity-using production technologies is a very interesting one, albeit outside the scope of this study.

4.2 Aggregate impact of public infrastructure

The first part of the empirical investigation focuses on aggregate state-level panel data. Here we approach the main question of interest in two different ways:

- What is the impact on aggregate manufacturing output of increases in public sector generation capacity and the growth-accounting decomposition of that impact?

- What is the impact on manufacturing output of power shortages (power supply position), treating generation capacity as an instrumental variable?

The first approach is more of a reduced-form, as generation capacity affects industrial outcomes via improvements in the availability and cost of electricity to end users. It is worth pursuing in addition to the latter because, while the latter is perhaps more conceptually attractive, the data on output and generation capacity cover 1979-2005, while that on power supply position only goes back to 1992.

4.2.1 Electricity infrastructure and aggregate manufacturing output

Do expansions of public power infrastructure increase aggregate output, and if so through what mix of productivity gains and increased factor demand? Recalling the simple model above, one might expect a relatively immediate impact of better power availability to arise through greater labor use (as plants with a policy of shutting down when public power is not available can operate for more hours) and through greater productivity (as startups, shutdowns and equipment damage are reduced). Increases in investment are also plausible as firms' marginal costs fall, particularly if there is some additional complementarily between electricity supply quality and capital productivity. Longer-run impacts might be expected via capital accumulation and via transition to higher-productivity, electricity-reliant technologies, but the methods used here will not identify such impacts.

To address this question, we use a standard production function approach augmented by infrastructure variables and other controls. Letting Y, K and L denote value-added, fixed capital and labor in logarithms, we can write the following system of equations:

(13) $Y_{st} = TFP_{st} + \alpha_k K_{st} + \alpha_l L_{st} + \phi_s + \varphi_t + \varepsilon_{st}$

(14) $K_{st} = \mathbf{X}_{st}\boldsymbol{\beta}_k + \phi_s^k + \varphi_s^k + \varepsilon_{st}^k$

(15) $L_{st} = \mathbf{X}_{st}\boldsymbol{\beta}_l + \phi_s^l + \varphi_s^l + \varepsilon_{st}^l$

(16) $TFP_{st} = \mathbf{X}_{st}\boldsymbol{\beta}_a + \phi_s^a + \varphi_s^a + \varepsilon_{st}^a$

This system is estimated in first differences using a Seemingly Unrelated Regressions (SUR) systems estimation technique that accounts for the correlation among the errors across equations. We alternatively use direct estimation of the production function parameters (**α**) and the standard assumption of capital and labor shares of 1/3 and 2/3, respectively.[12]

The interpretation of the identification conditions here is straightforward: changes in the stock of infrastructure, e.g. completions of power plant construction projects, should not be themselves affected by state-level manufacturing outcomes or correlated with other omitted variables that drive aggregate manufacturing output or factor demand at the state level. This is a reasonable assumption as infrastructure projects, while initiated by political and bureaucratic decisions, are generally large multi-year undertakings that owe a great deal to engineering factors, delays and cost overruns in their final completion date.[13] For example, over five Department of Power planning cycles between 1956 and 1989, additional public sector capacity completed fell short of capacity originally planned and budgeted for by nearly 40% on average, ranging from 31% over 1978-83 to 51% over 1969-74. Of 36 thermal power plants built over this period, the average construction delay was 14.6 months with a range of -4 to 40 months; of 13 hydro projects, the average delay was 54 months, with a range of 18-108 months.[14]

There are three main infrastructure variables of interest here: installed generation capacity (in mW), the length of power line networks (in km), and the distribution capacity of transformers (in mW). The main focus is on generation capacity, despite the conceptual importance of the distribution network, because it is a much cleaner indicator of what the power sector can deliver (e.g. the length of the power line network may be a better indicator of the power system's penetration into remote rural areas than its ability to deliver adequate electricity to industrial zones in major metropolitan areas). Control variables include rainfall, which in India is usually found to be a major determinant of agricultural productivity and aggregate demand, and an indicator for major flooding (which in India can be extremely destructive). We also try interacting rainfall with hydroelectric generation capacity. All specifications contain year fixed effects to clean out the effects of the Indian business cycle and other common shocks.

First, Table 2 presents the single-equation results for net value added in manufacturing, e.g. estimation of $Y_{st} = X'_{st}\beta + \phi_s + \varphi_t + \varepsilon_{st}$ in first-differences. Column (1) just includes (log) generation capacity as well as its lag in case there are some delayed effects in the addition of new plants to the grid. The coefficient on generation capacity is 0.258, corresponding to a roughly 0.26% increase in manufacturing output per 1% increase in capacity, and is significant at 5%. Column (2) adds the distribution variables (power lines, transformer capacity), which have small and insignificant coefficients; the coefficient on generation capacity falls to 0.136 and becomes insignificant. Interaction effects between capacity and the

[12] Dholakia (1996) estimates factor shares for the Indian economy over 1960-1992. Across all sectors, he finds a 61% labor share, 15% land share and 24% capital share. If we hold land aside and adjust labor and capital shares up in proportion, this leaves a 71% labor share and 29% capital share, quite close to the common 2/3, 1/3 rule of thumb for industrialized countries.
[13] Electoral cycles are not a problem here because of year fixed effects and similar state election timing.
[14] As reported in Surrey (1988) from the Indian 1984-85 Annual Plan.

distribution variables are not significant (not shown). This raises some questions about the robustness of the results due to multicollinearity, given the large increase in the standard error on generation capacity when including the distribution variables, so in the policy analysis we often return to this lower coefficient estimate to be conservative. Column (3) removes the distribution variables and adds a control for rainfall, which is a major driver of aggregate demand in India; the coefficient is positive and significant, and that on generation capacity remains close to its original size. The effect of interacting rainfall with hydroelectric capacity goes in the expected direction but the standard errors are large.

Table 3 presents the results for the full system, reproducing column (1) from Table 2 and then adding equations (14)-(16). The decomposition results are not estimated that precisely, except for the labor impact component, but the results suggest that manufacturing investment, employment and productivity are all boosted incrementally by greater electricity generation capacity. The coefficient on manufacturing employment is large and highly significant, implying a 0.163% increase in labor absorption after a 1% increase in generation capacity. The impacts on productivity and capital accumulation are lower, around 0.10% for a 1% increase in capacity. In a static model of monopolistic competition with an elasticity of substitution of -3,[15] the coefficient on output in the range of 0.15-0.25 implies that a 10% increase in public generation capacity reduces firms' marginal costs by around 0.75-1.25%. The result that labor accumulation is one of the strongest and most precisely estimated channels of impact is consistent with the simple model traced out in Section 3.1, in which deteriorating electricity supply results in idle capacity during power outages.

These results are somewhat robust to alternative specifications, e.g. including lags of the variables of interest and including control variables. However, the sample is not huge and it does matter (for example) how outliers are treated. In the results above we trim the top 1% and bottom 1% of year-on-year changes in the dependent and independent variables of interest; if we do not trim outliers the coefficients on generation capacity become smaller and the standard errors rise, rendering the results insignificant at traditional confidence levels (not shown).

It is worth noting that, while the Indian electricity system is administered at the state level and fragmented in terms of distribution, so that the impact of new generation capacity should primarily be felt in its home state, but there is still some inter-state and inter-regional transfer of electricity. As such, we might expect the total economic impact of the addition in capacity to be greater than the estimates above. I did try including the generation capacity of neighboring states as an additional regressor, but the coefficients were economically small and statistically insignificant (results not shown).

[15] This corresponds to a 33% markup over marginal cost and is the value used by Hsieh and Klenow (2009) in their seminal study of Indian manufacturing productivity. With an elasticity of substitution of -5 and the coefficient estimates above, a 10% increase in public generation capacity would correspond to

Table 2. Electricity infrastructure and net value-added, first-differences regression

	(1)	(2)	(3)	(4)
Generation capacity, mW	0.258**	0.136	0.247**	0.222*
	(0.119)	(0.147)	(0.119)	(0.132)
(One-year lag)	-0.017	-0.013	-0.014	-0.012
	(0.033)	(0.033)	(0.033)	(0.033)
Power line network, km		0.041		
		(0.042)		
Transformer capacity, mW		-0.013		
		(0.024)		
Rainfall, cm			0.065	0.018
			(0.044)	(0.080)
Rainfall x hydro capacity				0.009
				(0.010)
First-differences	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y
Years	1979-2007	1979-2007	1979-2007	1979-2007
Observations	391	360	375	353
R-squared	0.093	0.110	0.104	0.106

* All continuous variables are in logs. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 3: Channels of Aggregate Impact, first-differences regression

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Value added	Fixed	Employment	TFP[1]	TFP[2]
Generation capacity, mW	0.247**	0.096	0.163***	0.030	0.090
	(0.119)	(0.128)	(0.053)	(0.143)	(0.158)
Rainfall	0.065	0.015	0.003	0.073	0.055
	(0.044)	(0.047)	(0.020)	(0.053)	(0.058)
First-differences	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
Years	1979-2005	1979-2005	1979-2005	1979-2005	1979-2005
Observations	375	360	375	360	360
R-squared	0.104	0.095	0.264	0.209	0.216

* All continuous variables are in logs. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.2.2 Power supply position

The channel via which one expects public sector electricity generation capacity to affect economic outcomes is the availability or shortage of power. The CEA collects data on the power supply position, or the (percent) difference between the available electricity supply and forecasted electricity demand. A substantial deficit in the power supply position indicates that the state power utilities are consistently generating too little electricity to meet demand, translating into power-rationing in the form of rolling or forced blackouts.

The obvious econometric problem is that the power supply position in equilibrium is itself a function of industrial outcomes, as rapid growth in production increases overall electricity demand and exacerbates the power deficit. Changes in infrastructure variables – the commissioning of new power plants and the mothballing of old plants, and extension of the network of power lines and transformers – effectively provide shifts in the electricity supply curve[16], allowing identification for the impact of the power supply position. The other instrument used here is an interaction between rainfall and hydroelectric generation capacity. Rainfall itself is a control variable in all the regressions, as it plays a major role in determining agricultural incomes and aggregate demand.

The relationship between in-state electricity generation capacity and the power supply position is slightly subtle. Each state has its own dedicated capacity, receives some electricity from central government plants and other states, and sends some electricity out to other states. Letting EA denote electricity supply available, ER denote electricity requirement and NET denote net inter-state electricity transfers (all in kW), we have $PSP_{st} = (EA_{st} + NET_{st} - ER_{st}) / ER_{st}$. Available electricity supply in turn equals available capacity times the capacity utilization rate less all technical and non-technical distribution losses, or $EA_{st} = C_{st} \times U_{st} \times (1 - L_{st})$. In a perfectly integrated system, a new power plant's output could just go to a general pool via net transfers and not have any differential impacts by state regardless of its location. However, the Indian power system is administered and regulated at the state level, and each state's authorities are primarily responsible for supplying their customers. Interstate distribution infrastructure is fragmented to the point that it is expensive or impossible to move power from some areas to others, and increased capacity in one state is not immediately met by proportionately increased demands for transfers to other states. In the end it is an empirical question how much the local power balance improves when local generation capacity expands. Data and timing issues aside, the coefficient on log capacity in a power supply position regression pins down how much net power outflows from the state are triggered by an increase in available local capacity.

Table 4 presents the first-stage estimates of the impact of changes in the state-level infrastructure stock on changes in power supply balance, with successive columns gradually introducing additional instruments and controls. The first panel (4a) restricts the sample to observations which also have the output data needed for the IV regressions; the second panel

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[16] This language is not meant to imply that the electricity market is competitive. The primarily state-owned power sector faces prices fixed by regulation and a mandate to supply as much demand as possible at these prices.

(4b) includes additional state-year observations with no available output data, including for smaller states prior to 1987. Interestingly, the most robust result is the positive relationship between the power balance and lagged increases in electricity generation capacity. Estimates of the contemporaneous relationship are consistently positive and of similar magnitude to the lagged relationship, but not statistically significant. This contrasts somewhat with the results in Tables 2 and 3, where the contemporaneous relationship is important and lags small and insignificant. Unfortunately the overall power of the instruments is modest, with F statistics ranging between 2.44 and 2.94 for the sample which overlaps with output data. This foreshadows the relatively imprecise results for the instrumental variables estimation.

Table 5 presents the instrumental variables estimates of the system (13)-(16) where power supply balance is the independent variable of interest and the best-F-statistic instrument set from Column (2) in Table 4. Unfortunately none of the coefficients are statistically significant; the two TFP variables even have opposite signs, and the standard errors are extremely large.

This is unfortunate because the power supply position is a more natural set of units for linking the econometric results to the theoretical framework above. For example, the deficit relative to supply is conceptually very much reminiscent of *(1-Q)* in Section 3. One can speculate about the right interpretation of the weakness of these results in light of the relative strength of those presented in Tables 2-3. In the end the power supply position data are relatively limited and insufficiently precise for convincing inference.

Table 4a: Generation Capacity and Power Balance (First Stage)

***State-Level, Only Observations with Output Data*

Variable	*Power supply balance (%)*				
	(1)	(2)	(3)	(4)	(5)
Generation capacity	0.032	0.026	0.057	0.021	0.022
	(0.030)	(0.030)	(0.042)	(0.031)	(0.034)
(lag)		0.020***	0.017**	0.020***	0.020**
		(0.007)	(0.007)	(0.007)	(0.008)
Power lines			-0.054		
			(0.035)		
Transformers			0.003		
			(0.005)		
Rainfall				0.001	0.001
				(0.013)	(0.022)
Rainfall * Hydro					0.000
					(0.040)
First Differences	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y
Years	1992-2005	1992-2005	1992-2005	1992-2005	1992-2005
Observations	291	289	257	277	259
R-squared	0.106	0.131	0.156	0.133	0.139
F-statistic#	2.53	2.94	2.77	2.67	2.44

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

F-stat is for the joint test that coefficients on all independent variables (not including FE) equals zero.

Table 4b: Generation Capacity and Power Balance (First Stage)
***State-Level, All Available Observations*

Variable	*Power supply balance (%)*				
	(1)	(2)	(3)	(4)	(5)
Generation capacity	0.026	0.022	0.027	0.015	0.015
	(0.022)	(0.022)	(0.032)	(0.027)	(0.029)
(lag)		0.019***	0.018**	0.020***	0.020**
		(0.007)	(0.008)	(0.007)	(0.008)
Power lines			-0.011		
			(0.021)		
Transformers			0.003		
			(0.005)		
Rainfall				0.007	0.005
				(0.012)	(0.014)
Rainfall * Hydro					0.000
					(0.001)
First Differences	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y
Years	1992-2007	1992-2007	1992-2007	1992-2007	1992-2007
Observations	415	413	326	338	315
R-squared	0.130	0.145	0.148	0.136	0.143
F-statistic	3.98	4.21	3.15	3.16	2.93

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Power Balance and Aggregate Manufacturing Output, IV Approach

	(1)	(2)	(3)	(4)	(5)
	Value added	*Fixed capital*	*Employment*	*TFP[1]*	*TFP[2]*
Power balance	0.586	0.566	-0.359	-1.588	0.414
	(1.826)	(0.743)	(1.137)	(2.112)	(1.538)
Rainfall	0.071	-0.009	0.011	-0.049	0.078
	(0.079)	(0.032)	(0.049)	(0.094)	(0.067)
First-differences	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Years	1992-2005	1992-2005	1992-2005	1992-2005	1992-2005
Observations	209	209	209	191	209
R-squared	0.119	0.129	0.167	0.105	0.154

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4.3 Differential impacts and market structure

The above section provided some evidence of aggregate impacts of expansion of public sector electricity infrastructure on manufacturing output and factor accumulation. However, a very interesting part of the story of electricity is the different impacts public power service quality may potentially have on firms of different sizes. Large firms can generate power using private generators at a much lower unit cost than small firms (e.g. see the data in Eifert, 2010), so one might suspect that poor-quality public power service slants the playing field away from smaller firms in industries which otherwise are not characterized by large economies of scale.

Hence we turn to the firm-level data. Three caveats bear mention immediately. First, while the state-level data covers 1979-2005, the firm-level ASI data I have available for this study covers 1988-2004 with several missing years in between. Second, as mentioned above, because the Indian government scrambles the firm identifiers, the data is a repeated cross-section, not a true panel. Third, the Indian firm-level data was originally collected for purposes of regulation and central planning, which raises difficult questions about the types of systematic biases that might be present.

That said, the questions of interest here are:

- Do small firms benefit more in productivity terms from improvements in public power infrastructure, potentially because of the greater cost of generating their own power?

- Do improvements in public power infrastructure influence the firm size distribution over time, e.g. leading to more medium-sized firms and less dominance by very large firms?

There is a tricky trade-off in the time horizons of analysis here; see Eifert (2010) for a theoretical development that illustrates this. The first question can be addressed in a relatively robust econometric fashion because we can restrict ourselves to studying variation within states over time in the relative productivity of small and large firms. However, if firms choose production technologies – some of which are higher-productivity but more sensitive to the quality of electricity service, and vice versa – in response to the prevailing power situation, one might imagine that adjusting those technologies in the short run is costly. As a result, we could even observe the opposite of the effect we are looking for in a year-on-year analysis: smaller firms could appear to be less-affected by changes in the quality of the power supply. For example, small garment kitting firms using hand-powered manufacturing techniques would appear to be virtually unaffected by reductions in power shortages in the short run, though in the longer run they might introduce high-throughput powered machinery.

The longer time horizon used in addressing the second question will capture the potential long-run effects from shifting production technology as well as firm entry and exit. However, it also raises more difficult econometric questions, because long-run trends in power supply balances at the state level are likely related to other political, institutional and regulatory processes that affect economic outcomes. There is no easy way around this trade-off.

The first sub-section describes the approach to measuring firm-level productivity, which boils down to using several feasible but imperfect methods and checking the consistency of results. The remaining two sections address the two questions in the bullet points above in turn.

4.3.1 Preliminaries: measuring firm-level productivity

True "physical" total factor productivity (TFP) is notoriously difficult to measure, given that most firms have heterogeneous inputs and outputs and detailed information on prices and demand is rarely available to the econometrician. We are somewhat limited here by the lack of panel data, as the Indian statistical agency scrambles the ASI firm identifiers across years for data confidentiality reasons. This rules out several modern production function estimation approaches like those introduced by Olley and Pakes (1996) and Levinsohn and Petrin (2003).[17]

There are at least two underlying issues here: (a) how to estimate the factor loading parameters of the production function, and (b) how to deal with unobserved input and output prices and potential market power. This study follows Hseih and Klenow (2009), the seminal study of productivity in China and India, in using industry factor shares from US data for the production function and a standard model of monopolistic competition to deal with unobserved output prices.[18] They derive the following expression for plant-level productivity in terms of revenue (in practice, value-added), inputs, factor shares and the elasticity of demand:

$$(17) \qquad TFP_{ist} = \kappa_{st} \frac{R_{ist}^{\sigma/(\sigma-1)}}{K_{ist}^{\alpha_{ks}} L_{ist}^{\alpha_{ls}}}$$

Where κ is a sector-level constant of proportionality that can be normalized away here, and the elasticity of substitution is assumed to be -3 following Hseih and Klenow.[19]

The implicit assumption in the monopolistic competition model is that plants with higher physical output must face lower prices further down a common demand curve. This assumption of a fixed deterministic relationship between price and quantity is certainly problematic because of heterogeneous market size, fixed costs of entering different markets, customer search costs, and so forth. The opposite extreme assumption is independence of price and quantity, which implies the alternative measure devoid of the elasticity of demand:

[17] Note the difference between (17) and (13)-(16). Expression (17) handles the estimation of firm-level productivity in a sample of imperfectly competitive manufacturing firms which face downward-sloping demand curves. The system (13)-(16) addresses aggregate output, which is typically modeled as the output of a perfectly competitive "final goods" sector, e.g. Hsieh and Klenow (2009). Hence there is no elasticity of demand in that system of equations.

[18] The author thanks Pete Klenow for sharing his data on US factor shares.

[19] This corresponds to a 50% price markup over marginal cost. Results do not change materially when using an elasticity of substitution of -5; inspecting equation [17], this only impacts the dispersion of measured TFP.

$$(18) \qquad T\tilde{F}P_{ist} = \tilde{\kappa}_{st} \frac{R_{ist}}{K_{ist}^{\alpha_{ks}} L_{ist}^{\alpha_{ls}}}$$

We would probably expect "true" TFP to lie somewhere in between (17) and (18).

Hsieh and Klenow's use of US industry factor shares for the production function parameters is based on the underlying assumption of a common technological opportunity set, allowing us to avoid bias induced by noisy or systematically inaccurate Indian data and market distortions that cause marginal revenue products to fail to equalize across firms. These are major advantages, but the common technology assumption is strong. Hence as a robustness check the production function parameters are estimated directly from the firm-level ASI data using OLS.[20]

To summarize, the four measures of TFP used here are:

A. $TFP_{ist}^{A} = \kappa_{st} R_{ist}^{\sigma/(\sigma-1)} / \left(K_{ist}^{\alpha_{ks}(US)} L_{ist}^{\alpha_{ls}(US)} \right)$

B. $TFP_{ist}^{C} = \kappa_{st} R_{ist} / \left(K_{ist}^{\alpha_{ks}(US)} L_{ist}^{\alpha_{ls}(US)} \right)$

C. $TFP_{ist}^{B} = \kappa_{st} R_{ist}^{\sigma/(\sigma-1)} / \left(K_{ist}^{\hat{\alpha}_{ks}(OLS)} L_{ist}^{\hat{\alpha}_{ls}(OLS)} \right)$

D. $TFP_{ist}^{D} = \kappa_{st} R_{ist} / \left(K_{ist}^{\hat{\alpha}_{ks}(OLS)} L_{ist}^{\hat{\alpha}_{ls}(OLS)} \right)$

4.3.2 Are smaller firms more productive with better public power?

Ideally, with a firm-level panel we could look at whether smaller firms in states where power infrastructure improved experienced faster productivity gains than larger firms. With a repeated cross-section, we are limited to a more basic exercise: checking whether smaller firms have higher productivity (relative to large firms) in states with better power supply, controlling for state and year fixed effects:

$$(19) \qquad TFP_{ist} = \mathbf{X}_{st}\boldsymbol{\beta} + \mathbf{Z}_{ist}\boldsymbol{\gamma} + \lambda_1 \cdot Size_{ist} + \lambda_2 (PowerVariable_{st} \times Size_{ist}) + \phi_s + \varphi_t + \varepsilon_{ist}$$

[20] This is a method with questionable reliability for reasons very well explored in the productivity literature (see e.g. Levinsohn and Petrin, 2003), but given the lack of panel data or meaningful instruments for inputs it is perhaps a reasonable robustness check.

The coefficient of greatest interest here is λ_2. We use two alternative measures of size: labor (in logs) and predicted log output $\alpha_l \log(L) + \alpha_k \log(K)$. As in the above section, we attempt both OLS estimation of the reduced-form using generation capacity as the independent variable and IV estimation using power supply balance instrumented by generation capacity. The regressions are weighted so as to give equal weight to each state-year, as the primary variables of interest involve state-year-level observations, and standard errors are always clustered at the state level to handle serial correlation.

Table 6 displays the results for the four different measures of TFP (see above for legend). The upper panel uses labor as the measure of firm size; the lower panel uses $\alpha_l \log(L) + \alpha_k \log(K)$. Suggestively, we see that in the top panel, using labor as the measure of firm size, columns A and B show positive coefficients on log capacity and negative interactions with firm size, statistically significant in column A. This corresponds to using TFP measures A and B constructed from US factor shares at the 3-digit level from Hsieh and Klenow (2009). The level coefficients of 0.062 and 0.085 lie in between the two estimates of the impact of new capacity on aggregate state-level productivity from Table 3 (0.030 and 0.090). The interaction coefficients, estimated at -0.003 and -0.004, imply that relative to a very small firm, 25% of the impact of new capacity is lost at around a firm size of 150 workers, and 50% at around 22,500 workers, with some positive impact prevailing over any relevant firm size range.

However, inspecting columns C and D of the top panel and columns A-D of the bottom panel, this result appears to be sensitive to the definition of firm size and the use of US factor shares as opposed to estimated production function parameters. The latter might be explained away as the result of the unreliability of OLS estimation; the level coefficient retains the same sign and the interaction term flips, both becoming small and statistically insignificant. However, the former seems more problematic, and suggests some kind of contemporaneous correlation between firms' capital-labor mix and changes in generation capacity. The theory above suggests that firms might increase labor use in response to reductions in power blackouts, which would cause a spurious correlation between improvements in power on the one hand and firm size as measured by labor on the other; if anything this should bias the interaction effect towards zero when size is measured by labor, which is not what is happening here. Hence the results remain suggestive but inconclusive.

One interpretation of the weakness of the results here relates to the technology choice issue discussed in Eifert (2010); smaller firms in power-scarce environments may use technologies which avoid dependence on electricity, and may only be able to adopt new technologies over the longer run, which the year-on-year time horizon may not capture. Another potential culprit is the reliability of the firm-level data.

Table 6: Firm size, generation capacity and productivity

Panel A: (size = labor)

	TFP(A)	TFP(B)	TFP(C)	TFP(D)
log_capacity	0.065**	0.082**	-0.002	-0.002
	(0.032)	(0.031)	(0.084)	(0.084)
logY_capacity	-0.003*	-0.004*	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Constant	-1.331***	0.185	1.143***	1.143***
	(0.272)	(0.258)	(0.679)	(0.679)
State fixed effects	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y
Observations	225453	225453	225302	225302
R-squared	0.083	0.675	0.180	0.793

Panel B: (size = regression-predicted output)

VARIABLES	TFP(A)	TFP(B)	TFP(C)	TFP(D)
log_capacity	0.015	0.019	-0.020	-0.030
	(0.016)	(0.017)	(0.052)	(0.052)
logL_capacity	0.004	0.003	0.012	0.019
	(0.003)	(0.005)	(0.011)	(0.011)
Constant	0.113*	6.196***	3.201***	8.771***
	(0.071)	(0.123)	(0.194)	(0.261)
State fixed effects	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y
Observations	238304	238304	225302	225302
R-squared	0.030	0.406	0.059	0.477

* Standard errors (clustered by state) in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. TFP measurements: A = factor shares from regression, price and quantity independent; B = factor shares from regression, price and quantity from monopolistic competition model; C = factor shares from US data, price and quantity independent; D = factor shares from US data, price and quantity from monopolistic competition model

4.3.3 The plant size distribution

If small and medium sized plants disproportionately benefit from the improvement of public electricity infrastructure, we might expect to see gradual changes in the plant size distribution and apparent increases in the level of product market competition. This process is likely to evolve over a longer time scale than captured by the year-on-year panel data analysis carried out above, particularly if the adoption of higher-productivity electricity-using technologies by smaller firms is part of the story. This raises some hard questions – e.g. are longer-run trends in electricity infrastructure and power deficits independent of other drivers of the firm size distribution? It is entirely possible that they are not, but from an econometric standpoint there is little we can do; finding valid instruments for identifying causal relationships in long-term dynamic equilibria like this is a pretty difficult exercise.[21] However, it is worth at least checking whether the results are consistent with the theoretical framework we have in mind.

To get a sense of these longer-run dynamics, we split states into three groups: those which experienced a dramatic improvement in the average power supply balance over 2002-2004 versus 1992-1994 (> 5 percentage points); those which experienced a dramatic worsening (< -5 percentage points); and those in between. The resulting split is relatively even (8 improving substantially and 6 deteriorating substantially, with 17 in between); see Figure 2 below for a map and list of states. We then compare the distributions of plant size and productivity in 1992-1994 versus 2002-2004 across these groups of firms using kernel density estimates.[22] We also calculate several metrics characterizing the plant size distribution for each of these groups, including the percent of value-added accounted for by the largest 100 and 1000 plants.[23]

Visual inspection of Figure 3 shows an interesting trend. Note that the firm size distributions for all three groups of states widened and flattened substantially between 1992 and 2004. In 1992, the firm size distribution in worsened-electricity states was relatively more concentrated in the mid-sized region than the distribution in improved-electricity states, with skinnier tails and more mass in the middle. By 2004, the left and right tails of the worsened-electricity states were fatter than that of the improved-electricity states, particularly the right tail. That is, states which experienced relatively large deteriorations in public power supply balance became increasingly dominated by very large firms and very small firms relative to states which experienced relatively large improvements in power supply balance.

To formally test this visual intuition, we need to compare relative *changes* in two distributions. This is a different setting than the traditional Kolmogorov-Smirnoff test for differences between distributions, and the asymptotic theory of the latter does not apply. We can form an analogous test statistic $K = \sup |[F_{n1}(x) - F_{n2}(x)] - [G_{n1}(x) - G_{n2}(x)]|$, equal to

[21] In particular, we would need some variables which influence relative long-run trends in power supply across states which is in no way statistically associated with other variables that influence relative trends in economic activity.

[22] I chose three years at the beginning of the period and three years at the end to increase the sample size for the comparisons and smooth over idiosyncrasies in the data for any particular year.

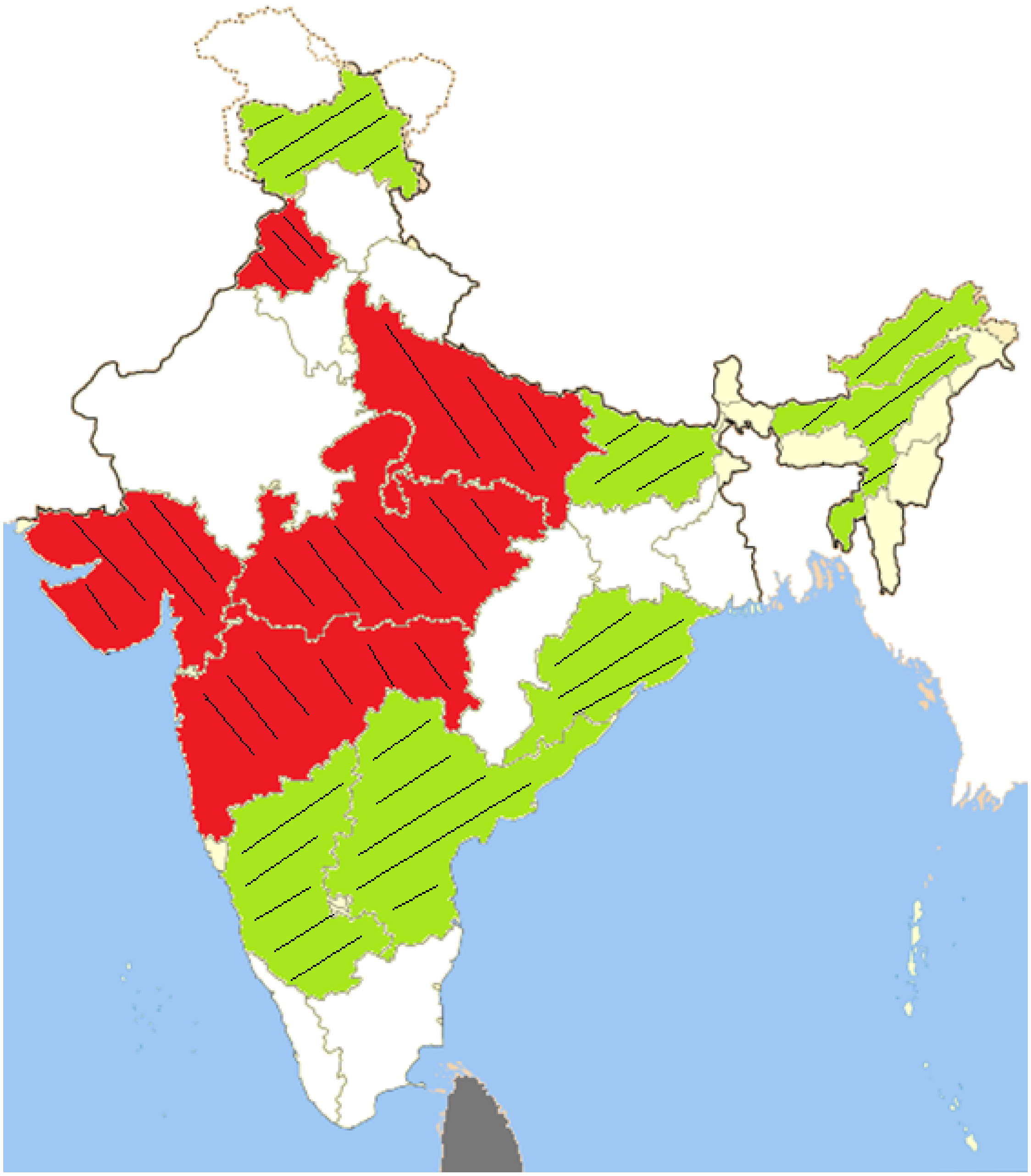
[23] Ideally we would be able to study firm size dynamics in more detail, but this would require true panel data where we have only a repeated cross-section.

the largest difference in the change in the firm size distribution between the two groups of states between 1992 and 2004. The asymptotic distribution of this test statistic is unknown to my knowledge but can easily be simulated using a bootstrapping method. In particular, I create a sample of S re-sampled firm size distributions from the original firm size distribution for each group of states (improved electricity and worsened electricity), and re-compute the test statistic K for each re-sampled distribution, therefore approximating its small-sample distribution. Given the large sample size (70,900 observations in 1992-94 and 37,189 in 2002-04), and using $S = 1000$, the changes in the two firm-size distributions are very statistically significantly different (K = 0.082, P-value = 0.001).

Next, Figure 4 plots the time-series of the output share of the largest 1% of manufacturing plants by the same grouping of states (the flat spot over 1995-97 is due to unavailable data). The story here is similar: the "improved" states had a substantially higher level of market dominance in the late 1980s and early 1990s relative to the "worsened" states, 55-60% versus 45-47%, a gap which had converged by 2000. Also note that the states which did not have a dramatic change in power supply position in either direction over the period ("similar") started with a high degree of market dominance and appear to be improving vis-à-vis the "worsened" states, albeit later and more slowly. One interpretation is that improving electricity service quality as a result of smaller power shortages contributed to a gradual reduction in the market dominance of the largest firms.

As mentioned above, I do not want to push the interpretation of these results too strongly, because firm size distributions evolve slowly over time in response to a host of factors and the likelihood that long-term trends in state-level electricity infrastructure quality are really independent of other macroeconomic factors seems low. Furthermore, as Figure 4 illustrates, there does seem to be some geographic component to this decomposition, with states in the west and north-west more likely to have experienced deteriorating power quality over the sample period and states in the south and east more likely to have improved. Nonetheless the results are at least consistent with the theoretical framework sketched above and its broad hypothesis about the way the quality of the power supply affects firms.

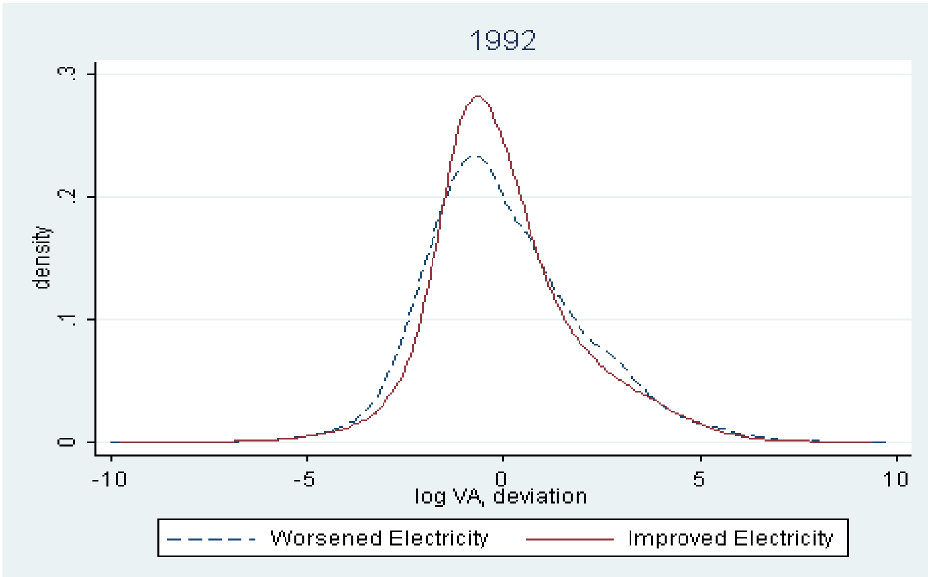
Figure 2. Improving, deteriorating and stable power supply balance across India, 1992-2005

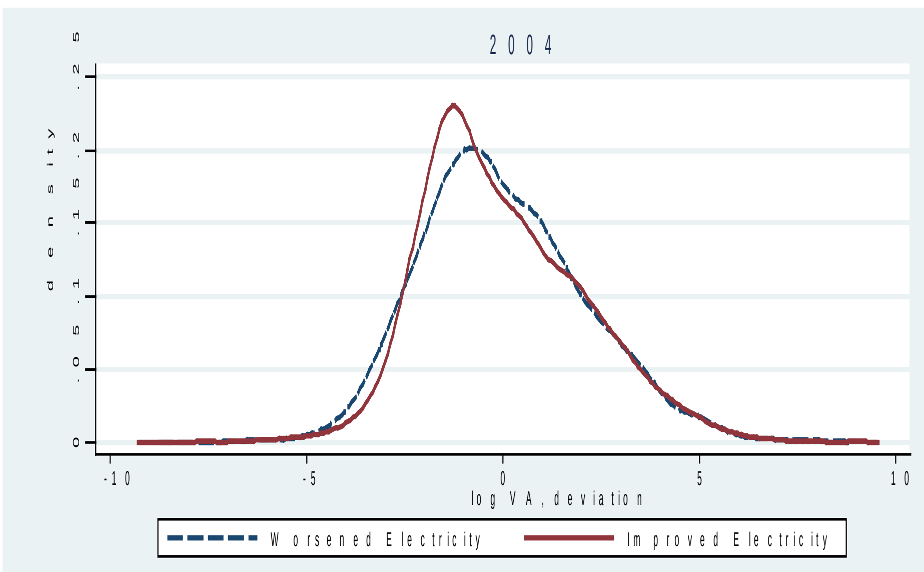


*<u>States with substantially improved electricity</u>: Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Jammu & Kashmir, Karnataka, Manipur, Mizoram, Nagaland, Orissa, Tripura. <u>States with substantially worsened electricity</u>: Gujarat, Madhya Pradesh, Maharashtra, Meghalaya, Punjab, Uttar Pradesh. <u>Stable states</u>: A & N Islands, Chandigarh, Chhattisgarh, D & N Haveli, Daman & Diu, Goa, Haryana, Himachal Pradesh, Jharkhand, Kerala, Lakshadweep, Pondicherry, Rajasthan, Sikkim, Tamil Nadu, Uttarakhand, Uttaranchal, West Bengal.
* Down/right crosshatch = power balance worsened by 5 percentage points or more between 1992-2004. Up/right crosshatch = power balance improved by 5 percentage points or more.

Figure 3. Distributions of firm-level log value added around mean, 1992-94 versus 2002-04

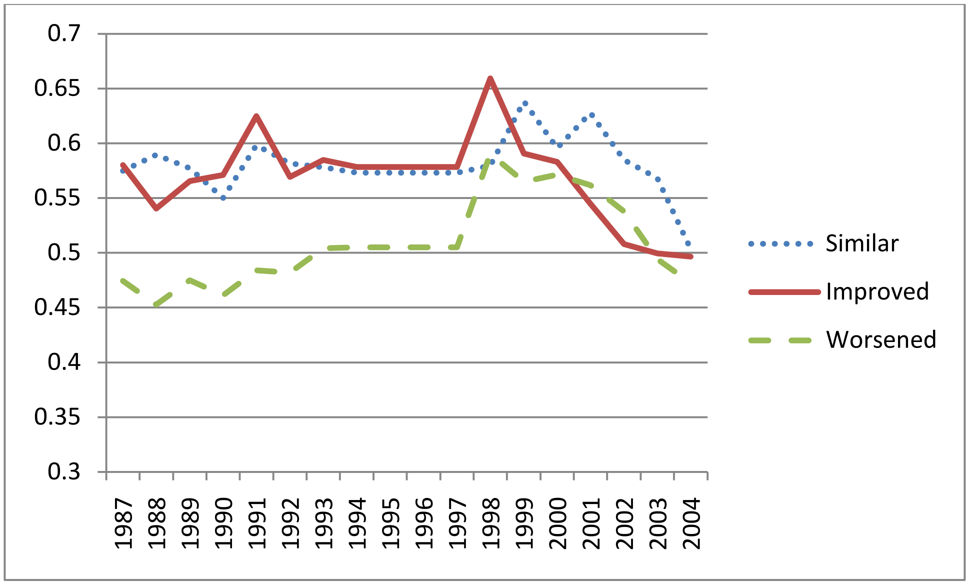
State groupings by power balance trend (substantially improved, substantially worsened)





*States where power balance improved by 5 percentage points or more over 1992-2004: Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Jammu & Kashmir, Karnataka, Manipur, Mizoram, Nagaland, Orissa, Tripura. States where power balance worsened by 5 pp or more: Gujarat, Madhya Pradesh, Maharashtra, Meghalaya, Punjab, Uttar Pradesh. Other states: A & N Islands, Chandigarh, Chhattisgarh, D & N Haveli, Daman & Diu, Goa, Haryana, Himachal Pradesh, Jharkhand, Kerala, Lakshadweep, Pondicherry, Rajasthan, Sikkim, Tamil Nadu, Uttarakhand, Uttaranchal, West Bengal.
Sample sizes: 30,840 (1992-94, improved); 41,060 (1992-94, worsened); 16,188 (2002-04, improved), 20,901 (2002-04, worsened).

Figure 4. Output share of largest 1% of manufacturing firms, by power balance trend



*States where power balance improved by 5 percentage points or more over 1992-2004: Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Jammu & Kashmir, Karnataka, Manipur, Mizoram, Nagaland, Orissa, Tripura. States where power balance worsened by 5 pp or more: Gujarat, Madhya Pradesh, Maharashtra, Meghalaya, Punjab, Uttar Pradesh. Other states: A & N Islands, Chandigarh, Chhattisgarh, D & N Haveli, Daman & Diu, Goa, Haryana, Himachal Pradesh, Jharkhand, Kerala, Lakshadweep, Pondicherry, Rajasthan, Sikkim, Tamil Nadu, Uttarakhand, Uttaranchal, West Bengal.
Sample sizes: 30,840 (1992-94, improved); 41,060 (1992-94, worsened); 16,188 (2002-04, improved), 20,901 (2002-04, worsened).

5. Improving the electricity supply

The evidence presented above is somewhat mixed, but it does suggest that public sector electricity generation capacity is associated with positive outcomes in the Indian manufacturing sector, particularly aggregate growth and factor accumulation and potentially also better performance of smaller firms. This section briefly reflects on India's difficulties sustaining adequate levels of public and private investment in the power sector, and concludes with a back-of-the-envelope cost-benefit analysis for new power plan construction.

The main engines of public sector participation in the Indian electricity markets are the state electricity boards (SEBs). The core difficulty with the SEBs is their perpetually weak financial positions. They collectively lose more than 1% of Indian GDP every year, resulting in chronic under-investment in new generation and distribution capacity and poor maintenance of existing capacity. This fiscal situation has several major causes. First, while large commercial enterprises in India pay close to international average rates for electricity (roughly \$0.09 per kWh in 2007, compared to \$0.076 on average for G10 countries), residential and agricultural customers pay closer to \$0.03 per kWh, compared to \$0.126 in G10 countries. Political pressures to maintain low prices for residential and agricultural customers are very strong. Second, transmission and distribution losses are extremely high in India, 38.2% in 2006 and 37.4% in 2007, compared to 8% internationally. These stem primarily from theft and misappropriation of electricity, which is notoriously common in India, and local police have demonstrated little incentive or motivation to crack down on abuses. Third, the SEBs face political pressure to provide generous and plentiful employment. While one might characterize the financial costs of low prices and T&D losses as transfers from the government to consumers of electricity and to workers, many of whom are relatively poor, the resulting perpetual fiscal crisis and under-investment in new public infrastructure suggests this is not particularly efficient.

The ongoing challenges facing the SEBs suggest that focusing on increasing private sector participation and investment in the power sector might be an appropriate strategy, via regulatory reforms, tax incentives and the like. Developing and transition countries now have some substantial experience with electricity sector reform from which to draw tentative conclusions. There seems to be some agreement in the literature that reforms which introduce greater competition into electricity markets can improve outcomes, including installed capacity growth rates and end user prices. Zhang, Parker and Kirkpatrick (2008) provide econometric evidence from panel data on 36 developing and transitional countries over 1985-2003, finding that a one-standard-deviation increase in their measure of market competition is associated with a roughly 2% increase in generation capacity. The estimates here suggest this would add \$520 million - \$1.2 billion to Indian manufacturing output annually. The same authors find that privatization and deregulation alone does not lead to greater electricity generation, installed capacity or efficiency, consistent with the results of several other studies including Megginson and Netter (2001) and Parker and Kirkpatrick (2005). The consensus in the literature is that effective regulation and public sector management is key to achieving good outcomes in reform programs.

However, many of the structural problems that beset the SEBs also deter private investment in India. Excess transmission and distribution losses affect all power sector participants, in this case taking the equivalent of 30% of revenue right off the top. Where private companies sell electricity directly to consumers, they face the same regulated power prices. Where they sell to SEBs via electricity purchasing contracts, the latter's unstable finances are a major risk; over the last decade there have been several high-profile incidences of SEBs failing to uphold their payment obligations, causing dramatic declines in private sector participation since 2000 (Wolak, 2008). The large fixed costs associated with investment in generation and distribution capacity are particularly unattractive in an environment where firms face large T&D losses and price controls and are uncertain whether they will even be paid. This suggests that tackling the underlying causes of the SEBs' losses – especially the huge price subsidies to residential and agricultural customers and the widespread theft of electricity – is essential both for enabling public investment and for attracting private investment.

5.1 Cost-benefit analysis for public power generation capacity

Finding funds for new generation capacity may be difficult, but here I provide some back-of-the-envelope calculations that suggest the returns from doing so are handsome indeed.

On the cost side of the equation, construction costs for new coal-fired power plants depend on many contextual factors, but a reasonable ballpark range for 2010 is probably about $2,500 -- 3,500/kW, with 4-6 year project completion times (Schlissel, Smith and Wilson, 2008). Cleaner power sources such as natural gas and nuclear cost more, potentially in the range of $3,500 - $4,500 per kW. On the benefit side, the range of coefficients in Table 2 suggests that a 1% increase in generation capacity India-wide (or + 1,041 megawatts) would add 0.13 - 0.26% to manufacturing output. India's manufacturing output for the 2008-2009 fiscal year was roughly Rs 9 trillion, or $200 billion at an exchange rate of Rs 45 per dollar.

Using these ranges, a back-of-the-envelope number for manufacturing output gained from a coal plant investment of $2.6 – 3.6 billion over an average construction time of about five years would be $260-520 million per year. The benchmark 10-year Indian central government bond yields around 7.75% in February 2010; choosing this as the discount rate, the present value of the increase in future manufacturing output generated by the investment is $6.8 – 13.6 billion, a multiple of the costs of at least two and possibly as much as four. The coefficient of 0.16 on labor in Table 3 combined with a labor force of around 500 million for India suggests this investment would also create around 800,000 formal sector manufacturing jobs, or about $3,250 per job.

From a purely cost-recovery standpoint, the issue is not as clear. Taking the midpoints of the cost and impact estimate ranges, assuming a financing cost of 7.5%, and a marginal tax rate of 20% (roughly equal to India's tax share of GDP), the investment in power generation capacity does not pay for itself, generating $78 million per year in tax revenues once it is fully operational but incurring $232 million per year in interest. In order for increased output to completely cover the financing costs of new investments in generation capacity, the agricultural and service sectors would need to respond with similar magnitude as manufacturing, which seems unlikely from a technological standpoint. This highlights the importance of tackling the underlying issues of SEB financing.

6. Conclusions

This study has examined the impact of public electricity infrastructure on manufacturing in India. It set out to investigate aggregate impacts on output, employment, capital accumulation and productivity as well as relative impacts across the size distribution of firms.

In the state-level data, this study finds some evidence of moderate impacts of expansions of public sector electricity generation capacity on state-level manufacturing output, channeled primarily through increases in productivity and employment. In particular, a 1% increase in public sector electricity generation capacity at the state level is associated with a 0.13-0.26% increase in state manufacturing output, of which about half is due to increased employment and the other half to increases in productivity and capital accumulation. Attempts to use generation capacity as an instrument to "switch units" and directly study the impact of power shortages on output were inconclusive and not robust, partly due to limited data coverage.

Using firm-level data, I carry out two exercises. First, I check whether the relative productivity of small firms versus large firms increases in states where public generation capacity increases more. Though there is some suggestive evidence here of a positive impact on productivity which is significant and decreasing with the number of employees, when following the Hsieh and Klenow (2009) approach to measuring productivity, this result is not robust to alternative measures of productivity and firm size. The weakness of the result here is not entirely unexpected, as discussed above, because smaller firms in electricity-poor environments may use technologies that are less sensitive to the quality of the power supply, and can only adjust to improvements in the power supply over the medium to long run.

Second, I compare the longer-run evolution of the firm size distribution in states which experienced different trends in power supply balance. I find some evidence that the firm size distribution has become less fat-tailed in states where the power supply balance has improved over 1992-2004, with more medium-sized firms and fewer very large and very small firms. This result links closely to Hsieh and Klenow (2009), who find that a substantial share of the low aggregate productivity in China and India relative to the US can be attributed to inefficient dispersion in the distribution of firm size in the former, especially the long left tail of small, relatively unproductive firms. The dominance of very large firms also fell in states which saw significant improvements in power quality relative to those which saw significant deteriorations; the largest 1% of firms accounted for 55-60% of output in the first group in 1992-94, which fell to about 50% by 2004, while in the latter group the share of the largest 1% remained relatively constant at 45-50%. This makes theoretical sense; in environments with very poor centralized electricity systems, large firms can generate their own power cost-effectively and dominate many markets, while a preponderance of micro-firms making inexpensive, low-quality goods using "traditional" technologies subsist in sectors which do not require electricity. If power quality improves substantially, over time these small firms can potentially adopt more productive technologies that use electricity and grow to take market share from larger incumbents.

However, this result is suggestive, as long-run state trends in power balance are likely associated with a complex set of policy and institutional dynamics that affect economic growth in other ways.[24] This is a tricky analytical issue, as much of the impact of improvements in the power system on entry and the dynamics of the firm size distribution can only be expected to accumulate over time, ruling out "tight" econometric approaches. A particularly interesting question for future research is whether substantial improvements in the reliability of the power system allows small, informal firms that in India use predominantly hand-powered technologies to begin to adopt higher-productivity electricity-using technologies and begin to compete with larger firms over the medium and long run.

The data unfortunately do not permit the decomposition of the aggregate impacts estimated here into the impact on new entry versus growth of existing firms, because firms cannot be linked across years to build a true panel. This is a key distinction for policy purposes. To the extent that researchers and governments in developing countries can collaborate to create more consistent, longitudinal sources of firm-level data, efforts to identify channels of policy impact will be more fruitful.

[24] In addition, the quality and reliability of the firm-level data raise some fair and important questions about the results. The data are noisy and incomplete, and was historically collected by government agencies for the purpose of resource allocation (hence firms' responses were subject to poor incentives). An alternative interpretation of any results involving the evolution of the firm size distribution might involve changes in data quality over time.

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Chapter 2

Infrastructure, Technology and Market Structure

In Least-Developed Countries

1. Introduction

The quality of public services in least-developed countries is often abysmal. As field researchers know, power outages are a near-daily occurrence in many places, including many African countries and most regions of India (Figure 1). Transport infrastructure tends to be worn and unreliable. Telecommunications services were often characterized by service interruptions, high prices and long waiting times for connections until the recent introduction of cellular service.

This paper suggests that some types of service shortfalls – in particular, those which lead many businesses to produce the relevant inputs in-house – may have systematic effects on the viability of small firms. The classic example is energy. In industries which require electricity-intensive technologies, firms use private generators when public power goes offline. Because electricity generation is associated with sharp economies of scale, poor public electricity service imposes much higher costs on small firms than on large firms in electricity-using industries, resulting in higher prices and greater market share for large firms. In the many light-manufacturing industries where technological economies of scale are exhausted after modest plant size is reached, this dynamic could have a substantial impact on market structure. The argument can be viewed as an offshoot of older work on the technological determinants of market structure, but where effective scale economies are influenced by the environment in which firms operate.

This logic is illustrated in a simple homogenous-products oligopoly model with a fixed set of large incumbent firms facing potential scale-constrained entrants. Firms choose from production technologies with varying electricity requirements and decide whether or not to purchase an electricity generation technology. Under certain conditions incumbent firms' equilibrium profits and market share are non-monotonic in the reliability of centrally provided electricity, as the latter intensifies competition by lowering their small rivals' costs more than their own.

The strength of this effect depends centrally on the industry-specific productivity advantage of technologies which use electricity intensively. For example, markets for handicrafts or simple textiles which can be produced cost-effectively with hand-powered tools are little affected, while markets for complex, high-value products which require continuous-process manufacturing technologies are sharply affected. By translating economies of scale in the self-provision of intermediate inputs into economies of scale in the production of outputs, and doing so with differential force depending on the input requirements of an industry, the cost and reliability of centralized electricity service thus may have significant and predictable downstream impacts on market structure. Similar results would obtain for other inputs with similar features, like security.

The latter part of the paper endogenizes the quality of the electricity supply, examining the incentives of public service providers. Unregulated utility monopolists will charge high prices but will avoid systematic quality shortfalls, resulting in a level playing field. Regulatory schemes imposing low prices in an under-capacity environment naturally result in quality shortfalls. Perhaps most interesting is the possibility that incumbent firms may bargain with the utility for (inefficient) preferential treatment that keeps the playing field asymmetric. Hence the paper offers a potentially serious source of misallocation of resources in an economy.

This story may provide an additional explanation for the "missing middle" phenomenon[25] seen in least-developed countries.[26] In particular, one often observes large firms dominating markets for manufactures and processed products; small and medium competitors are often scarce. Large numbers of tiny informal firms exist, but these primarily provide small-scale distribution and non-traded services, rarely competing with formal firms. As a result, domestic product markets are concentrated and oligopolistic, with healthy profits for large incumbent firms but a distinct lack of competitive innovation and dynamism.[27] These patterns are most stark in, but by no means limited to, sub-Saharan Africa. Interestingly, ministers at the 2006 African Development Bank meetings cited chronic power shortages across Africa as undermining investment and growth. They also expressed concern that "poor power, phone and road services contributed to the missing middle - referring to the fact Africa has a number of large conglomerates and millions of tiny businesses owned by families or individuals, but little in between."[28]

It is important to be forthright about the dependence of this story on institutional features of very poor countries. Most important is the failure of the private market to provide a reliable, low-cost electricity supply in the absence of such service from the public sector. Legal monopoly barriers in most poor countries prevent large private firms from selling electricity directly to small firms; this is a large part of the story. The harder thing to explain is why multiple small firms cannot easily share one large generator, which empirically is quite rare. Contracting problems are an intuitive possibility but this needs to be explored in more detail.

Finally, the model is primarily designed for clarity. While the basic empirical implications follow directly, any serious attempt to take this logic to firm-level data deserves more substance on the production technology side in particular and on the demand side as well. This will generate a richer description of the size distribution of firms, which here is captured

[25] As described by UNCTAD in its *Least Developed Countries Report 2006*, "The "missing middle" refers to the weak development of formal sector small and medium enterprises […]. At one end of the size distribution, there are a multitude of informal micro-enterprises, most of which are characterized by the use of basic and traditional technologies and cater to the needs of restricted and relatively small local markets […] at the other end of the spectrum, there are a few large firms, which are mainly capital-intensive, resource-based, and import-dependent […] between these two extremes, there are very few formal sector SMEs." (p. 222).

[26] Existing explanations for weak competition and SME performance seem plausible, though some are inconsistent. Small market size and limited market integration can account for the former but not the latter. More promising explanations include over-regulation, poorly functioning financial markets and the scarcity of entrepreneurial skills.

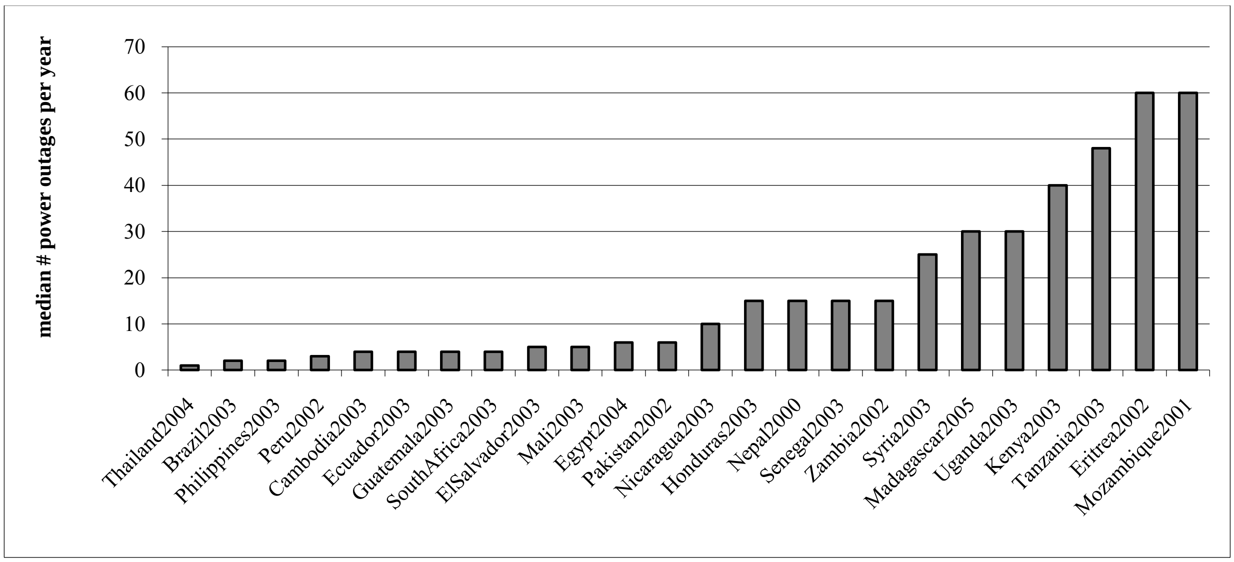
[27] Opening to trade has increased exposure to competition, but non-trivial tariffs often remain in "priority" industries, and natural barriers created by dysfunctional ports, geography and poor interior transport still protect incumbents.

[28] Reuters, Thursday May 18 2006, Alistair Thomson.

only by the number of entrant firms and incumbents and the market share of the incumbents and entrants.

Section 2 briefly discusses literature on the size distribution of firms in poor countries. Section 3 elaborates the concepts introduced above and provides some basic evidence for the relevance of its conditions. Section 4 lays out a simple model which demonstrates the mechanisms at work. Section 5 endogenizes the quality of electricity supply and discusses some political economy implications. Section 6 concludes, suggesting future directions for research.

Figure 1. Frequency of power outages (annual), by country



Source: World Bank Investment Climate Surveys, 2000 – 2005

2. The Missing Middle and the Size Distribution of Firms

Most research on the size distribution of firms focuses on developed countries, where it tends to be roughly lognormal in the cross-section. Early papers like Viner (1932) focused on the role of economies and diseconomies of scale and scope. Lucas (1978) described the evidence against Viner's theory as an explanation of the size distribution of firms (as opposed to plants or stores) as overwhelming, and proposed an alternative idea, that the size distribution of firms may be a simple function of the underlying distribution of managerial talent.

Newer studies based on panel data illustrate more detail. In developed countries, individual cohorts usually enter with left-skewed distributions, which then flatten out over time as some firms grow and others exit. Cabral and Mata (2003) suggest that the life-cycle size distribution of cohorts of firms reflect financial market imperfections, with young firms starting off constrained by the wealth of their owners and survivors overcoming those constraints over time. Their work builds on research like Evans and Jovanovic (1989), Cressy (1996) and others which demonstrate that financial constraints restrict young firms' investment decisions. However, the distribution of firm-level productivity displays similar patterns over time, so financing constraints probably do not tell the whole story; see Roberts and Tybout (1996) and Aw, Chen and Roberts (2001).

In contrast, the firm size distribution in very poor countries tends to be heavily left-skewed even in the cross-section, with a second, smaller mode at the right end. Hence the missing middle. Figure 2 illustrates this pattern in the Nicaraguan industrial census. Tybout's (2000) survey of the literature on manufacturing in developing countries cites evidence of the missing middle phenomenon from several continents. Policy literatures also refer to this phenomenon extensively, expressing concern about its implications for competition and social mobility; see the UNCTAD *Least Developed Countries Report 2006*. The missing middle phenomenon is also also associated with weak competitition in product markets dominated by large firms.

The skewed size distribution in poor countries is paralleled by evidence on firm performance. Van Biesebroeck (2005) finds that small formal-sector firms in sub-Saharan Africa rarely grow to reach the top of the size and productivity distribution, unlike in more developed countries. Large firms appear more productive everywhere,[29] but the gaps are the most stark in very poor countries, especially in sub-Saharan Africa. Large firms in Ghana are significantly less likely to exit than small firms even controlling for age and productivity (Frazer 2005).

The literature does not provide a satisfying explanation for these patterns. Lewis's notion of the distribution of managerial talent echoes the instincts of development economists; entrepreneurial skills are certainly scarce in very poor countries, particularly in those with legacies of violent conflict or state ownership. However, the returns to managerial skill in such a context should be very high, and with countries of ten or twenty million people it is difficult to believe that scarcity of potential managers alone limits the formal private sector as

[29] Keep in mind that "productivity" in such studies is confounded with market power and output prices.

much as is evident in sub-Saharan Africa. Credit constraints in of themselves might slow the growth of smaller firms, but should not prohibit them from competing with larger firms in industries without large economies of scale. Several authors are skeptical of the role of credit constraints in explaining the woes of small firms in developing countries, e.g. Kochar (1997). Other arguments about small market size have bearing on weak competition but not on the dominance of large firms per se.

Over-regulation in poor countries offers a more plausible story. Small and medium enterprises may be too large to escape notice by corrupt government officials but too small to buy them off; see *Doing Business 2006*. The failure of bureaucrats to adequately price-discriminate among firms of different sizes causes firms which otherwise could grow to remain tiny and informal. This can be viewed as a form of rent-sharing between regulators and large incumbent firms, who earn anticompetitive rents because of the effective entry barriers created by over-regulation.

In general, credit constraints combined with non-convexities in production offer a potential mechanism for anticompetitive markets in which large incumbent firms systematically dominate entrants. If credit constraints restrict the potential size of entrants in an environment which is hostile to small firms, it is very difficult for entrants to compete. The argument of this paper relies on such a mechanism: if centrally available electricity or similar inputs have high cost and low reliability, then the possibility of firms self-providing the relevant inputs creates economies of scale, which protects incumbent firms from competition if entrants are scale-constrained.

3. Infrastructure, Costs and Economies of Scale

This section provides a heuristic overview of the argument and provides some evidence that the underlying assumptions are relevant in the types of environments under consideration.

a. The Basic Logic

The notion that infrastructure plays a role in competition and market structure is not new. It is well-known that poor internal transport systems segment markets and insulate local producers, resulting in weak competition and smaller average firm size.[30] The argument here is different. Consider the class of intermediate inputs with the following three characteristics:

C1: Rivalry. Firms capture the primary benefit of self-production of the input.
C1: Economies of scale in production. Self-provision of the input is expensive for small firms.
C3: Low substitutability. The elasticity of substitution between the intermediate input and other inputs is less than one.

[30] Aghion and Schankerman (1998) model this phenomenon and its implications, focusing on competition in transition economies. Brown and Earle (2001) provide supporting evidence from Russia, finding that the inverse relationship between market concentration and productivity is weaker where transport infrastructure is poor.

Electricity is the best example of an input meeting C1-C3. Firms can capture the full benefits of electricity they produce using private generators; per-kilowatt-hour costs of private electricity generation fall dramatically with scale; electricity is typically complementary to capital inputs and in many industries is not easily substitutable for other inputs. Security is also a good candidate, as the cost of providing security to a large facility rises less than proportionally with the size of the premises, which is the basic logic of centrally-provided police services. Transport infrastructure is the best example of a high returns to scale input which generally fails the rivalry condition, except on a truly massive scale: it is worth noting that some mining conglomerates in Africa build their own direct-to-port railway lines.

Returning to electricity, the argument follows directly: (i) firms cannot easily substitute other inputs for electricity, by C3; (ii) firms have incentives to self-provide electricity when centralized electricity service is poor, by C1;[31] and (iii) large firms can self-provide electricity much more cheaply than small firms, by C2; therefore (a) lower quality of centralized electricity services increases the production costs of small firms more than that of large firms, and (b) the magnitude of the effect in a particular industry is determined by the productivity advantage of electricity-using technologies relative to non-powered technologies (the natural electricity intensity of the industry). Poor central electricity service effectively creates artificial scale economies which act as an informal entry barrier to small firms, resulting in low viability of SMEs and larger firm size.[32] If the number of large domestic incumbents is small, this also reduces competition.

Extensions of this argument generate more implications. Electricity, communications and similar inputs are used intensively in modern technologies and tend to be complementary to capital (Bernt and Wood 1975) and skilled labor. Hence their poor reliability may cause small firms to use 'backwards' technologies. While small firms can avoid the direct costs of poor electricity systems by using hand-powered machines or hand tools, the productivity of such technologies is very low and the fact that firms can and do adopt them in response to poor electricity systems can hardly be viewed as evidence that electricity systems are unimportant. Indeed, one of the most important questions in growth theory is why better technologies do not diffuse more rapidly to poor countries; one answer may be that advanced technologies use infrastructure-related inputs relatively intensively.[33] Such effects on technology choice may also play a role in depressing the demand for skilled labor, and more broadly, may have major negative impacts on aggregate productivity through complementarities (e.g. Jones 2005).

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[31] The argument in this paper is irrelevant for highways, for instance, because firms can only capture a small fraction of the total benefit of a self-produced highway. Hence firms will not respond to poor transport infrastructure by building highways themselves. Of course, in a world with no transactions costs and perfectly enforceable complex contracts, many different existing and potential firms could organize to build and share roads and railways and ports. We do not observe this in reality, particularly given the adverse contracting environments in very poor countries.

[32] Note the similarities between this argument and those focusing on regulatory burdens, which essentially posit increasing returns to scale in bribing government officials.

[33] For instance, small firms which sell handicrafts to tourists on the street are ubiquitous in Africa, but small firms selling arts and crafts to developed country markets over the internet are rare, unlike in Brazil or China. Of course, there are several possible explanations for this.

b. Empirical Relevance of the Conditions

It is worth commenting on the empirical content of the conditions under which the argument holds to convince the reader of their plausibility. To begin with, classical economic analyses of firms think of capital, labor and raw materials as the key inputs in production; one might be skeptical of the plausibility of an argument which posits large effects of the cost and quality of other inputs. Two responses to this point are in order. First, in very poor countries, *indirect costs* for inputs other than capital, labor and raw materials account for 15-30% of manufacturing firms' costs, dwarfing labor costs in some (Eifert, Gelb and Ramachandran 2006); see Figure 1. In value terms, most of these inputs are associated with infrastructure and public services: in Kenya, energy accounts for 35% of indirect costs on average, transport for 16%, communications for 8%, and security expenditures for 5%. These magnitudes suggest the costs of indirect inputs can indeed be a source of significant competitive advantage or disadvantage.

Second, the reliability of the electricity supply has sharp implications for productivity. Firms with electricity-using technologies cannot operate when the power is out unless they run a generator. In countries where power outages occur on a near-daily basis (see Figure 2) firms which depend on the public grid must maintain excess capacity relative to what would otherwise be necessary to produce their target output. This contributes to low capacity utilization among manufacturing firms in very poor countries, which tends to be in the 50-60% range compared to 80% or more in major manufactures exporters (Eifert and Ramachandran, 2004). If outages are unpredictable, firms are also stuck paying labor which is useless whenever the power goes out.

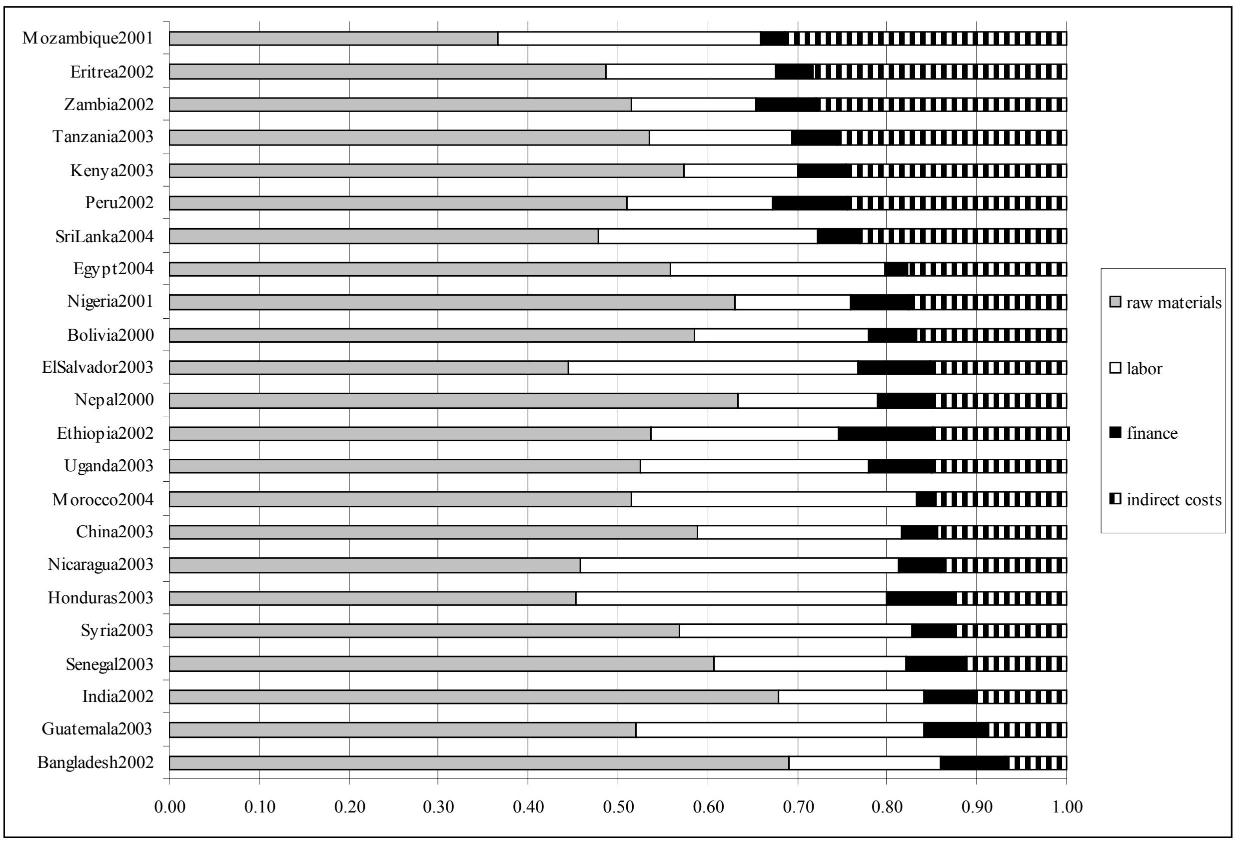
Another concern may be the degree of scale economies inherent in self-provision of services like electricity. Figures 3 and 4 provide data from Cummins on the fuel efficiency and purchase price per kW capacity of diesel generators. The purchase price of Cummins 60hz industrial diesel generators ranges from the equivalent of $1,214 per kW for a 6.8 kW prime-rated unit to the equivalent of $155 per kW for a 1825 kWh prime-rated unit, and the fuel efficiency of a 7-15 kW generator is in the range of 0.11 gallons of diesel fuel per kWh compared to 0.065 gallons per kWh for larger units. The operating life of larger units is also longer. Altogether, the average cost of electricity from a generator larger than 400kW is roughly $0.20 per kWh, compared to roughly $0.60 per kWh from a 7.5kW generator.[34] Big generators are still expensive compared to the $0.05 – $0.07 range for electricity from most public grids but nonetheless produce at around one-third of the cost of small-scale generation. In addition, generator costs are heavily front-loaded in the purchase price, so the real cost to small firms in developing countries facing very high interest rates is correspondingly higher.

Finally, one might imagine small firms co-producing and sharing inputs like electricity, or private firms responding to poor government services by providing services to the market on a large scale. The latter is simply illegal in most countries; utility monopolies rarely appreciate competition. In Nigeria, any firm wishing to import a generator – even for purely private use – must obtain a license from the government utility monopoly itself. As for the former, it is

[34] Assuming $4 per gallon for diesel fuel and an operating life of 10,000 hours for the 7.5kW generator and 15,000 hours for the 2,000 kW generator.

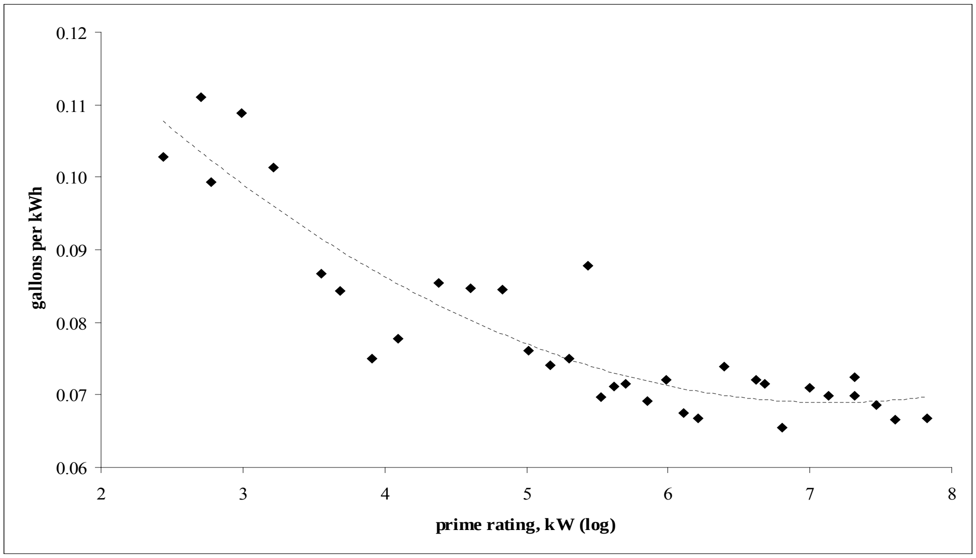
legal in principle, but difficult in practice for two reasons. First, contracts between firms are difficult to enforce in very poor countries; courts take years to complete cases and lawyers are far too expensive for small firms to hire (see *Doing Business* 2007). This is complicated further by the difficulty of monitoring the quantity of electricity used by individual firms sharing a generator. In practice, even in retail districts of African capital cities where generator-sharing between neighboring shops might be easier, one often sees a small generator running outside each and every shop.

Figure 1. Cost Structures of Manufacturing Firms, Firm-Level Average by Country



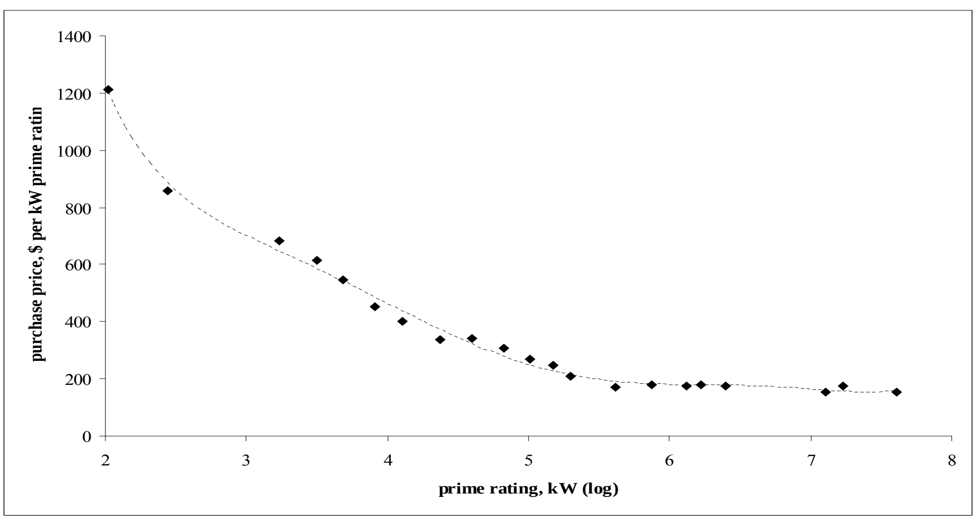
Source: Eifert, Gelb and Ramachandran (2006)

Figure 3. Diesel generator capacity (kW, prime output rating) versus fuel efficiency, log scale



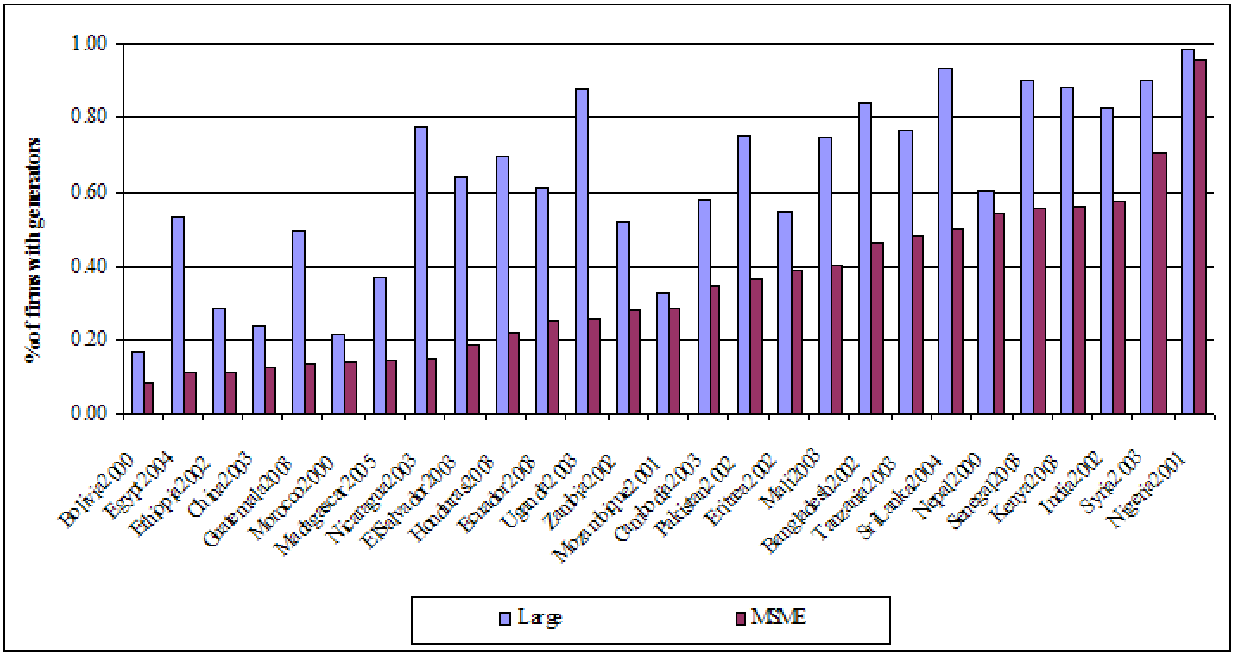
Source: Cummins Power specification and data sheets for 60hz diesel generator sets, www.cummins.com.

Figure 4. Diesel generator capacity versus purchase price ($ per kW prime rating), log scale



Source: Cummins Power specification and data sheets for 60hz diesel generator sets, www.cummins.com.

Figure 5. Private generator ownership, large firms (100+ employees) versus SMEs



Source: World Bank Investment Climate Surveys, 2000 – 2005

4. A Simple Model

This section illustrates the way the quality of electricity supply disproportionately increases small firms' costs and the resulting implications for competition and equilibrium outcomes.

The next section lays out a simple model illustrating the above logic. While the results are fairly general, the model is framed with respect to electricity and uses simplifying assumptions to maximize clarity and transparency.

a. Basic Setup

The model is a static oligopoly game with technology choice and potential entry. First, potential entrants decide whether or not to enter a market occupied by a set of incumbent firms. Second, firms in the market invest in capacities and choose technologies. Third, firms compete on price subject to the capacity constraints and technologies chosen in the previous phase. The outcome in most regards mimics a potentially asymmetric Cournot-Nash game with entry.[35] Several special features of the model are adopted for analytical convenience, but the basic results will hold in any quasi-competitive oligopoly setting in which firm profit (industry output) is a smoothly decreasing (increasing) function of the number of firms in the market.

[35] See Kreps and Scheinkman (1983).

Demand. Consider a small market for a homogenous manufactured good with a relatively elastic demand assumed to be linear for simplicity: $p = \overline{p} - \alpha Y$, where Y is total market output.

Firms. There are J identical incumbent firms j in the market, with outputs y_j. Assume the incumbents have access to credit and/or sufficient retained earnings to cover capacity investments over the relevant range for the market. Think of these firms as well-established, oligopolistic and profitable, and their number as small. One way to interpret the assumption of a "small" number of large incumbent firms is as ex-state-owned enterprises in the context of transitions from heavily regulated economies.

Potential indigenous entrants are indexed by *k*. These are the SMEs which can enter and compete with larger incumbents. Assume that entrants are constrained at start-up to a capacity of $\overline{z}$ or less: we can think of this as arising from financial market imperfections, lack of managerial capital like in Lucas (1978), convex adjustment costs in a dynamic framework, or some other source of "smallness". Note that entrants must not be able to seamlessly reach the scale on which the incumbents operate, or the mechanism offered here has no bite.[36]

Production technologies. There are two production technologies $h \in \{t, m\}$ available, a *traditional* technology *t* and a *modern* technology *m*. The former uses labor alone, according to the production function $y(L;t) = \beta^{-1} \cdot L$, with $\beta > 1$ an (inverse) productivity parameter. The latter uses labor and an indirect input (electricity), with $y(L,e;m\} = \min\{L,e\}$. That is, the modern technology is labor-saving but requires an intermediate input.

Capacities. Firms initially invest in capacities and subsequently are restricted to produce at or below their installed capacities: $y_i \leq z_i \quad i = j,k$. The user cost of capacity is $\tau > 0$, assumed for simplicity to be the same across technologies. The key assumption is that entrants are constrained to a maximum of $\overline{z}$ units of capacity.

In order to capture the notion of a small market as simply as possible, it is assumed that a minimum scale (MS) constraint bounds the production of each firm below at $\hat{y}$. It would suffice to assume fixed costs or increasing returns to scale in the basic production technologies over some range, hence determining $\hat{y}$ endogenously, but formulation is a very useful simplifying device and produces results that are qualitatively identical.

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[36] Potential large foreign entrants clearly violate these conditions. Like imports, the possibility of entry by foreign firms places an upper bound on the profitability of a domestic oligopoly. However, start-up costs for foreign firms entering new international markets are quite high, so this is primarily relevant in larger developing countries with lucrative domestic markets. A world-class international firm will be more efficient than most domestic producers in a small African country, but the limited demand available in such a market may not justify the costs of such a firm devoting its managerial capital to setting up operations.

Phases.

1. Equilibrium among the J incumbents is characterized as the status quo;
2. Firms enter until the marginal entrant makes zero profits upon entry;
3. Firms in the market choose technologies h_i and capacities z_i;
4. Prices p_i are chosen in Bertrand price competition;
5. Profits are realized.

In the static model, a *no-entry equilibrium* is a symmetric equilibrium among incumbents only, and a *free-entry equilibrium* is a potentially asymmetric equilibrium in which entrants come in until the marginal entrant makes zero profits upon entry.

b. Benchmark Case: No Private Infrastructure

Suppose that electricity is only available from a monopolist utility supplier, so that the production technologies available are t (traditional technology) and m_n (modern technology, no generator). Central electricity service has two characteristics: (i) it is available for a fraction q of the day, and (ii) it carries an unit price v. The availability parameter q captures the fact that many electricity customers in poor countries only receive electricity part of each day, sometimes in a predictable pattern and sometimes not. Here, a firm using an electricity-dependent technology and relying solely on the public grid can produce a maximum output of qz, but must pay the full cost of labor inputs for producing z units of output. This corresponds to an unpredictable electricity supply and a corresponding inability to schedule labor around known outage periods, which is a common environment in very poor countries. Hence the inefficiencies associated with an unreliable electricity supply include the costs of idle labor and idle capacity.[37]

Under these assumptions, firms using the traditional technology have cost functions $c(y;t) = (\beta w + \tau)y$ for production levels $y \le z$, and firms using the modern technology have costs $c(y;m_n) = [(w+\tau)/q + v]y$ for $y \le qz$. The technology choice problem is identical for all types of firms because of constant returns to scale, so all firms use the modern technology if $\beta w + \tau > (w+\tau)/q + v$ and the traditional technology otherwise.

Once capacity is installed, Bertrand price competition will result in firms producing at their effective capacities $\tilde{z}(h_i) \equiv \{z \text{ if } h_i = t,\ q \text{ if} zh_i = m\}$, e.g. installed capacity for firms using traditional technology or installed capacity times q for firms using modern technology. The market price is that which sets demand equal to the sum of effective capacities. See Kreps and Scheinkman (1983) for elaboration of this argument. Also note that we do not have to worry about the case in which firms make negative profits at the market price because there is no uncertainty in this problem: such firms will not enter in the previous period.

[37] Of course, even in some poor countries regular power outages are scheduled and precisely implemented, so that in principle firms could hire workers around the schedule of power outages. None of the qualitative results of the model depend on having to pay workers when the power is out; all that is necessary is that there is some cost for firms of not always having access to electricity from the public grid, which is fulfilled by having to finance the cost of capacity that is unused because of lack of electricity.

Knowing all this, firms which have entered the market choose capacities and technologies to maximize profits. We can think of firms as choosing y, their production in the subsequent phase, which is equivalent to choosing effective capacity $\tilde{z}(h_l)$. Each firm solves the problem:

$$[1] \qquad \max_{y_i} \pi_i = \left(\overline{p} - \alpha(y_i + Y_{-i}) - mc_i\right) y_i \qquad\qquad i = j,k$$

Where $mc = \min\{\beta w + \tau, (w+\tau)/q + v\}$, and $Y_{-i} \equiv Y - y_i$ is the total production of the other firms in the market. Assume that $mc < \overline{p}$ so that the industry exists. Let $Y^C \equiv (\overline{p} - mc)/\alpha$ be the total industry output under competitive (price equals marginal cost) behavior. To simplify notation, let $\boldsymbol{\theta} = (q, v, x, \overline{p}, \alpha, \beta, J, F, \hat{y}, \overline{z})$ be a collection of the parameters of the model. With no entry, the initial symmetric Cournot equilibrium among incumbents is given by:

$$[2a] \qquad y_j^*(\boldsymbol{\theta}) = \frac{1}{J+1} Y^C \qquad\qquad [2b] \qquad Y^*(\boldsymbol{\theta}) = \frac{J}{J+1} Y^C$$

$$[2c] \qquad p^*(\boldsymbol{\theta}) - mc_j = \frac{1}{J+1} \alpha Y^C \qquad\qquad [2d] \qquad \pi_j^*(\boldsymbol{\theta}) = \alpha \left(\frac{1}{J+1} Y^C \right)^2$$

In the final stage entry occurs. In this constant returns world, small indigenous firms can match large incumbents' production costs, so they enter until they (and hence, all firms) make zero profits. That is, we have the following result:

***Claim 1*: if the available technology set is $H = \{t, m_n\}$, then $y_i = \hat{y} \quad \forall i = j,k$ in equilibrium, and the number of entrants is $K^*(\boldsymbol{\theta}) = (Y^C / \hat{y}) - J$.**

The proof (appendix 1.1) relies on the fact that profits in a Cournot equilibrium can never be zero if the minimum scale constraint does not bind. The intuition is that cost symmetry and free entry for indigenous firms leads to an approximately competitive outcome. The equilibrium is closer to atomistic perfect competition the smaller is $\hat{y}$ and the larger is the market ($\overline{p}$).

We conclude that free-entry equilibrium requires that the minimum efficient scale constraint is binding: $y_i^* = \hat{y} \quad \forall i = j,k$, so $p^*(\boldsymbol{\theta}) - mc_j = \overline{p} - mc_j - \alpha \hat{y}(J+K) = 0$, and ignoring integer constraints, $K^*(\boldsymbol{\theta}) = Y^C / \hat{y} - J$. With constant returns to scale there is no incumbency advantage, so the equilibrium is competitive and socially efficient.

c. Basic Model with Private Infrastructure

Now suppose that, in addition to their choice of production technology, firms have access to a private infrastructure technology (here a generator). They can use the public grid as before, but now they can also privately generate electricity when the private grid is offline. Private generation of electricity is associated with a fixed cost of F and a variable cost of x per unit of e.[38] Assume that $v < x$, as is the case in almost anywhere: when one can get power from the public grid, its price is lower than the cost of private generation.

Now there are three available technologies $h \in \{t, m_g, m_n\}$: a traditional technology as well as a modern technology with or without a generator, with cost functions $c(y;t,\mathbf{\theta}) = (\beta w + \tau)y$, $c(y;m_n,\mathbf{\theta}) = [(w+\tau)/q + v]y$, and $c(y;m_g,\mathbf{\theta}) = [w + \tau + qv + (1-q)x]y + F$. Firms consider whether to incur the cost of generator ownership and operation, the efficiency losses associated with dependence on the public grid, or the productivity disadvantage of traditional technology.

As above, the choice between the traditional and modern no-generator technologies follows immediately from technological parameters and prices: traditional technology dominates if $\beta w + \tau < (w+\tau)/q + v$, and vice versa. The worse the quality of the public grid, both in terms of its reliability q and its effective cost v, the more attractive the traditional technology. In contrast, the modern technology combined with a generator has convex costs. Define:

$$[3] \qquad \hat{y}(\mathbf{\theta}) \equiv \max\left\{ \frac{F}{(q^{-1}-1)(w+\tau)-(1-q)(x-v)} \, , \, \frac{F}{(\beta-1)w - qv - (1-q)x} \right\}$$

Past the output threshold $\hat{y}(\mathbf{\theta})$, the modern technology with a generator is the least-average-cost technology. The first object inside the braces is the output level such that $c(y;m_g,\mathbf{\theta})$ just equals $c(y;m_n,\mathbf{\theta})$. In the denominator, the first term is the cost advantage from being able to operate at full capacity. The second is the variable cost advantage of power from the public grid (when available) over generator-produced power. The second object inside the braces is the output level such that $c(y;m_g,\mathbf{\theta}) < c(y;m_t,\mathbf{\theta})$. In the denominator, the first term is the productivity advantage of the modern technology. The other two terms are the cost of electricity, with fraction q from the public grid and $(1-q)$ privately generated. If the per-unit cost advantage of using a generator multiplied by total production exceeds the fixed cost of the generator in both cases, then the modern technology supplied by a generator is the least-average-cost technology.

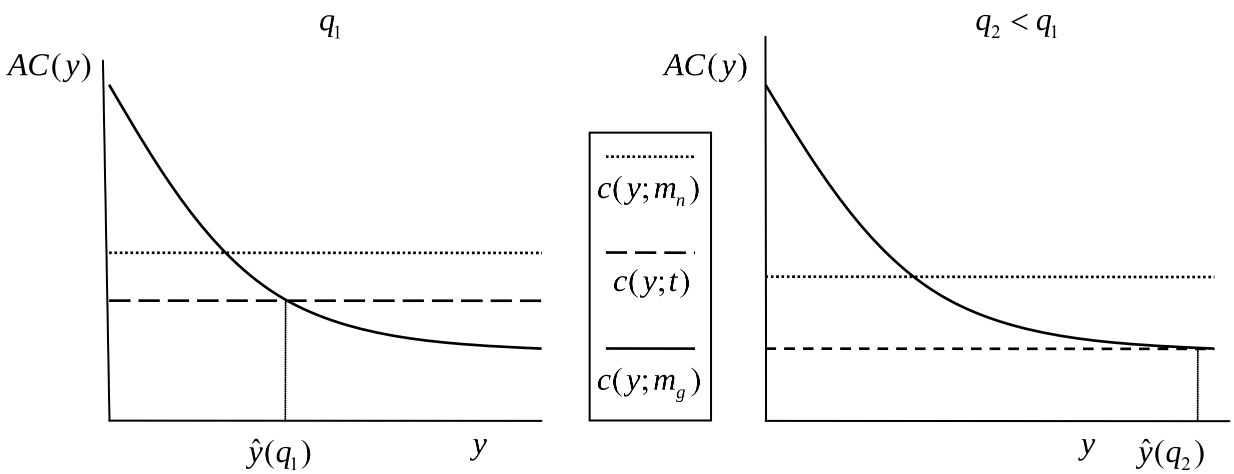
Figure 6 illustrates firms' choice of technology. Fix v and imagine it is relatively low, as is the case in most places. At a small scale, firms cannot self-provide electricity cheaply, so the non-generator technologies dominate. Which one is lower-cost depends on q and β. The right panel of Figure 6 illustrates an environment in which reliability q is high, such that $h = m_n$ is the least-average-cost option up to some very high level of production. The left panel

[38] This is not quite realistic: in reality the cost of a generator does rise with size, though the per-capacity-unit cost of a generator falls dramatically as capacity rises, and the variable cost also falls moderately with size. This specification is adopted for maximum simplicity and tractability.

corresponds to an environment in which q is low and β is not too large, with two implications: (i) $h = t$ will be optimal at low levels of production because the capacity utilization penalty $(q^{-1} - 1)(w + \tau)$ for $h = m_n$ is large; and (ii) $h = m_g$ will be cost-effective at some moderate level of production.

The intuition is straightforward. On a small scale, self-generation of electricity is simply not economical. When centrally provided electricity is inexpensive and reliable, small firms are able to profitably use higher-productivity electricity-requiring technologies. When public grids are highly unreliable, small firms are forced into using backwards technologies which avoid relying on electricity, while large firms are able to generate their own electricity supply cheaply enough to use the modern technology, attaining a lower average cost level than small firms. This builds a new dimension of economies of scale into any industry where electricity-reliant technologies are more productive than traditional technologies.

Figure 6. Technology Choice



First, we characterize the symmetric no-entry equilibrium with J incumbents, which one can think of as the status quo or initial conditions of the market:

[4a] $$y_j(\boldsymbol{\theta}) = \frac{1}{J+1}\frac{\overline{p} - mc_j}{\alpha}$$

[4b] $$Y(\boldsymbol{\theta}) = \frac{J}{J+1}\frac{\overline{p} - mc_j}{\alpha}$$

[4c] $$p(\boldsymbol{\theta}) - mc_j = \frac{1}{J+1}\left(\overline{p} - mc_j\right)$$

[4d] $$\pi_j(\boldsymbol{\theta}) = \frac{1}{\alpha}\left(\frac{\overline{p} - mc_j}{J+1}\right)^2 + \mathbf{1}\left(y > \hat{y}\right)F$$

Where $mc_j = \begin{cases} w+\tau+qv+(1-q)x & , \ y_j(\boldsymbol{\theta}) \geq \hat{y} \\ \min\{\beta w+\tau,\ (w+\tau)/q+v\} & , \ y_j(\boldsymbol{\theta}) < \hat{y} \end{cases}$.

Now, suppose that indigenous firms may enter the market up to the point where the marginal entrant earns negative profits, and consider the resulting asymmetric equilibrium with J incumbents and K entrants.

If $y_j(\boldsymbol{\theta}) \leq \tilde{z}(h_k)$, where $\tilde{z}(h_k) = \{\overline{z} \text{ if } h_k = t,\ q^{-} \text{ if} zh_k = m\}$, then individual entrants can match the scale of incumbents. If $y_j(\boldsymbol{\theta}) \leq \hat{y}$ then incumbents are too small to profitably use generators. In either case the distinction between incumbent and indigenous firms in the model is irrelevant and the equilibrium outcome is symmetric and approximately competitive. Hereafter, assume that $y_j(\boldsymbol{\theta}) > \hat{y} > \tilde{z}(h_k)$ unless otherwise specified. Note that this condition is substantive: in some environments it may fail, as in the case of a low-cost and perfectly reliable centralized power system in which $\hat{y} \to +\infty$.

As above, the parameters fully determine the choice between the traditional technology and the modern technology with no generator: firms use the former if $\beta w+\tau < (w+\tau)/q+v$ and the latter otherwise. In addition, if $y_j^*(h=m_g;\boldsymbol{\theta}) > \hat{y}$ then the incumbent firms use the modern technology with a generator. Consider the following cases:

Case 1: $\beta w+\tau < (w+\tau)/q+v$; $y_j(h=m_g;\boldsymbol{\theta}) > \hat{y}$. Here the public grid is expensive and/or unreliable enough relative to the productivity advantage of modern technology that firms using the public grid use $h=t$. However, incumbent firms can profitably use $h=m_g$. In this case, indigenous firms are capacity-constrained and also technology-constrained; they cannot reach the scale necessary to overcome the high costs of electricity inputs, but incumbent firms can. The incumbent firms hold an average cost advantage over the indigenous entrants which is equal to $(\beta-1)w-qv-(1-q)x-F/y_j(\boldsymbol{\theta})$, the difference between the unit labor cost savings of the modern technology and the average cost of electricity required to supply the modern technology under m_g.

Case 2: $\beta w+\tau > (w+\tau)/q+v$; $y_j(h=m_g;\boldsymbol{\theta}) > \hat{y}$. Here the public grid is reliable enough that indigenous entrants can profitably use the modern technology, though they are still at a cost disadvantage because of the scale economies of generators. The incumbent firms hold an average cost advantage over the indigenous entrants equal to $(w+\tau)(q^{-1}-1)-(1-q)(x-v)-F/y_j(\boldsymbol{\theta})$, where the first term is the advantage from being able to operate at full capacity, and the second is the variable cost disadvantage of generator-produced-power relative to power from the public grid, when you can get the latter.

Other parameter configurations give rise to other cases, but the above are the most interesting to us, as small indigenous firms are constrained in their technology choices relative to incumbents and hence are at a cost disadvantage.[39] All else constant, Case 1 corresponds to a worse infrastructure environment than Case 2, as the former is characterized by $\beta w + \tau < (w+\tau)/q + v$, compared to $\beta w + \tau > (w+\tau)/q + v$ in the latter. Industries with high values of β, in which traditional technologies simply cannot be cost-effective, fall immediately into Case 2.

First, we state a result which is analogous to Claim 1 one above, and an immediate corollary.

***<u>Claim 2</u>*: If the technology set is $H = \{t, m_g, m_n\}$ and $\overline{y} < \hat{y}$, if any indigenous firms enter, all indigenous firms produce $y_j = \hat{y}$ in equilibrium.**

The intuition here is almost identical to that above. Because indigenous firms cannot profitably use generators, they all have the same constant marginal costs, and hence will produce the approximately competitive outcome amongst themselves. This is only possible if the indigenous firms in the market are no longer able to maintain positive profits by cutting their production. If indigenous firms are producing above MES, one can show that they must be earning positive profits regardless of their number, which contradicts the definition of free-entry equilibrium.

Formally, if *J* incumbents and *K* indigenous entrants choose production with $y_i > \hat{y}\ \ \forall i = j,k$, then $y_k(\boldsymbol{\theta}) = \alpha^{-1}(J+K+1)^{-1}[\overline{p} - mc_k]$ and $\pi_k(\boldsymbol{\theta}) = \alpha^{-1}(J+K+1)^{-2}[\overline{p} - mc_k]^2$ which is strictly positive for any *K*. In contrast, if $y_k = \underline{y}$ it is straightforward to solve for the quantity K which satisfies free-entry equilibrium: $K^* = [\overline{p} - mc_k]/\alpha\hat{y} - J$. Therefore any free-entry equilibrium in which $K > 0$ must have $y_k = \hat{y}$. □

***<u>Claim 3</u>*: As long as $\tilde{z}(h_k) \equiv \{\overline{z}$ if $h_k = t,\ q^{-}$ ifz$h_k = m\} < \hat{y}$, if any indigenous firms enter, the equilibrium market price and quantity are pinned down: $p^* = mc_k$, $Y^* = (\overline{p} - mc_k)/\alpha$.**

[39] **Case 3:** $\beta w + \tau < (w+\tau)/q + v$; $\hat{y} < y_j(h = m_g; \boldsymbol{\theta})$. Here the traditional technology is best on all relevant scales: both incumbent firms and indigenous entrants are too small to reach the point where switching to a generator is cost-effective. Therefore both types of firms use traditional low-productivity technology, and there is no cost asymmetry between small and large firms. This is could happen, for instance, if the market is very small, competition among incumbents stiff and/or tariffs on imported generators very high.

Case 4: $\beta w + \tau > (w+\tau)/q + v$; $\hat{y} < y_j(h = m_g; \boldsymbol{\theta})$. Here the modern technology supplied by electricity from the public grid dominates the traditional technology. Moreover, it is not economical for either type of firm to use a private generator. This roughly corresponds to a developed-country or well-managed middle-income country environment: centralized infrastructure services are of sufficient quality to eliminate the type of cost asymmetries studied in this paper.

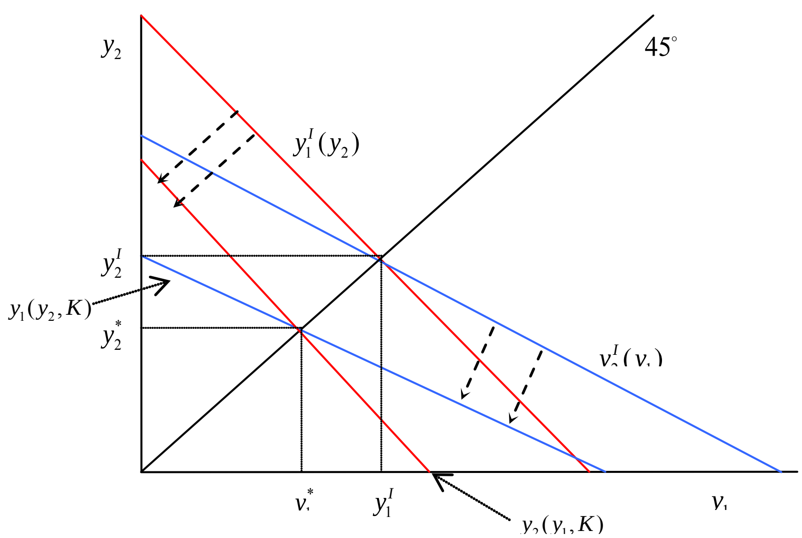
Entry among indigenous entrants ceases when the marginal entrant's profits are zero. With constant-returns technologies among entrants, the market price in free-entry equilibrium equals entrants' marginal costs, and industry output is equal to the corresponding level of demand. □

Now return to the incumbents. Letting $Y = Jy_j + K\underline{y}$ in the first-order condition for incumbent firms' profit-maximization yields their optimal production level:

$$[5] \qquad y_j^* = \left[\frac{\overline{p} - mc_j}{\alpha} - K\widehat{y}\right]\frac{1}{J+1}$$

This equation illustrates the effect of competition on incumbent firms' production levels. If entry occurs, it shifts the reaction curves of the incumbents inward (Figure 7), because each entrant will end up producing $y_k = \underline{y}$ in equilibrium. The new equilibrium is symmetric among incumbents but asymmetric as a whole.

Figure 7. Effects of Entry on Incumbents' Reaction Curves (two-incumbent case)



d. Case 1: Technological and Scale Asymmetry

We begin with Case 1, in which the poor quality of the public grid drives indigenous firms to use traditional technology while large incumbent firms use modern technology with private generators. Recall that the conditions for Case 1 reflect some combination of very unreliable centralized electricity service and modest productivity disadvantages of traditional technology.

Consider the no-entry equilibrium price from [4c], which here is $p(\boldsymbol{\theta}) = (1+J)^{-1}\left[mc_j + \bar{p}J\right]$. Indigenous entrants using the traditional technology are viable iff $p(\boldsymbol{\theta}) \geq \beta w + \tau$, e.g. if the symmetric oligopoly price equals or exceeds their marginal costs. This condition can be written generally as $K^*(\boldsymbol{\theta}) > 0$ iff:

$$[5] \qquad mc_k - mc_j < (\bar{p} - mc_k)/J \qquad\qquad mc_j = w + \tau + qv + (1-q)x, \quad mc_k = \beta w + \tau$$

That is, the cost gap between the traditional and modern-cum-generator technologies cannot be too large or entrants are completely excluded. Subject to remaining in Case 1, the following factors increase the likelihood that small firms cannot survive:

- A higher-cost environment, e.g. a higher wage w and user cost of capacity τ;
- A more competitive baseline environment, e.g. a larger number of incumbents J;
- A lower variable cost of private electricity x and a larger productivity advantage of modern technology β, both of which increase the cost advantage of incumbents;
- Higher reliability q and lower price v of centralized electricity service, which both increase incumbents' cost advantage while indigenous firms use traditional technology.

Some indigenous firms will enter if [5] is satisfied. By the claim above, entry then drives the market price down to indigenous firms' marginal cost levels: $p^*(\boldsymbol{\theta}) = \beta w + \tau$. It follows immediately that $Y(\boldsymbol{\theta}) = Jy_j(\boldsymbol{\theta}) + K\bar{y} - (p - \beta w - \tau)/\alpha$. Plugging this into [5.1] pins down the number of indigenous entrants in equilibrium and the production of each incumbent firm:

$$[6] \qquad K^*(\boldsymbol{\theta}) = \left[\frac{\bar{p} - mc_k}{\alpha} - J \cdot \frac{mc_k - mc_j}{\alpha}\right](1/\bar{y}) \qquad [7] \qquad y_j(\boldsymbol{\theta}) = \frac{J}{J+1}\left[\frac{mc_k - mc_j}{\alpha}\right]$$

Incumbents' equilibrium profits [8.1] depend on their equilibrium production level and the difference between their marginal costs and those of indigenous firms, as well as the fixed cost of the generator. The equilibrium market share of incumbent firms, σ_J in [9.1], is also determined by the marginal cost gap. Incumbent profits and market shares are the result of the dynamics of competition between incumbents and indigenous entrants: what makes entrants worse off makes incumbents better off.

$$[8] \qquad \pi_j^*(\boldsymbol{\theta}) = \frac{J}{J+1}\frac{1}{\alpha}\left[mc_k - mc_j\right]^2 - F \qquad\qquad [9] \qquad \sigma_J(\boldsymbol{\theta}) = \frac{J}{J+1}\left[\frac{mc_k - mc_j}{\bar{p} - mc_k}\right]$$

Consider the effect of marginal reductions in v and q, the price and reliability of energy from the public grid. As long as $\beta w + \tau < (w+\tau)/q + v$, we remain in Case 1 and indigenous firms use the traditional technology, so marginal reductions in v have no effect on indigenous firms' costs. However, $mc_j = w + \tau + qv + (1-q)x$, with $\partial mc_j / \partial v = -1$ and $\partial mc_j / \partial q = -(x - v)$, so improved price and quality of central electricity reduce incumbents' costs. In equilibrium, lower costs relative to indigenous entrants increases both the quantity produced by incumbents and their price-cost margin, so incumbent profits rise roughly with the square of improvements in grid quality and cost. Here incumbents clearly have incentives to lobby for infrastructure investments.

e. Case 2: Scale Asymmetry

Under Case 2, $\beta w + \tau > (w+\tau)/q + v$, so indigenous firms use the modern technology supplied by the public grid and improvements in grid reliability are cost-reducing for them.

This case has two interpretations. The first is an industry which would fit Case 1 if the centralized power system was sufficiently worse. That is, there exists a traditional technology which entrants could use and still survive in the market but q is sufficiently high to make the modern technology cost-effective. The second is an industry in which electricity-avoiding technologies are simply not viable, such that any entrant which is capacity constrained below $\hat{y}$ must make do with the modern technology and the public grid. Many activities in manufacturing and resource processing fit this description, particularly when one moves up the quality ladder away from very inexpensive locally sold products.

The conditions for entry of indigenous firms and the expressions for incumbent production, profits and market share are [6] – [9] above with $mc_k = (w+\tau)/q + v$. Taking partial derivatives of the incumbent firms' profit with respect to the quality and price of the electricity supply:

[10] $$\frac{\partial \pi_j(\boldsymbol{\theta})}{\partial q} = \frac{J}{J+1}\frac{1}{\alpha}\left[-(w+\tau)/q^2 + (x-v)\right] < 0$$ [11] $$\frac{\partial \pi_j(\boldsymbol{\theta})}{\partial v} = \frac{I}{I+1}\frac{1}{\alpha}(1-q) > 0$$

Strikingly, [10] illustrates that the reliability of the public grid q reduces equilibrium incumbent profits, where the sign follows from the cost functions: $mc(y_j; h_j = m_g) < mc(y_k; h_k = m_n)$ implies that $(w+\tau)/q > x - v$. The first (negative) term is the reduction in the capacity utilization penalty; the second (positive) term is the marginal reduction in incumbents' variable cost of electricity as the public grid becomes available more often. In addition, lower prices of electricity from the public grid actually reduce incumbent profits by equation [11], because entrants use more public electricity per unit of output than incumbents.

To reiterate, improvements to either the cost or the reliability of the power supply *decrease* incumbents' equilibrium profits and market share if indigenous firms are using modern technology. As v falls and q rises, the size threshold at which generators are profitable, $\hat{y}$, rises steadily. Meanwhile, as the gap between the marginal costs of indigenous entrants and incumbent firms shrinks, incumbents also lose their market dominance, by [9] above. As incumbent firms become smaller and the size threshold $\hat{y}$ rises, it eventually becomes cost-effective for incumbents to switch to the public grid, and their advantage over indigenous firms is fully dissipated, yielding an approximately competitive free-entry equilibrium.

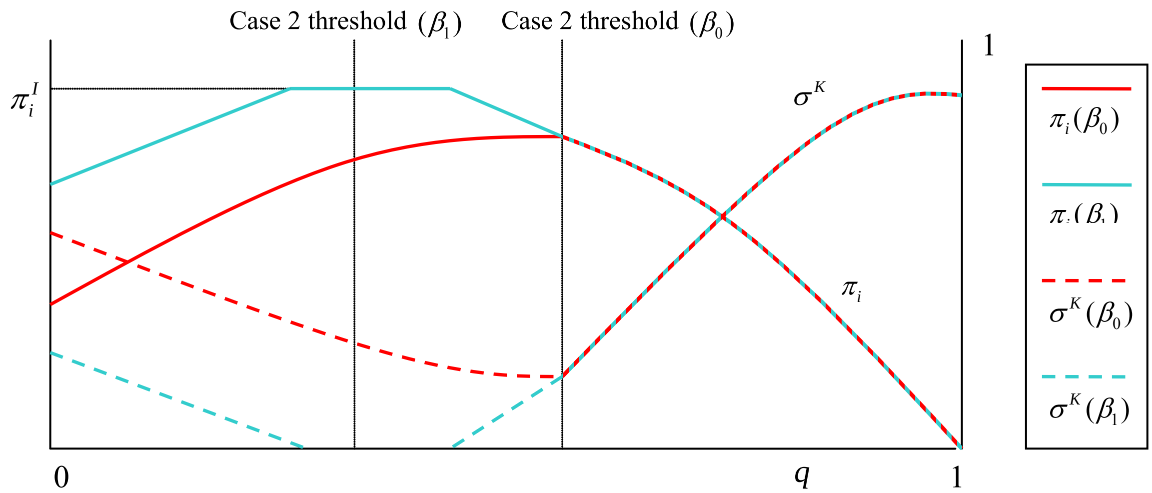
Figure 8 summarizes some of the key results thus far, mapping the reliability of central electricity service q into incumbent profits and the collective market share of entrant firms. Two separate sets of curves are shown, one for an industry with moderate natural electricity intensity β_0, and one for an industry with a higher natural electricity intensity β_1. The threshold above which entrants use modern technology is lower in the latter case, as the productivity shortfall of traditional technology is relatively large. As q increases past the relevant threshold, indigenous entrants switch to modern technology and steadily gain market share while incumbent profits fall. To the left of the relevant threshold, indigenous firms' market share is decreasing in q, because more reliable electricity supply is benefiting only the incumbent firms.

It naturally follows that entrant market share is lowest and incumbent profits highest at the thresholds between Case 1 and Case 2. These points corresponds to the level of public grid reliability under which incumbents are receiving as much cheap public electricity as possible without enabling small firms to overcome their technology constraints. As drawn, the more electricity-intensive industry has a region of q around its Case 2 threshold where no indigenous firms enter. Incumbent profits in this range correspond to those from symmetric no-entry equilibrium, the maximum possible achievable for the incumbent firms.

This non-monotonicity of incumbent profits in the quality of public infrastructure is a striking and counter-intuitive result. It follows from the general nature of imperfect competition in homogenous products: with free entry, the equilibrium profits of existing firms depend on how much lower their unit costs are than the entrants. With standard entry costs, incumbents would be more insulated from competition by entrants than outlined above, but their equilibrium profits would remain exactly the same up to an additive constant equal to the entry barrier: the logic remains identical.

It is important to note that this is fundamentally a medium-to-long-run result. In the short run a much-improved power system benefits everyone. However, infrastructural improvements which level the playing field along the firm size dimension threatens the quiet life of the oligopolist, providing small firms with a low-cost, competitive environment.

Figure 8. Public grid reliability versus incumbent profits and entrant market share



5. On the Quality of Electricity Supply

The previous sections demonstrate some of the perverse results that may obtain in a world with extremely poor public infrastructure services, in particular electricity. In what follows we endogenize the quality of electricity service in various ways, exploring the incentives of electric utility firms under different regulatory frameworks supplying industries like the one above.

a. Unregulated Electric Utility

Suppose for simplicity that the consumers of electricity include one industry made up of J large incumbents and K small entrants as above. Suppose throughout that we remain in the most interesting case, in which electricity is a sufficiently important input in this industry that both entrants and incumbents use the modern technology, but only incumbents use generators to maintain production when the public grid is offline (Case 2). Total electricity demand is given by $E^{tot} = Y^* = (\bar{p} - mc_k)/\alpha$, of which a share $\varphi \equiv (1-q)\sigma_I$ is privately generated and the rest, $E \equiv (1-\varphi)E^{tot}$, is supplied by the public grid.

Consider a private, profit-maximizing monopolist in a unified electricity production and distribution industry. The generator sets q and v to maximize profits given the electricity demand functions and the quadratic cost function $C(E) = b_1E + (1/2)b_2E^2$. Denoting $\boldsymbol{\theta}$ as the vector of parameters characterizing the manufacturing industry (less v and q) and $\boldsymbol{\gamma}$ as the vector of cost parameters for the electric utility, we have:

[12] $$\left(q^*(\boldsymbol{\theta},\boldsymbol{\gamma}),\, v^*(\boldsymbol{\theta},\boldsymbol{\gamma})\right) = \underset{q\in[0,1],\, v\geq 0}{\arg\max}\ Ev - Eb_1 - (1/2)b_2E^2$$

The objective is concave in v so we know there will be an interior solution for $v^*(\boldsymbol{\theta},\boldsymbol{\gamma})$. The relevant first-order condition implies that $v^*(\boldsymbol{\theta},\boldsymbol{\gamma}) = a_1 + E(a_2 - 1/E_v)$, where $E_v \equiv \partial E / \partial v$. That is, the profit-maximizing price of electricity is increasing in the marginal cost parameters and the scale of demand and is decreasing in the sensitivity of demand to price.

A closed-form solution for q is not easily available, but it is straightforward to prove that $q^* = 1$: a profit-maximizing firm will never systematically choose to ration electricity supply. Formally, the first-order condition for an interior maximum for q requires that $v = a_1 + a_2 E$, which given the first-order condition for v is only possible if $E = 0$. The intuition is straightforward. Over most of the relevant range of output the generator wants to sell more electricity at any given price and hence has no interest in rationing. As demand becomes sufficiently large and the generator's cost curve becomes very steep, the generator wants to reduce production to lower its costs, and can do so either by increasing v or decreasing q. Of those two mechanisms, increasing v brings in revenue while decreasing q does not, so reducing the quality of service is always inefficient for a profit-maximizing generator.

With $q^* = 1$, private generators are unnecessary, which implies that incumbents and entrants have the same marginal costs.[40] It follows that the equilibrium is symmetric and approximately competitive as in the benchmark case in Section 3. That is, a profit-maximizing, monopolistic electric utility, while it may make large profits and price electricity higher than the socially efficient rate, should not induce systematic power rationing that will produce an uneven playing field for small and large firms.

b. Price-Cap Regulation

Now suppose that the utility monopolist is regulated at a fixed price $\bar{v}$ below the monopolist's price $v^*(\boldsymbol{\theta},\boldsymbol{\gamma})$. The utility may be subsidized, indeed heavily, but the key is that those subsidies do not operate on the price margin. Also, while price-cap regulatory arrangements typically mandate that the utility meets all demand at the regulated price, such mandates are clearly not enforced in poor countries where we observe major blackouts on a weekly or daily basis. We are agnostic here about the reason for this regulatory framework, simply noting that its main features are quite common in developing countries.

Taking the price as given, the generator now solves the problem:

[13] $$q^*(\boldsymbol{\theta},\boldsymbol{\gamma}) = \arg\max_{q\in[0,1]} \; Ev - Eb_1 - (1/2)b_2E^2 \quad s.t. \;\; v = \bar{v}$$

If $\bar{v} \geq a_1 + a_2 E$ when $q = 1$, then demand is sufficiently low or the price sufficiently high that the generator's marginal revenues exceed its marginal costs at the regulated price, and the generator sets $q = 1$. In this case, regulation simply transfers profits from the utility to the

[40] Large firms in developed countries with very reliable power supplies often have generators because even one or two blackouts over the course of a year can be very expensive in terms of opportunity costs, but we considering a different phenomenon here, the systematic use of generators as primary power sources.

consumers of electricity. However, if $\bar{v} < a_1 + a_2 E$ when $q = 1$ then the utility is losing money on the marginal unit of electricity. Its preference would be to raise the price in order to reduce demand and get its costs down. In order to reduce demand to the point where $\bar{v} = a_1 + a_2 E$ and the first-order condition holds, the firm must use the only instrument it has: it lowers q until $E(q,\bar{v}) = (\bar{v} - a_1)/a_2$. In the process, the gap between the marginal costs of the entrants and the incumbents expands: $-\partial(mc_k - mc_j)/\partial q = (w+\tau)/q^2 - (x - v) > 0$. How low the resulting value $q^*(\boldsymbol{\theta},\boldsymbol{\gamma})$ ends up depends on how large the demand is relative to the cost parameters: that is, how adequate the overall electricity infrastructure system is relative to the country's needs. A useful dynamic extension of this model would characterize the utility's capacity investment decisions along with its static quality problem.

c. Preferential Treatment

The nature of electricity distribution lends itself quite well to preferential treatment of certain large customers: one simply ensures that a particular set of switches stays on when shortages lead to others being turned off. The 2005 documentary *Power Trip* traces the story of multinational electricity firm AES in its attempt to create a viable generation and distribution system in Tbilisi, the capital of Georgia in the wake of Soviet collapse. Despite the best efforts of AES executives to shut off power to a host of delinquent industrial customers, high-level interventions from government ministries ensured that reliable power supply flowed to the politically well-connected while shortages and blackouts plagued the rest of the city. Insiders remarked that the primary qualification of a minister of energy in Georgia is the ability to deliver electricity to the businesses owned by relatives of the president.

In the model above, the utility can in principle deliver a different q_i to each firm. In the one-quality world above, incumbents' profits rise as q falls even though their own costs rise, because poor-quality power systems raise their rivals' costs even more than their own. If preferential treatment is available, incumbents would be willing to pay substantial sums of money to keep their own connections running full-time: not only do their own costs fall with higher q_j, they also benefit from the fact that the utility's convex costs lead it to compensate for higher q_j by further reducing q_k, the quality of electricity supply to their rivals. In what follows, we characterize a Nash bargaining equilibrium with a regulated price $\bar{v}$ in which $q_j = 1$ for all incumbents and $q_K < q^*(\boldsymbol{\gamma},\boldsymbol{\theta})$ above so the power supply for entrants is even worse than before, with the incumbents and the generator sharing the resulting rents.

Suppose that $q_j = 1 \;\; \forall j$ and $q_k < 1$. The central utility now provides all electricity consumed in the industry, so it solves the problem:

$$[14] \qquad q^*(\boldsymbol{\gamma},\boldsymbol{\theta}) = \underset{q\in[0,1]}{\arg\max} \;\; E^{tot}v - E^{tot}b_1 - (1/2)b_2(E^{tot})^2 \quad s.t. \;\; v = \bar{v}$$

The first-order condition is $E^{tot} = (\bar{v} - a_1)/a_2$. For any fixed quality level $q_0 < 1$, the total quantity of centrally supplied electricity $E \equiv (1-\varphi)E^{tot}(q_0,\bar{v})$ under the uniform quality regime above is lower than that supplied under the discriminatory regime,

$E^{tot}(q_j = 1,\, q_K = q_0,\, \overline{v})$, because $E^{tot} = Y^*(q, \overline{v}, \boldsymbol{\theta}) = (\overline{p} - mc_k)/\alpha$. If the first-order condition holds in both regimes, it follows that $q_k^*(\boldsymbol{\gamma},\boldsymbol{\theta}) < q^*(\boldsymbol{\gamma},\boldsymbol{\theta})$: that is, the quality of the electricity supply to small entrants is lower in the discriminatory regime than in the uniform quality regime. The equilibrium value of q_K^* and the resulting expression for the marginal costs of the small entrant firms are:

[15] $$q_k^p(\boldsymbol{\gamma},\boldsymbol{\theta}) = \frac{w+\tau}{\overline{p} - \overline{v} - \alpha(v - a_1)/a_2}$$ [16]

$$mc_k^p(\boldsymbol{\gamma},\boldsymbol{\theta}) = \overline{p} - \alpha(\overline{v} - a_1)/a_2$$

Where the p superscript denotes preferential treatment. Note the perverse result: in equilibrium, small firms' marginal costs are *decreasing* in the regulated price of public electricity, because the regulated utility responds to a higher price by providing higher-quality service, which in turn levels the playing fields between small entrants and large, generator-equipped incumbents. Compare [15] and [16] to the corresponding expressions in the uniform-quality regime:

[17] $$q_k^u(\boldsymbol{\gamma},\boldsymbol{\theta}) = \frac{w+\tau}{\overline{p} - \overline{v} - \alpha(v - a_1)/[(1-\varphi)a_2]}$$ [18] $$mc_k^u(\boldsymbol{\gamma},\boldsymbol{\theta}) = \overline{p} - \frac{\alpha(\overline{v} - a_1)}{(1-\varphi)a_2}$$

Where u denotes uniform quality and $(1-\varphi)$ is the fraction of total electricity demand met by the utility.[41] Now consider the profits of the incumbent firms in these two regimes:

[19] $$\pi_j^p(.) = \frac{J}{J+1}\frac{1}{\alpha}\left[mc_k^p(\boldsymbol{\gamma},\boldsymbol{\theta}) - mc_j^p(\boldsymbol{\gamma},\boldsymbol{\theta})\right]^2 - F$$

[20] $$\pi_j^u(.) = \frac{J}{J+1}\frac{1}{\alpha}\left[mc_k^u(\boldsymbol{\gamma},\boldsymbol{\theta}) - mc_j^u(\boldsymbol{\gamma},\boldsymbol{\theta})\right]^2 - F$$

The extra profit for each incumbent firm in the preferential regime is:

[21] $$\pi_j^p - \pi_j^u = \frac{J}{J+1}\frac{1}{\alpha}\left[\Delta mc_k - \Delta mc_j\right]^2$$

$$\Delta mc_j = \frac{\alpha(v-a_1)}{(1-\varphi)a_2} - \frac{\alpha(v-a_1)}{a_2} \quad ; \quad -\Delta mc_j = \frac{(x-v)(w+\tau)}{\overline{p} - \alpha(v-a_1)/a_2} - \frac{(x-v)(w+\tau)}{\overline{p} - \alpha(v-a_1)/[(1-\varphi)a_2]}.$$

$\Delta mc_j > 0$ is the increase in the marginal costs of entrants after the switch to the preferential regime and $-\Delta mc_j > 0$ is the reduction in the marginal costs of incumbents.

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[41] φ is a function of q, but the true closed-form expression for q as a function only of exogenous variables takes nearly a page to write down. This formulation will be adequate for the analysis that follows.

In equilibrium, entrants are willing to pay up to $\hat{y}$ for each unit reduction in their marginal (=average) costs. Therefore the total willingness to pay of the entrants to avoid the regime switch is $wtp_K = K\hat{y}\Delta mc_k$, compared to a total willingness to pay of incumbents to force the regime switch, $wtp_J = J^2(J+1)\alpha^{-1}\left[\Delta mc_k - \Delta mc_j\right]^2$. If wtp_J strictly exceeds wtp_K, the total surplus to large incumbents from successfully lobbying for the regime switch exceeds the maximum amount that entrants would collectively be willing to pay to avoid it. If this is true, then assuming a simple Nash bargain between the utility and the incumbent firms results in the generator implementing the preferential treatment regime with $q_j = 1$ and a 50-50 split of the resulting surplus profits between the incumbents and the generator. After some algebra, we have:

$$[24] \qquad wtp_J > wtp_K \text{ if } J > \left(\frac{\Delta mc_k - \Delta mc_j}{mc_k - mc_j}\right)^{-1} \cdot \frac{\Delta mc_k}{\Delta mc_k - \Delta mc_j}$$

The first factor on the right-hand-side is the (inverse of the) additional marginal cost gap induced by the regime switch as a percentage of the original marginal cost gap. The second factor is the increase in entrants' marginal costs as a percentage of the total increase in the marginal cost gap. Condition [24] is more likely to hold the more incumbents are in the market, the larger is the potential percentage increase in the incumbents' cost advantage and the larger is their marginal cost reduction $-\Delta mc_j$ relative to the total increase in their marginal cost advantage.

Calibrationally, this condition can only fail to hold when the incremental reduction in quality of service for entrant firms from the regime switch is small. A series of simulations under plausible ranges of the firms' marginal cost parameters suggest that one incumbent is almost always sufficient and only very strange cases would require more than two incumbents.[42] The reason for this is straightforward: small firms are only willing to pay to reduce their own costs, but large firms are willing to pay both to reduce their own costs and to *increase* those of their rivals, hence raising the output price they face and transferring resources from consumers to themselves.

The resulting equilibrium is clearly inefficient. The aggregate industry production level $Y^* = (\bar{p} - mc_k)/\alpha$, and hence the entrants' marginal cost, is a sufficient statistic for social welfare in this model. The redirection of electricity supply from entrants to oligopolistic incumbents reduces price competition and total industry output. As a result, consumers of the manufacturing firms' products pay higher prices, generating anticompetitive rents which are split between the incumbent firms and their friends at the power utility.

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[42] For instance, denoting the initial uniform quality level as q and the quality level facing entrants in the discriminatory regime as q_k, suppose that $w = 0.475$, $\tau = 0.475$, and $v = 0.05$, scaled such that a firm in a $q = 1$ environment would have 47.5% of its costs accounted for by labor, 47.5% by capital and 5% by electricity. Suppose that $x = 0.20$, $q = 0.75$ and $q_k = 0.5$. Then $mc_k = 0.56$, $\Delta mc_k - \Delta mc_j = 0.52$ and $\Delta mc_k = 0.48$, so condition [24] holds with only one incumbent in the market.

6. Discussion

This is a paper about the causes and effects of misallocation of resources in an economy. The basic idea is that even certain public services which have broad-based positive impacts on an economy may in fact erode the rents of entrenched constituencies, potentially giving rise to political economy dynamics that obstruct the emergence of good governance.

a. The Basic Logic

First the paper sets up a technological argument: a particular type of intermediate inputs which are closely related to the quality of public services may have downstream effects on market structure and profits. The peculiar feature of this technological result is that large incumbent firms in some circumstances may be more profitable in equilibrium when the quality of those inputs is *low*. Dysfunctional public electricity grids increase their small competitors' costs much more than their own because of economies of scale in self-provision of electricity.

The paper then points out the implications of that peculiarity for how we think about the quality of electricity supply in very poor countries. An unregulated monopolist electricity supplier would provide high quality service, and hence a level playing field for large and small firms, albeit potentially at a high price. The much more common real-world environment, with price-cap regulation and excess demand, results in the utility using quality shortfalls to force effective demand down to a level it is willing to supply at the regulated price. Worse still, in a political economy framework in which incumbent firms can bargain with the electricity supplier for preferential treatment, under weak conditions they will collude together to extract surplus from consumers, resulting in even greater market concentration, lower total output and higher prices.

The basic mechanism generating the sharp inefficiency detailed here is that incumbents' profits depend not only on their own costs but also on the costs of their potential rivals. When they bargain with regulators for a high-quality electricity supply they directly increase entrants' costs. The reduction in competition transfers resources from consumers to incumbents and to the managers of the utility with whom they collude.

The model is framed with respect to electricity, but the general principles hold for any input meeting C1-C3 above. The impact of the introduction of cellular services in Africa provides an excellent and optimistic illustration. Prior to cellular service, African small businesses and micro-enterprises rarely had any form of modern communications technology, because the minimum cost of basic telephone service made it prohibitively costly. Cellular service and text messaging effectively bypassed dysfunctional telecommunications monopolies and offered a low-cost modern communications option for businesses of any size, eliminating economies of scale in the use of communications services. Now cell-phone penetration among small and medium enterprises in most African countries is very high, allowing SMEs to compete in activities which require modern communications, especially longer-range trading and distribution. See the Vodafone (2002) report on the impact of cellular services in Africa.

b. Limitations and Extensions

The model as it stands conveys the basic intuition, but has several main limitations and could be extended in several directions.

First, the static model abstracts from crucial dynamic considerations. In particular, the electricity utility's decisions about investment in new capacity (in the model, lowering a_2) are central to understanding the quality of the electricity supply over the medium and long run. Adding more nuance to the short-run versus long-run effects of infrastructure reform on the profits of incumbents and entrants would also be useful. The dynamic extension of this model would add significant insight, though it would complicate the analysis significantly.

Second, the model focuses entirely on domestic markets, but this sets aside a very interesting set of issues. Note that exporters care only about their costs relative to the world price, unless they also sell on a lucrative domestic market, so if the incumbent firms export most of their output their equilibrium profits will not be decreasing in the quality of public electricity service. If the incumbents are exporters they still may bargain for a high-quality electricity supply for themselves at the expense of entrants. However, their equilibrium profit gains from the preferential treatment regime are much lower, unless the domestic market is also a significant source of their revenue. More generally, it is intuitive that exporters have stronger incentives to lobby for high-quality public services because any cost reductions that result turn into profits rather than being partially passed along to domestic consumers through competition.

Third, the model retains the assumption of homogenous products throughout. With vertically differentiated products, the natural assumption would be that higher-quality products use infrastructure-related inputs like electricity more intensively, while traditional technologies are good at producing low-quality products. It would follow that large incumbent firms dominate the sale of higher-value, higher-quality products and charge high markups, while indigenous entrants are restricted to low value, low-quality products targeted at price-sensitive, quality-insensitive segments of the domestic market. This corresponds tightly to the nature of the informal sector in very poor countries; micro firms rarely compete directly with large firms, but instead produce low-quality, low-price products with little growth potential or room for innovation.

Fourth, the logic of the model suggests that firms in dysfunctional infrastructure environments should be more likely to choose vertically integrated structures in order to exploit economies of scale in the self-provision of infrastructure. This reduces opportunities for specialization and gains from trade but also reduces dependence on fickle public services. It also potentially suggests that firms could have a small presence in many markets and achieve the same cost savings. In a way this suggests that if firms cannot share generators or other infrastructure because of contracting problems they should merge in order to overcome those problems. However, this notion no doubt suffers from diseconomies of scope and the practical limitations of many small entrepreneurs joining together in one disparate firm.

Finally, the story is applicable in a limited set of circumstances and may not explain most of the widespread poor performance of small firms in very poor countries. Its applicability is limited to markets where trade barriers and transport costs still insulate domestic producers, like machinery and processed resources, not textiles and garments. It is also limited to relatively small markets, like those found in most African and Central American countries, except where transport costs effectively segment large markets into many small markets (perhaps some parts of India).

c. Empirical Implications

The model laid out above is very stylized, with no meaningful heterogeneity or dynamics. However, it does seem to allow a few empirically relevant insights.

First, and most obvious, the quality of central electricity infrastructure should affect aggregate measured productivity, because the cost of private electricity generation by industrial firms is much higher on average than the cost of electricity generated at scale by utilities. Second, poor-quality centralized electricity service should create larger excess costs and productivity shortfalls for smaller firms because of the economies of scale in the private generation of electricity. This may in turn have equilibrium implications for concentration and product market competition.

However, firms' ability to choose from a set of production technologies – including "modern" technologies which may have higher productivity but be more sensitive to the quality of the power supply, and "traditional" technologies which can be operated largely without electricity – complicates the empirical relationship between power service quality, firm size and measured productivity. Because small firms in electricity-poor environments may primarily use hand-powered technologies, improvements in power supply may have a much smaller impact on this group than on larger firms *in the short run*. However, in the long run better power supply may lead existing small firms to adopt higher-productivity electricity-using technologies or lead to the entry of new small firms using such technologies. This suggests that econometric exercises which use contemporaneous variation in power supply quality and productivity may have difficulty identifying differential effects across firm sizes, and that exercises focused on longer-run dynamics in the firm size distribution may be more fruitful. Of course, such exercises are more problematic econometrically given the likely association between long-run trends in power supply and other policy and institutional variables that might affect the firm size distribution. Direct observation of the technology adoption choices made by small firms would be very informative here.

The political economy implications of bargaining between large incumbents and electricity service providers are interesting albeit very demanding in terms of data. If one could observe the fraction of time that public utilities were providing electricity to different districts and industrial zones within a metropolitan area, and if one also had data on the specific locations of firms, one could test whether large firms benefit from preferential access. Of course, one would have to deal with confounding issues like large firms having greater resources to rent or buy more expensive land in areas which historically receive better power service.

d. Conclusions

In making progress on understanding why some poor countries find themselves on rapid growth trajectories and others remain stagnant, the notion of systematic misallocation of resources seems to play an important role. One mechanism that can generate misallocation of resources is weak competition and barriers to entry. This paper offers a story for how the low-quality provision of crucial public services can generate barriers to entry and secure rent streams for oligopolistic incumbents in industries which require the relevant inputs intensively. Worse, it suggests that those incumbents may have incentives to bargain with the providers of public services to ensure outcomes that keep the playing field asymmetric. This reduces competitive pressure on incumbents to adopt new technologies, reduce costs and develop new products. Given the fact that high-value activities use infrastructure-related inputs like electricity and telecommunications relatively intensively, this dynamic may reinforce the failure of very poor countries to diversify into nontraditional, higher-value exports and generally distort the development process.

7. Appendix A1: Proof of Claim 1

If the MES constraint does not bind there are two possibilities: $y_j^* > \tilde{z}(\boldsymbol{\theta})$ and $\tilde{z}(\boldsymbol{\theta}) > y_j^*$.

First, suppose that J and K are such that $y_j^* > \tilde{z}(\boldsymbol{\theta})$, such that in equilibrium the indigenous firms are capacity constrained. Then re-solving the Cournot problem with $y_k = \tilde{z}(\boldsymbol{\theta})$, we have:

[A.1] $$y_j^* = \frac{1}{J+1}\left[\frac{\overline{p}-mc}{\alpha} - K\tilde{z}(\boldsymbol{\theta})\right]$$ [A.2]

$$p^* - mc = \frac{1}{J+1}\left[(\overline{p}-mc) - \alpha K\tilde{z}(\boldsymbol{\theta})\right]$$

Equation [A.1] with $y_j^* > \tilde{z}(\boldsymbol{\theta})$ implies $\tilde{z}(\boldsymbol{\theta}) < \frac{1}{J+K+1}\left[\frac{\overline{p}-mc}{\alpha}\right]$; substituting into [A.2] yields:

[A.3] $$p^* - mc > \frac{1}{J+K+1}(\overline{p}-mc) > 0$$

Equation [A.4] contradicts the definition of a free-entry equilibrium, because replacing K with $K+1$ leaves a positive price markup over marginal costs, so additional indigenous firms would enter. Moreover, [A.3] implies that $\forall K \in \square$, $p^* - mc > 0$. We conclude that indigenous firms cannot be capacity constrained in a free-entry equilibrium. Because indigenous firms are not capacity constrained, they are effectively identical to incumbents, and we know the equilibrium will be symmetric.

Now suppose that the symmetric free-entry equilibrium has J and K such that $y_i^* > \widehat{y} \quad \forall i = j,k$. Then $p^* - mc = (J+K+1)^{-1}(\overline{p}-mc) > 0$, again contradicting the definition of equilibrium because $\forall K \in \square$, $p^* - mc > 0$.

With $y_i^* = \widehat{y} \quad \forall i$, we have $p^* - mc = \overline{p} - mc - \alpha\widehat{y}(J+K) = 0$, and ignoring integer constraints, $K^* = Y^C / \widehat{y} - J$. □

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Chapter 3

Does Management Matter?

Evidence from India[43]

[43] Jointly authored with Nicholas Bloom, Aprajit Mahajan, David McKenzie and John Roberts

1. Introduction

Economists have long puzzled over why there are such astounding differences in productivity between firms and across countries. For example, US plants in very homogeneous industries like cement, block-ice, white-pan bread and oak flooring display 100% productivity spreads between the 10th and 90th percentile (Syversson 2004, Foster, Haltiwanger and Syverson, 2008). At the country level, Hall and Jones (1999) and Jones and Romer (2009) show how the stark differences in productivity across countries account for a substantial fraction of the differences in per capita income. Understanding the source of these differences is clearly a central issue for economics, as well as many other disciplines in social science.

A natural explanation for these productivity differences lies in variations in management practices. Indeed, the idea that "managerial technology" determines the productivity of inputs goes back at least to Walker (1887), and is central to the Lucas (1978) model of firm size.[44] Yet while management has long been emphasized by the media, business schools and policymakers, models of growth and productivity by economists have typically ignored management, reflecting skepticism in the economics profession about its importance.

One reason for this skepticism is the inherent fuzziness of the concept, making it hard to measure and quantify management.[45] Yet recent work has moved beyond the emphasis on the "soft skill" attributes of good managers or leaders such as charisma, ingenuity and the ability to inspire – which can be difficult to measure, let alone change – towards a focus on specific management practices which can be measured, taught in business schools or by consultants, adopted by firms and transferred to other managers. Examples of such practices include key principles of Toyota's "lean manufacturing," the implementation of systems for regular maintenance and repair of machines, continual analysis and refinement of quality control procedures, inventory management and planning, and human resource practices such as performance-based incentives. Ichniowski, Prennushi and Shaw (1998), and Bloom and Van Reenen (2007) measure many of these management practices and find large variations across establishments, and a strong association between better management practices and higher productivity.[46]

But another reason for this skepticism is whether these differences in management explain variations in productivity, or are they simply a reflection of different market conditions? For example, are firms in developing countries not adopting quality control systems because wages are so low that repairing defects is cheap? Without evidence on the causal impact of

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[44] Francis Walker's 1887 paper entitled "*On the sources of business profits*" discussed the extent to which variations in management across firms were responsible for their differences in profitability. Walker was an important character in the early years of the economics discipline as the founding president of the American Economics Association, the second president of MIT, and the Director of the 1870 Economic Census.

[45] Lucas (1978, p. 511) notes that in his model "it does not say anything about the tasks performed by managers, other than whatever managers do, some do it better than others".

[46] In related work, Bertrand and Schoar (2003) use a manager-firm matched panel and find that manager fixed effects matter for a range of corporate decisions. They do not explicitly measure the management practices carried out by these managers, but do identify differences in the patterns of managerial decision-making which they call "styles" of management. Lazear and Oyer (2009) provide an extensive survey of the literature.

management practices on performance it is impossible to quantify the impact of management practices on performance, or even say if "bad management" exists at all.

This paper seeks to provide the first experimental estimates of the importance of management practices in large firms. We use a randomized consulting design and collect unique time-series data on management practices and plant performance. The field experiment takes a group of large multi-plant Indian textile firms and randomly allocates their plants to management treatment and control groups. Treatment plants received five months of extensive management consulting from a large international consulting firm, which diagnosed areas for improvement in core management practices in the first month, followed by four months of intensive support in implementation of these recommendations. The control plants received only the one month of diagnostic consulting, provided only in order to collect performance data from them.

The treatment intervention introduced modern management practices for factory operations, inventory control, quality control, human resources, planning and sales and order management. We found this management intervention led to significant improvements in quality, lower inventory levels and higher production efficiency. We estimate the interventions to have increased productivity by about 10.5% and profitability by $320,000 per year (about 11.4%). Longer run impacts of good management on productivity and profitability could be much larger, because our numbers focus only on short-run changes in a very narrow set of management practices. For example, plants do not change their production manning levels, investment schedules or product mix within the experimental time frame. Firms also spread these management improvements from their treatment plants to other plants within the same group, providing additional revealed preference evidence on their beneficial impact.

The improvements were substantial because our sample of plants had very poor management practices prior to the consulting intervention. Most of them had not adopted basic procedures for efficiency, inventory or quality control that have been commonly used for several decades in comparable European, US and Japanese firms. Since these practices do not typically require any capital expenditure, and were introduced with the help of the consulting firm during the five-month intervention period, this raises the question of why these profitable management practices had not been previously adopted.

Our evidence suggests that one important factor is informational constraints – Indian firms are simply not aware of the many modern management practices that are common in Western and Japanese firms. Management practices evolve over time, with innovations like the American System of Manufacturing, Taylor's Scientific Management, Ford's mass production, Sloan's M-form corporation, Demming's quality movement, and Toyota's "lean production". These management technologies spread slowly across firms and countries – for example, the US automotive industry took two decades to adopt Japanese lean manufacturing. We find our Indian firms are far from the management technological frontier and have little exposure to the modern management practices that are now standard in the US, Japan and Europe.

Another important factor was the family firm directors' prior beliefs and procrastination that impeded the adoption of better management practices. All our firms were family owned and managed, so that there was a wide distribution of managerial talent across the firms. In several cases the directors repeatedly cited intent to introduce profitable management practices but had not managed to make the changes. In other cases, different directors from the same family disagreed whether improving management practices would pay off, with occasionally domestic squabbles leading to family breakdowns and paralysis in decision making.

A related question is why product market competition did not drive these badly managed firms out of business? One reason is the reallocation of market share to well managed firms is restricted by span of control constraints on firm growth. In every firm in our sample only members of the owning family are in senior managerial positions. Non-family members are given junior managerial positions whose power is limited to making non financial decisions. The reason is that family members are worried about non-family members stealing from the firm. For example, they worry if they let their plant managers run yarn procurement they might buy yarn at inflated rates from friends and receive kick-backs. And since the rule of law is weak in India legal sanctions are not the same deterrent against theft as they are in developed countries.

As a result of this inability to decentralize every factory requires a trusted family member to manage it. This means firms can only expand if male family members are available to take up plant manager positions. Thus, by far the best predictor of firms size in our sample was the number of male family members. All the biggest multi-plant firms had multiple brothers, while the best managed firm had only one plant because the founder had no brothers or sons. Hence, well managed firms do not generally grow large and drive unproductive firms out from the market. This helps to explain the lack of reallocation in China and India (Hsieh and Klenow, 2009a) and the centralization of control in firms in developing countries (Bloom, Sadun and Van Reenen, 2009). Furthermore, entry is also limited by the large financing costs for starting a textile firm (our firms have an average of $13m of assets). So badly run firms are not rapidly driven out of the market.[47]

We also find two other results of the impact of better management practices in leading to greater decentralization and computerization of production management. Turning first to decentralization we the improved management practices led the firm's owner to allow plant managers greater autonomy over hiring, investment and pay decisions. This arises partly because the improved collection and dissemination of information enables owners to better monitor their plant managers, reducing the risk of managerial theft; and partly because the modern management practices improve the ability of plant managers to run their factories, allowing the owners to relax their direct control. Turning to computerization the extensive data collection, processing and display requirements of modern management practices led to a

[47] Another related question is given the large profits from improving management practices why don't consulting firms generate more business? One obvious constraint is firms are approached all the time by companies offering cost saving products – from cheap telephone lines to better weaving machines – so simply contacting firms to tell them about the huge profits from consulting will not be effective. Of course the consultants could offer their services in return for profit sharing with the firms. But profit sharing is hard to enforce ex post as the firms can hide their profit numbers from the consultants, as they do frequently from the tax authorities. As a result in India – as in the rest of the world – consulting is almost never offered on a profit-sharing basis.

rapid increase in computer use. For example, installing production quality control systems requires firms to record each individual quality defect, and then to analyze these by shift, loom, weaver and design.

This paper relates to several strands of literature. First, there is the extensive productivity literature which reports large spreads in total-factor productivity (TFP) across plants and firms in dozens of developed countries. From the outset this literature has attributed much of this spread to differences to management practices (Mundlak, 1961), but problems in measurement and identification has made this hard to confirm (Syversson, 2010). This dispersion in productivity appears even larger in developing countries (Banerjee and Duflo, 2005, and Hsieh and Klenow, 2009a). But, despite this there are still very few experiments on productivity in firms (McKenzie, 2009), and none involving the type of large multi-plant firms studied here.

Second, our paper builds on the literature on the management practices of firms. This has a long debate between the "best-practice" view that some management practices are routinely good and would benefit all firms to adopt these (Taylor, 1911), and the "contingency view" that every firms is already adopting optimal practices but these are different for every firm (Woodward, 1958). The empirical literature trying to distinguish between these views has traditionally been case-study based, making it hard to distinguish between the different explanations and resulting in little consensus in the empirical management literature.[48]

Third, it links to the large theoretical literature on the organization of firms. Papers generally emphasize optimal decentralization either as a way to minimize information processing costs, or as a way to trade of incentives and information within a principal-agent model.[49] But the empirical evidence on this is limited, focusing on natural experiments like the adoption of on-board computers in trucking (Baker and Hubbard, 2003 and 2004), or de-layering in large Compustat firms (Rajan and Wulf, 2006, Guadalupe and Wulf, 2010). In this paper we have the first experimental evidence on decentralization in large mutli-plant firms.

Fourth, it links the rapidly growing literature on Information Technology (IT) and productivity. A growing body of work has emphasized the relationship between technology and productivity, emphasizing both the direct productivity impact of IT and also it's complementarity with modern management and organizational practices (i.e. Bresnahan et al. 2002, Brynjolfsson and Hitt, 2003, and Bartel, Ichniowski and Shaw, 2007). But again the evidence on has focused on panel IT and organizational survey data, with no prior experimental data. Our experimental evidence suggests one route for the impact of computers on productivity is via facilitating better management practices, and this occurs simultaneously with the decentralization of production decisions.

[48] See Gibbons and Roberts (2009) and Bloom, Sadun and Van Reenen (2010) for surveys of this literature.

[49] See, for example, Bolton and Dewatripont (1994), Garicano (2000) for examples of information processing models and Aghion and Tirole (1997), Baker, Gibbons and Murphy (1999), Rajan and Zingales (2001), Hart and Moore (2005), Acemoglu et al. (2007) and Alonso et al. (2008) for examples of principal-agent models. Recent reviews of this literature are contained in Mookherjee (2006) and Gibbons and Roberts (2010).

Finally, recently a number of other field experiments in developing countries (for example Karlan and Valdivia, 2010, Bruhn et al. 2010 and Drexler et al. 2010) have begun to estimate the impact of business training in microenterprises. This work focuses on training the owners in tasks such as separating business and personal finances, basic accounting, marketing and pricing. It generally finds significant effects of these business skills on performance, supporting our results on management practices in larger firms with evidence on managerial training in smaller firms.

2. Management in the Indian Textile Industry

2a. Why work with firms in the Indian textile industry?

Despite rapid growth over the past decade, India's one billion population still has a per-capita GDP in PPP terms of only one-seventeenth of the United States. Labor productivity is only 15 percent of that in the U.S. (McKinsey Global Institute, 2001). While average levels of productivity are low, most notable is the large variation in productivity, with a few highly productive firms and a long tail of low productivity firms (Hsieh and Klenow, 2009a).

Like those in other developing countries for which data is available, Indian firms are typically poorly managed. Evidence from this is seen in Figure 1, which plots results from the Bloom and Van Reenen (2007, 2010a) double-blind telephone surveys of manufacturing firms in the US and India. The Bloom and Van Reenen (BVR) methodology scores establishments from 1 (worst practices) to 5 (best practices) on specific management practices related to monitoring, targets, and incentives. This yields a basic measure of the use of modern management practices that is strongly correlated with a wide range of firm performance measures like productivity, profitability and growth. The top panel of Figure 1 plots the histogram of these BVR management practice scores for a sample of 751 randomly chosen medium-sized (100 to 5000 employee) US manufacturing firms and the second panel for Indian ones. The results reveal a thick tail of badly run Indian firms, leading to a much lower average management score (2.69 for India versus 3.33 for US firms). Indian firms tend to not collect and analyze data systematically in their factories, they tend to use less effective target-setting and monitoring and to employ ineffective promotion and reward systems. Bloom and Van Reenen, (2010a) show that scores for other developing countries are very similar to those for India, with Brazil and China shown as examples in the third panel with a score of 2.67. In the fourth panel we show the management scores for the Indian textile industry, which looks similar to the whole manufacturing sector. Finally, in the bottom panel we should the management scores for our experimental firms, which have similar management scores to the whole population of firms in developing countries.

India thus appears broadly representative of large developing countries in terms of poor management practices and low levels of productivity. If we are interested in conducting an experiment to improve management, it makes sense to work in a country that is important in of its own right as well as one which contains firms that are broadly representative of firms globally with low initial levels of management quality. India fits the bill.

In order to implement a common set of management practices across firms and measure a common set of outcomes, it is necessary to focus on a specific industry. We chose textile production, since it is the largest manufacturing industry in India, accounting for 22% of manufacturing employment (around 30 million jobs). The bottom panel of Figure 1 shows the BVR management practice scores for textile firms in India, which are similar to those for all Indian manufacturing, with an average score of 2.60.

Within textiles, our experiment was carried out on 28 plants operated by 17 firms in the woven cotton fabric industry. These plants weave cotton yarn into cotton fabric for suits, shirting and home furnishing. They are vertically disintegrated, which means they purchase yarn from upstream spinning firms and send their fabric to downstream dyeing and processing firms. As shown in Figure 1 these 17 textile firms involved in the field experiment had an average BVR management score of 2.60, very similar to the rest of Indian manufacturing. Hence, our sample of 17 Indian firms appear broadly similar in terms of management practices to other manufacturing firms in developing countries.[50]

2b. The selection of firms for the field experiment

The firms we selected operate around Mumbai, which we targeted as a centre of the Indian textile industry (US SIC code 22). The firms were chosen from the population of all public and privately owned textile firms around Mumbai, kindly provided to us by the Ministry of Corporate Affairs (MCA), supplemented with member lists from the Confederation of Indian Industry and the Federation of All India Textile Manufacturers Association. We kept firms with between 100 to 1 000 employees, to yield a sample of 529 firms.[51] We chose 100 employees as the lower threshold because by this size firms require systematic management practices to operate efficiently. We chose 1000 employees as the upper bound to avoid working with conglomerates and multinationals, which would be too large and complex for our intervention to have much impact in the field experiment time-period. Within this group we further focused on firms in the cotton weaving industry (US SIC code 2211) because it was the largest single 4-digit SIC group within textiles. Geographically we focused on firms in the towns of Tarapur and Umbergaon because these provide the largest concentrations of textile firms in the area, and concentrating on two nearby towns substantially reduced travel time for the consultants we employed to help the firms. This yielded a sample of 66 potential subject firms with the appropriate size, industry and location for the field experiment.

All of these 66 firms were then contacted by telephone by Accenture, our partnering international consulting firm. Accenture offered free consulting funded by Stanford

[50] Interestingly, prior work on the Indian textile industry suggested its management practices were also inferior to those in Europe in the early 1900s (Clark, 1987).

[51] The MCA list comes from the Registrar of Business, with whom all public and private firms are required to register on an annual basis. Of course many firms do not register in India, but this is generally a problem with smaller firms, not with 100+ employee manufacturing firms which are too large and permanent to avoid Government detection. The MCA list also provided some basic employment and balance sheet data.

University and the World Bank as part of a management research project. We paid for the consulting to be provided at no charge to the subject firms to ensure we controlled the intervention. We felt if firms co-paid for the consulting they might have tried to direct the consulting (for example asking for help on marketing or finance), generating a heterogeneous intervention. Moreover, if lack of information about the potential benefits of better management were a factor in inhibiting firms adopting better management practices, we might expect that poorly managed firms might not see ex ante the benefit of such services and so would not be as likely to participate if asked to pay.[52] However, the trade-off may be that firms who have little to benefit from such an intervention or do not really intend to pursue it seriously may choose to take it up when offered for free. We balanced this risk by requiring firms to commit one day per week of senior management time to working with the consultants. This time was required from the top level of the firm in order for changes to be implemented at the operational level. It also was intended to ensure buy-in for the project.

Of this group of firms, 34 expressed an interest in the project, and were given a follow-up visit and couriered a personally signed letter from the US. Of the 34 firms, 17 agreed to commit to senior management time for the free consulting program.[53] We compared these program firms with the 49 non-program firms we found no significant differences in observables.[54]

The study firms have typically been in operation for 20 years and are family-owned, with some into their second or third generation of family management. They all produce fabric for the domestic market, with many firms also exporting, primarily to the Middle East. Although the intervention took place against the backdrop of the recent global financial crisis, the participating firms do not appear to have been much affected by the crisis. If anything, demand for low grade fabric of the type produced by these plants may have increased somewhat as customers in urban markets traded down, while the textile market in rural India to which this product was usually directed was largely untouched.

Table 1 reports some summary statistics for the textile manufacturing parts of these firms (many of the firms have other parts of the business in textile processing, retail and real estate). On average these firms had about 270 employees, current assets of $13 million and sales of $7.5m a year. Compared to US manufacturing firms these firms would be in the top 2% by employment and the top 5% by sales[55], and compared to India manufacturing in the top 1%

[52] This may be analogous to Karlan and Valdivia (2009)'s finding that micro-entrepreneurs who expressed less interest in the beginning in business training were the ones who benefited most from it.

[53] The two main reasons for refusing free consulting on the telephone and during the visits was that the firms did not believe they needed management assistance or that it required too much time from their senior management (1 day a week). But it is also possible the real reason is these firms were suspicious of this offer, given many firms in India have tax and regulatory irregularities.

[54] For example, the program firms had slightly less assets ($12.8m) compared to the non-program firms ($13.9m), but this difference was not statistically significant (p-value 0.841). We also compared the two groups of firms on management practices, measured using the BVR scores, and found they were almost identical (difference of 0.031, with a p-value of 0.859).

[55] Dunn & Bradstreet (August 2009) lists 778,000 manufacturing firms in the US with only 17,300 of these (2.2%) with 270 or more employees and only 28,900 (3.7%) with $7.5m or more sales.

by both employment and sales (Hsieh and Klenow, 2009b). Hence, by this criterion, as well as by most formal definitions[56], these are large manufacturing firms.

These firms are also complex organizations, with a median of 2 textile plants per firm and 4 hierarchical levels from the shop-floor to the managing director. These levels typically comprise the worker, foreman, plant manager and managing director. In all the firms, the managing director is the single-largest shareholder, reflecting the lack of separation of ownership and control in Indian firms. All other directors are family members, with no firm having any non-family senior management. One of the firms is publicly quoted on the Mumbai Stock Exchange, although more than 50% of the equity is still held by the managing director and his father.

In exhibits (1) to (7) we include a set of photographs of the plants. These are included to provide some background information to readers on their size, production process and initial state of management. As is clear these are large establishments (Exhibit 1), with multiple several story buildings per site, and typically several production sites per firm, plus a head office in Mumbai. They operate a continuous production process that runs two 12-shifts a day, for 365 days a year (Exhibit 2). Their factories floors were (initially) often rather disorganized (Exhibits 3 and 4), and their yarn and spare-parts inventory stores lacking any formalized storage systems (Exhibits 5 and 6). Instances of clearly inefficient operational practices were easy to come across, such as using manual labor to transport heavy warp-beams because relatively cheap machinery had broken down and not been repaired (Exhibit 7).

3. The Management Intervention

3a. Why use management consulting as an intervention

The field experiment aimed to improve the management practices of a set of randomly selected treatment plants and compare the performance of these to a set of control plants whose management has not changed (or changed by less). To do this we needed an intervention that improved management practices on a plant-by-plant basis. To achieve this we hired a management consultancy firm to work with our treatment plants to improve their management practices.

We selected the consulting firm using an open tender. The winner was Accenture consulting, a large international management consulting and outsourcing firm. It is headquartered in the U.S. with about 180,000 employees globally, including 40,000 in India. The senior partners of the firm who were engaged in the project were based in the US, but the full-time consulting team of up to 6 consultants (including the managing consultant) all came from the Mumbai office. These consultants were all educated at top Indian business and engineering schools, and most of them had prior experience working with US and European multinationals. Selecting a high profile international consulting firm substantially increased the cost of the project. But it meant that our experimental firms were more prepared to trust the consultants

[56] Most European countries and international agencies define large firms as those with more than 250+ employees, the US as having 500+ employees, and India as having Rs 5 crore ($1.25 USD+) of revenue.

and accept their advice, which was important for getting a representative sample group. It also offered the largest potential to improve the management practices of the firms in our study, which was needed to understand whether management matters. The project ran from August 2008 until August 2010, and the total cost of this was $US1.3 million, or approximately $75k per treatment plant and $20k per control plant.[57] Note this is very different from what the firms themselves would pay for this themselves, which would be probably at least $500k. The reason for our much cheaper costs per plant is: (i) Accenture charged us pro-bono rates (50% of commercial rates) due to our research status, (ii) our partners' time (who were US based) and some of the initial Indian consulting time was provided for free, and (iii) there are large economics of scale in working across multiple plants.

While the intervention offered was high-quality management consulting services, the purpose of our study was to use the improvements in management generated by this intervention to understand how much management matters. It was not to evaluate the effectiveness of the international consulting firm. Our treatment effect is the impact on the average firm that would take-up consulting services when offered for free, which is unlikely to be the same as the effect for the average or even the marginal client for the consulting firm. The firms receiving the consulting services might change behavior more if they were voluntarily paying for these services, and the consulting company might have different incentives to exert effort when undertaking work for a research project like this compared to when working directly for paying clients. Based on our intensive interaction with the consulting company, including bi-weekly meetings throughout the project, and discussions with the clients, we do not believe the latter to be an important concern, but nevertheless acknowledge that any attempt to extrapolate the findings of this study to discuss the effectiveness of international management consultants faces these issues. In contrast, neither of these issues is an important concern for the central purpose of this experiment: to determine whether and how much management practices matter for firm performance.

3b. The management consulting intervention

Textile weaving is a four stage process (see Exhibit 2). In the first stage individual threads of yarn are aligned in a pattern corresponding to the fabric design and wound repeatedly around a "warp beam". The warp beam fits across the bottom of a weaving machine and carries the threads that will run vertically. In the second and third stages the warp beam is attached to a drawing stand and then a weaving loom, and the horizontal cross threads woven in. This cross thread is called the weft weave (as opposed to the vertical warp weave). Finally, the fabric is checked for quality defects, and defects repaired wherever possible.

A typical factory comprises several buildings in one gated compound (see Exhibit 1), operating 24 hours a day in two 12 hours shifts, working 365 days a year. One building

[57] These rates may seem high for India, but Accenture's India rates are about one third of their US rates. At the bottom of the consulting quality distribution in India consultants are extremely cheap, but of course their quality is extremely poor with these consultants typically having no better knowledge of management practices than our textile firms. At the top end rates are comparable to those in the US and Europe. This is because the consultants these firms employ are often US or European educated, and have access to international labor markets. In fact 2 of our team of 6 Indian consultants had previously worked in the US for large multinationals, and had chosen to return to India for family reasons.

houses the production facilities, comprising 2 warping looms occupying one floor and about 5% of the manpower, about 60 weaving looms occupying another floor and 60% of the manpower, and a large checking and repair section occupying about 20% of the manpower and a third floor. The remaining 15 % of the manpower works in the raw materials and finished goods stores which occupy an adjacent building, and in back-office processing, which is typically located in a third building. The combined size of these buildings (typically about 50,000 square feet and 130 employees), is similar to that of a U.S. Wal-Mart or Home Depot retail store. The average firm in our experiment has two plants like this, plus an office in downtown Mumbai (which is about 4 hours drive away) which deals with finance, administration, sales and marketing. Thus, these organizations are so large that no one person can physically observe the entire production process, so that formal management systems to collect, aggregate and process information are essential.

The intervention aimed to improve the management practices of these plants. Based on their prior experience in the textile industry and in manufacturing more generally, the consulting firm identified a set of 38 key management practices on which to focus. These 38 management practices encompass a range of basic manufacturing principles that are standard in almost all US, European and Japanese firms and that the consulting firm believed would be of benefit to the textile firms, and would be feasible to introduce during the intervention period. These 38 practices are listed individually in Table 2, alongside their frequency of adoption prior to the management intervention in the 28 plants owned, and the frequency of adoption pre and post the intervention in the treatment and control plants. The baseline adoption rates show a wide dispersion of practices – from 96% of plants who recorded quality defects to 0% of plants initially using scientific methods to define inventory norms[58] with an overall adoption rate of 26.9%. These practices are categorized into 6 broad areas:

- Factory Operations (to increase output): Plants were encouraged to undertake regular maintenance of machines, rather than repairing machines only when they broke. When machine downtime did occur plants were encouraged to record and evaluate this, so they could learn from past failures to reduce future downtime. They were also encouraged to keep the factory floor tidy and organized, both to reduce accidents and to facilitate the movement of materials and goods. Daily posting of performance of individual machines and weavers was suggested to allow management to assess individual and machine performance. Finally, plants were encouraged to organize the machine spares so these could be located in the event of a machine breakdown, and develop scientific methods to define inventory norms for spare parts.

- Quality control (to increase quality and reduce rework hours): Plants were encouraged to record quality defects by major types at every stage of the production process on a daily basis. They were encouraged to analyze these daily to address quality problems rapidly, so that the same defect would not repeatedly occur. Standard operating procedures were established to ensure consistency of operations.

[58] This involves calculating the cost of carrying inventory (interest payments and storage costs) and the benefits of carrying inventory (larger order sizes and lower probability of stock-outs) and using this to define an optimal inventory level. The use of inventory norms is almost universal in US, European and Japanese firms of this size.

- Inventory (to reduce inventory levels): Plants were encouraged to record yarn stocks, ideally on a daily basis, with optimal inventory levels defined and stock monitored against this. Yarn should be sorted, labeled and stored in the warehouse by type and color, and this information logged onto a computer, so yarn can be located when required for production. Yarn that has not been used for 6+ months should be utilized in new designs or sold before it deteriorates.

- Planning (to increase output and to improve due date performance): Plants were encourage to plan loom usage 2 weeks in advance to ensure prepared warp beams are available for looms as needed. This helps to prevent weaving machines lying idle. The sales teams (based in Mumbai) should meet twice a month with the production teams to ensure delivery schedules are matched against the factory's production capacity.

- Human-resource management (to increase output): Plants were encouraged to introduce a performance-based incentive system for workers and managers. The recommended system comprised both monetary and non-monetary incentives (e.g. a radio for the most productive weaver each month). Incentives were also linked to attendance to reduce absenteeism. Job descriptions were defined for all workers and managers to improve clarity on roles & responsibilities.

- Sales and order management (to increase output and to improve due date performance): Plants were encouraged to track production on an order-wise basis to prioritize customer orders with the closest delivery deadline. Design-wise and margin-wise efficiency analysis was suggested so that design-wise pricing could be based on production costs (rather than flat-rate pricing so that some designs sold below cost).

These 38 management practices in Table 2 form a set of precisely defined binary indicators which we can use to measure improvements in management practices as a result of the consulting intervention[59]. The indicators allow for differences in the extent to which a particular system is put in place. For example, in factory operations, a basic practice is to record machine downtime. A second practice is actually to monitor these records of downtime daily, while a third practice is to analyze this downtime and create and implement action plans on a regular (fortnightly) basis in order to act on this information. A general pattern at baseline was that in many cases plants recorded information (often in paper sheets), but had no systems in place to monitor these records or use them to make decisions. Thus, while 93 percent of the treatment plants recorded quality defects before the intervention, only 29 percent monitored them on a daily basis or by the particular sort of defect, and none of them had an analysis and action plan based on this defect data – that is, a system to address repeated quality failures.

[59] We prefer these indicators to the BVR management practice score for our work here, since they are all objective binary indicators of specific practices, which are directly linked to the intervention. In contrast, the BVR indicator measures practices at a more general level, with each measured on a 5-point ordinal scale. Nonetheless, the sum of our 38 pre-intervention management practice scores is correlated with the BVR score at 0.404 (p-value of 0.077) across the 17 firms.

Indeed we found that while plants usually had historic data of some form on production and quality, it was typically not in a form that was convenient for either them or us to access. The majority of plants had electronic resource planning (ERP) computer systems which they used to record basic factory operation metrics (such as machine efficiency, the share of time a machine is running) on a daily basis. These computer systems were designed by local vendors, and could be used to generate very simple reports that were looked at only on an irregular, ad hoc basis. Generating more detailed reports that went outside these simple reports required extracting the data and using it with other software. Quality records were worse. Plants typically had handwritten logs of defects, which they referred to only when customers complained. And most plants also did not frequently monitor inventory levels, typically running stock takes a few times a year. All this meant that the plants lacked the data needed to measure performance prior to the intervention.

The consulting treatment had three stages. The first stage took one month, and was called the *diagnostic* phase, which was given to all on-site plants (treatment and control). This involved evaluating the current management practices of each plant and constructing a performance database. The construction of this database involved setting up processes for measuring a range of plant-level metrics – such as output, efficiency, quality, inventory and energy use – on an ongoing basis, plus constructing a historical database from plant records. For example, to facilitate quality monitoring on a daily basis a single metric was defined, termed the Quality Defects Index (QDI), which is a severity-weighted average of the major types of defects. To construct historical QDI values the consulting firm converted the historical quality logs into QDI wherever possible. At the end of the diagnostic phase the consulting firm provided each treatment and control plant with a detailed analysis of their current management practices and performance. The treatment plants were given this diagnostic phase as the first step in improving their management practices. The control plants were given this diagnostic phase because we needed to construct historical performance data for them and help set up systems to generate ongoing data.

The second phase was a four month *implementation* phase which was given only to the treatment plants. In this the consulting firm followed up on the diagnostic report to help implement management changes to address the identified shortcomings. This focused on introducing the key 38 management practices which the plants were not currently using. The consultant assigned to each plant would work with the plant managers to put the procedures into place, fine-tune them, and stabilize them so that they could be readily run by employees. For example, one of the practices implemented was daily meetings for management to review production and quality data. The consultant would attend these meetings for the first few weeks of the implementation phase to help the managers run them, would provide feedback on how to run future meetings, and fine-tune their design to the specific plant's needs. During the rest of the implementation phase the consultant would attend the meetings on a weekly basis to check they were being maintained, and to further fine-tune them. As another example, the consultant would help the plant managers to set up a system for monitoring the aging of yarn stock, and would walk them through the steps needed to ensure old stock was used, sold or scrapped.

The third phase was a *measurement* phase which lasted until the end of the experiment (planned to be August 2010, with a one-year exit and then long run follow-up in Fall 2011). For budgetary reasons this phase involved only three consultants and a part-time manager, and was designed to collect performance and management data from the plants. In order to elicit this data from the firms the consultants needed to continued to provide some light consulting advice to the treatment and control plants, as providing detailed data is costly.

So, in summary, the control plants were provided with just the diagnostic phase and the measurement phase (totaling 225 consultant hours on average), while the treatment plants were provided with the diagnostic and implementation phase as well as the measurement phase (totaling 733 consultant hours on average). As such our measured impact of the experiment will be an underestimate of the impact of consulting since our control group also had some limited consulting. Nevertheless, by varying the intensity of the treatment we hoped to vary the change in management practices which occur for treatment versus control firms, enabling us to use this variation in management practices to determine the effect of management. In addition the consultants spent 12 hours on average at each off-site plant to collect their management, organizational and IT data.

3c. The experimental design

We wanted to work with large firms because their operational complexity means management and organizational practices are likely to be particularly important to them. However, providing consulting to large firms is expensive, which necessitated a number of trade-offs. These are detailed below and summarized in Table 3.

<u>Sample size:</u>
We worked with the 28 plants within our 17 experimental firms. This small sample was necessary to allow us to use international consultants to provide hundreds of hours of consulting to each treatment plant. We considered hiring much cheaper local consultants and providing a few dozen hours to each treatment plant, which would have yielded a sample of several hundred plants. But two factors pushed against this. First, many large firms in India are reluctant to let outsiders into their plants because of their lack of compliance with tax, labor and safety regulations. To minimize selection bias we offered a high quality consulting intervention that firms would value enough to take the risk of allowing outsiders into their plants. This helped maximize initial take-up (26% as noted in section II.B) and retention (100% as no firms dropped out). Second, the consensus from discussions with Indian business people was that achieving a measurable impact in large firms would require an extended engagement with high-quality consultants.

<u>On-site and off-site plants:</u> Due to manpower constraints we could only collect detailed performance data from 20 plants. The accurate collection of weekly data on quality, inventories, output, labor, electricity is time intensive as these plants did not typically have any formalized data recording systems. So building data collection systems and compiling historic databases required the consultants spending several hours each week on-site. However, slower moving management, organizational and IT data was gathered for all 28 plants as it only required bi-monthly visits, so the consultants did not need to be spend much

on-site for these plants. As a result the performance regressions are run only on the 20 on-site plants, while the management, decentralization and IT regressions are run on all 28 plants.

Treatment and control plants: Within the group of 20 on-site plants we randomly picked 6 control plants, and then 14 treatment plants. As Table 1 shows the treatment and control firms were not statistically different across any of the characteristics we could observe. The remaining 8 plants were defined as off-site treatment plants if they were in the same firm as another on-site treatment plant, and off-site control plants if they were in the same firm as another on-site control plant.[60]

Timing: The consulting intervention had to be initiated in three batches because of the capacity constraint of the six man consulting team. So the first wave started in September 2008 with 4 treatment plants. In April 2009 a second wave of 10 treatment plants was initiated, and in July 2009 the wave of 6 control plants was initiated. This design was selected to start with a small first wave as this was the most difficult because the process was new. The second wave included all the remaining treatment firms because: (i) the consulting interventions take time to affect performance and we wanted the longest time-window to observe the treatment firms; and (ii) we could not mix the treatment and control firms across waves because of the nature of the intervention process.[61] The third wave contained the control firms. Management and performance data for all firms was collated from April 2008 to August 2010. We picked more treatment than control plants because the staggered initiation of the interventions meant the different groups of treatment plants provided cross identification for each other, and because the treatment plants were more likely to be more useful for trying to understand why firms had not adopted management practices before.

3d. Statistical Power

This small sample could lead to leads to concerns about statistical power. However, there are several mitigating factors. First, these are extremely large plants with about 80 looms and about 130 employees so that idiosyncratic shocks – like machine breakdowns or worker illness – tend to average out. Second, the data was collected on-site in a consistent manner each week across plants by the consultants, so is likely to be much more accurate and comparable than self-reported survey data. Third, we collected weekly data, which provides high-frequency observations over the course of the treatment. Fourth, the firms are extremely homogenous in terms of size, product and region, and so that external shocks can be controlled for with the time dummies. Finally, the intervention was extremely intensive so that the treatment effects should be large.

[60] Treatment and control plants were never in the same firms. This was ensured by picking the 6 on-site control plants from 6 firms first, and then choosing the 14 on-site treatment plants from the remaining 11 firms.
[61] Each wave had a one-day kick-off meeting with all the firms, involving presentations from a range of senior partners from the consulting firm. This helped impress the firms with the expertise of the consulting firm and highlighted the huge potential for improvements in management. This meeting involved a project outline, which was slightly different for the treatment and control firms because of the different interventions. Since we did not tell firms about the existence of treatment and control groups we could not mix the treatment and control groups.

We also use permutation tests to generate finite sample errors for the standard errors. These provide standard errors with exact small sample properties so do not require any asymptotic assumptions. Of course we also generate the more usual bootstrap clustered standard errors.

3e. The impact of the intervention on plants management practices

In Figure 2 we plot the average management practice adoption of the 38 practices listed in Table 2 for the 14 treatment on-site plants, the 6 control on-site plants and the 8 of f-site treatment and control plants. This data is shown at 2 month intervals before and after the diagnostic phase. Data from the diagnostic phase onwards was compiled from direct observation at the factory. Data from before the diagnostic phase was collected from detailed interviews of the plant management team based on any changes to management practices during the prior year. Figure 2 shows five key results:

First, the plants in all of the groups started off with low baseline adoption rates of the set of 38 management practices. [62] Among the 28 individual plants the initial adoption rates varied from a low of 7.9% to a high of 55.2%, so that even the best managed plant in the group had in place just over half of the 38 key textile manufacturing management practices. This is consistent with the results on poor general management practices in Indian firms shown in Figure 1. For example, many of the plants did not have any formalized system for recording or improving production quality so that the same quality defect would not arise repeatedly. Most of the plants also had no organized yarn inventories, so that yarn was stored mixed by color and type, without labeling or computerized entry. Consequently, yarn was being ordered despite already being in stock (see also Exhibit 5). The production floor was often blocked by waste, tools and machinery, impeding the flow of workers and materials around the factory (see Exhibits 3-4). Machines often were not routinely maintained, so that they would break down frequently, leading to low efficiency levels. Pricing was not matched against production costs, so that complex designs were charged at the same rate as simple designs because no data was collected on production costs of different designs. This was as surprising to us as to our international consulting firm used to dealing with well managed Indian and foreign multinationals.

Second, the intervention did succeed in changing management practices. The on-site treatment plants increased their use of the 38 management practices over the period by 37.6 percentage points on average (an improvement from 25.6% to 63.2% of practices implemented).

Third, the increase in management practices the treatment plants occurred gradually over the intervention period. In part this is because it takes time to introduce and stabilize new management practices. Typically the consulting firm would start by explaining the new management practices, then would introduce the procedures, and finally spend time giving feedback and coaching to fine-tune the process. The slow take-up also reflects the time it takes for the consulting firm to gain the confidence of the firm's directors. Initially many directors were somewhat skeptical of the suggested management changes, and only

[62] The difference between the treatment, control and other plant groups is not statistically significant, with a p-value on the difference of 0.248 (see Table 2).

implemented the easiest changes around quality and inventory. Once these started to generate substantial improvements in profits the firms then started to introduce the more complex improvements around operations and HR.

Fourth, the control plants, which were given only the 1 month diagnostic, also increased their adoption of these management practices, but by only 12% on average. This is substantially less than the increase in adoption of the treatment wave, indicating that the four months of the implementation the treatment plants received was important in changing management practices. The control firms tended not to successfully adopt the more complex practices like daily quality meetings, formalizing the yarn monitoring process or defined roles and responsibilities for managerial staff.

Fifth, the off-site plants also saw a substantial increase in the adoption of management practices. In these 8 plants the management adoption rates increased by 11.2 percentage points.[63] This spillover of management practices within the treatment firms was driven by the directors copying the new management practices from their on-site treatment plants to their off-site plants.

3f. Management practice spillovers across plants within firms

To formally test whether the intervention has differentially changed management practices between the treatment and control plants, what types of practices have changed the most, and if practices have spilled over between different plants within the same firm we run the following plant-level panel regression:

$$MANAGEMENT_{i,t} = \alpha_i + \beta_t + \lambda_1 OWN\_TREAT_{i,t} + \lambda_2 SPILLOVER\_TREAT_{i,t} + \varepsilon_{i,t} \qquad (1)$$

where α_i are plant fixed effects, β_t are calendar month fixed effects, $OWN\_TREAT_{i,t}$=log(1+cumulative months since the implementation phase began), and $SPILLOVER\_TREAT_{i,t}$ =log(1+sum of cumulative months since implementation began in all other plants in the same firm). We use this logarithmic functional form because of concave adoption path of management practices shown in Figure 2. The parameter λ_1 estimates the semi-elasticity of the plants management practices with respect to the months of their own on-site consulting, while λ_2 estimates the semi-elasticity of spillovers from on-site consulting in other plants within the firm. The standard errors are bootstrap clustered by plant.

The results are shown in Table 4, we reports in column (1) that management practices significantly respond to own plant treatment, rising by about 0.121 for every unit change in log(1+ months treatment). We also see a significant response of 0.039 to log(1+ months treatment) in other plants within the same firm. This coefficient is about one third of the magnitude of the direct impact, suggesting substantial spillovers of management practices across plants within the same firm. In column (2) we add the three month lagged spillover term to investigate the timing of any potential spillover, and find the lagged term dominates. This is consistent with a delay in transferring management practices across plants. This arises

[63] Most of this increase was driven by the 5 off-site treatment plants, which increased the adoption of practices by 17.5%, compared with the 3 off-site control plants which increasing their adoption by 1%.

because the firms directors would typically evaluate the impact of the new management practices in their on-site plants before transferring these over to their off-site plants. In column (3) we use just the three month lag and find a coefficient of 0.050, at about 40% of the direct effect. Using even longer lags leads to larger coefficients – for example for a six-month lag we obtain a coefficient (standard-error) of 0.059 (0.020) - but reduces the sample size.[64] But whatever the exact specification, this data provides evidence of gradual spillovers of better management practices across plants within firms.

We also estimate the own treatment and spillover treatment effects for different subcomponents of the management practice score. In column (4) we look at inventory management, showing a direct and a spillover term. In column (5) we look at quality management showing a large direct and spillover term, reflecting the fact that the quality management practices were some of the easiest to introduce with some of the largest performance gains, so that their adoption rates were typically the highest. In column (6) we look at operations management, again seeing a direct and spillover effect. In column (7) we examine loom planning and see small insignificant effects, reflecting the greater complexity of these practices (which involve using computer loom planning tools to maximize efficiency) which tended to reduce adoption rates. In column (8) we look at HR practices and again see reasonably large significant direct and spillover effects, highlighting how incentive pay systems were also relatively easy to implement and effective in increasing performance. Finally, in column (9) we look at sales and order management practices and find very little evidence of a treatment effect, consistent with the greater complexity of these changes, which involve sophistication of customer pricing and prioritization. So overall this indicates the variation in take-up across different groups of practices reflecting their expected impact and difficult of implementation.

Most importantly for our study, these results also show that the experiment differentially changed management practices between treatment and control plants, providing variation which we can use to examine the impacts of this on plant-level outcomes. In our estimation strategy we use the log(1+own cumulative intervention) as the instrumental variable given its strong predict power for management practices.

4. The impact of management on performance

The unique panel data on management practices and plant level performance, coupled with the experiment which induces random variation in management practices, enables us to estimate whether management matters. We have a range of plant-level performance metrics, with the key variables being measures of quality, inventories, and output. This data was recorded at a weekly frequency for the 20 on-site plants. Historical data for the period before

[64] Distinguishing between different lag lengths is empirically hard because of their collinearity. For example, putting in the three and six month lags of spillovers together leads to point-estimates (standard-errors) on these of 0.050 (.032) and 0.010 (0.029) respectively. The own plant treatment effect shows no preference for a lag – for example the coefficients (standard-errors) on the current and the three month-lag of own treatments are 0.170 (0.031) and -0.053 (0.030).

the intervention was constructed from a range of sources, including firms' Electronic Resource Planning (ERP) computer systems, production logs, accounts and order books.

Previous literature (e.g. Black and Lynch (2001) and Bloom and Van Reenen, (2007)) has shown a strong correlations between management practices and firm performance in the cross-section, with other papers (e.g. Ichniowski et al. 1998) showing this in the panel.[65]

We begin with a panel fixed-effects specification:

$$OUTCOME_{i,t} = \alpha_i + \beta_t + \theta MANAGEMENT_{i,t} + \nu_{i,t} \qquad (2)$$

The concern is then of course that management practices are not exogenous to the outcomes that are being assessed, even in changes. For example, a firm may only start monitoring quality when it is starting to experience a larger than usual number of defects, which would bias the fixed-effect estimate towards finding a negative effect of better management on quality. Or firms may start monitoring quality as part of a major upgrade in worker quality and equipment, in which case we would misattribute quality improvements arising from better capital and labor to the effects of better management.

To overcome this endogeneity problem, we instrument the management practice score with log(1+ weeks of treatment). The exclusion restriction is then that the intervention only affected the outcome of interest through its impact on management practices, and not through any other channel. We believe this assumption is justified, since the consulting firm focused entirely on management practices in their recommendations to firms, and firms did not buy new equipment or hire new labor as a result of the intervention (at least in the short run).[66] The IV estimator will then allow us to answer the headline question of this paper – does management matter?

If the impact of management practices on plant-level outcomes is the same for all plants, then the IV estimator will provide a consistent estimate of the marginal effect of improvements in management practices, telling us how much management matters for the average firm participating in the study. However, if the effects of better management are heterogeneous, then the IV estimator will provide a local average treatment effect (LATE). The LATE will then give the average treatment effect for plants which do change their management practices when offered free consulting. If plants which stand to gain more from improving management are the ones who change their management practices most as a result of the consulting, then the LATE will exceed the average marginal return to management. While it will understate the average return to management if instead the plants that only change management when

[65] Note that other papers using repeated surveys have found no significant panel linkage between management practices and performance (Cappelli and Neumark (2001) and Black and Lynch (2004)), probably because of measurement error issues with repeated surveys. See Bloom and Van Reenen (2010b) for a full literature survey on management practices and productivity.

[66] The exceptions to this were that the firms hired on average \$34 (1,700 rupees) of extra manual labor to help organize the stock rooms and clear the factory floor, spent \$418 (10,900 rupees) on plastic display boards for the factory floor, standard-operating procedure notices and racking for the store rooms, and spent an additional \$800 on salary and prizes (like a radio and a watch) for managerial and non managerial staff. These and any other incidental expenditures are too small to have a material impact on our profitability and productivity calculations.

consulting is provided free are those with least to gain. There was heterogeneity in the extent to which treatment plants changed their practices, with the before-after change in average total management practice score ranging from 21.1% to 58.3%. The feedback from the consulting firm was that to some extent it was firms with the most unengaged, uncooperative managers who changed practices least, suggesting that the LATE may underestimate the average impact of better management if these firms have the largest potential gains from better management. Nonetheless, we believe the LATE estimate to be a parameter of policy interest, since if governments are to employ policies to try and improve management, information on the returns to better management from those who actually change management practices when help is offered is informative.

We can also directly estimate the impact of the consulting services intervention on management practices via the following equation:

$$OUTCOME_{i,t} = a_i + b_t + cTREAT_{i,t} + e_{i,t} \quad (3)$$

Where $TREAT_{i,t}$ is a 1/0 variable for whether plants have started the implementation phase or not. The parameter *c* then gives the intention to treat effect (ITT), and gives the average impact of the intervention in the treated plants compared to the control plants. This estimates the effect of giving firms the full implementation phase of the consulting, rather than just the diagnostic phase.

In all cases we include plant and time fixed effects, and bootstrap cluster the standard errors at the firm level. We have daily data on many outcomes, but aggregate them to the weekly level to reduce higher-frequency measurement errors.

4a. Quality

Our measure of quality is the Quality Defects Index (QDI), a weighted average score of quality defects, which is available for all but one of the plants. Higher scores imply more defects. Figure 3 provides a plot of the QDI score for the treatment and control plants relative to the start of the treatment period. This is September 2008 for Wave 1 treatment, April 2009 for Wave 2 treatment and controls plants.[67] This is normalized to 100 for both groups of plants using pre-treatment data. To generate confidence intervals we block bootstrapped over the individual plants.

As is very clear the treatment plants started to significantly reduce their QDI scores rapidly from about week 5 onwards, which was the beginning of the implementation phase following the initial 1 month diagnostic phase. The control firms are also showing a mild downward trend in their QDI scores from about week 30 onwards, consistent with their slower take-up of these practices in the absence of a formal implementation phase. These differences in trends between the treatment and control plants are also significant, as indicated by the non-overlapping 95% confidence intervals.

[67] Since the control plants have no treatment period we set their timing to zero to coincide with the 10 Wave 2 treatment plants. The maximizes the overlap of the data.

Table 5 in column (1) to (3) asks whether management practices improve quality using a regression approach. In column (1) we present the fixed-effects OLS results which regresses the monthly log(Quality Defects Index) score on plant level management practices, plant fixed effects, and a set of monthly time dummies. The standard errors are boostrap clustered at the firm level to allow for any potential correlation across different experimental plants within the same firm. The coefficient of -0.753 implies that increasing the adoption of management practices by 10 percentage points would be associated with a reduction of 7.53% in the quality defects index.

The reason for this large effect is that measuring defects allows firms to address quality problems rapidly. For example, a faulty loom that creates weaving errors would be picked up in the daily QDI score and dealt with in the next day's quality meeting. Without this the problem would often persist for several weeks since the checking and mending team has no system (or incentive) for resolving defects. In the longer term the QDI also allows managers to identify the largest sources of quality defects by type, design, yarn, loom and weaver, and start to address these systematically. For example, designs with complex stitching that generate large numbers of quality defects can be dropped from the sales catalogue. This ability to dramatically improve quality through systematic data collection and evaluation is a key tenet of the highly-successful lean manufacturing system of production (see, for example, Womack, Jones and Roos, 1992).

In Table 5, column (2), we instrument management practices using the experimental intervention to identify the causal impact of better management on quality. After doing this we see a significant point estimate of -2.031, suggesting that increasing the management practice adoption rate by 10% would be associated with a reduction in quality defects of 20.3%. The rise in the point estimate for the IV estimator could be due to measurement error in the underlying management index and/or because firms are endogenously adopting better management practices when their quality starts to deteriorate. There was some anecdotal evidence for the latter, in that the consulting firm reported some plants with improving quality were less keen to implement the new management practices because they felt these were unnecessary. This suggests that the fixed-effects estimates for management and performance in prior work like Ichniowski, Prennushi and Shaw (1997) may be underestimating the true impact of management on performance.

Finally, in column (3) we look at the intention to treat (ITT), which is the average reduction in the quality defects index in the period after the intervention in the treatment plants versus the control plants. We see this is associated with a 31.9% (exp(-.385)-1) reduction in the QDI index.

4b. Inventory

Figure 4 shows the plot of inventory levels over time for the treatment and control groups. It is clear that after the intervention the inventory levels in the treatment group falls relative to the control group, with this being significant by about 30 weeks after the intervention.

The reason for this effect is that these firms were carrying about 4 months of inventory on average before the intervention, including a large amount of dead-stock. This was frequently because firms discovered huge amounts of yarn they did not even know they had, because of poor records and storage practices. By cataloguing the yarn and sending the shade-cards to the design team to include in new products[68], selling dead yarn stock, introducing restocking norms for future purchases, and monitoring inventory on a daily basis, the firms dramatically reduced their inventories. But this takes time as the reduction in inventories primarily arises from lowering stocking norms and consuming old yarn into new products. In fact US automotive firms achieved much greater reductions in inventory levels (as well as quality improvements) when they adopted the Japanese lean manufacturing technology beginning in the 1980s. Many firms reduced inventory levels from several months to a few days by moving to just-in-time production (Womack, Jones and Roos, 1991).

Table 5 columns (4) to (6) look at the shows the regression results for raw material (yarn) inventory. In all columns the dependent variable is the log of raw materials, so the coefficients can be interpreted as the percentage reduction in yarn inventory. The results are presented for the 18 plants for which we have yarn inventory data (two plants do not maintain yarn stocks on site). In column (4) we present the fixed-effects results which regresses the monthly yarn on the plant level management practices, plant fixed effects, and a set of monthly time dummies. The coefficient of -0.707 says that increasing management practices adoption rates by 10 percentage points would be associated with a yarn inventory reduction of about 7.07%. In Table 5, column (5s), we see the impact of management instrumented with the intervention displays a point estimate of -0.939, again somewhat higher than the FE estimates in column (1). In column (6) we see the intervention is associated with an average reduction in yarn inventory of (exp(-.173)-1=) 15.9%.

4c. Output

In Figure we plot output over time for the treatment and control plants. The results here are less striking, although output of the treatment plants has clearly risen on average relative to the control firms, and this difference is statistically significant in some weeks towards the end of the period.

In columns (7) to (9) in table 5 we look at this in a regression setting with plant and time dummies. In column (7) we see that for the OLS specification increasing the adoption of management practices by 10 percentage points would be associated with a 1.25% increase in efficiency, although this is not statistically significant. In column (8), we see the impact of management instrumented with the intervention displays a higher and statistically significant point estimate of 0.239, suggesting a 10% increase in management adoption would lead to a 2.39% increase in output. Finally, in column (9) we look at the intention to treat (ITT) and see a point estimate of 0.040, implying a 4.1% increase in output (exp(0.040)-1), although this is not statistically significant. This is insignificant, in part because the output gains take several months to arise so that with only nine months of post-treatment data the average post-

[68] Shade cards comprise a few inches of sample yarn, plus information on its color, thickness and material. These are sent to the design teams (who are based in downtown Mumbai about 4 hours away) who use these to try and design the surplus yarn into new products.

treatment level of efficiency is not significantly higher than the pre-treatment level. We expect that this is likely to change as we continue to collect data through to August 2010.

There are several reasons for these increases in output. First, undertaking routine maintenance of the looms, especially following the manufacturers' instructions, reduces breakdowns. Second, collecting and monitoring the breakdown data also helps highlight looms, shifts, designs and yarn-types associated with more breakdowns and facilitates pro-actively addressing these. Third, visual displays around the factory floor together with the incentives schemes against these performance metrics motivate workers to improve operating efficiency. Since these incentives are partly individual based and partly group based, workers are motivated both by personal and group rewards to keep their efficiency levels high. Fourth, advance loom planning helps to reduce the amount of time weaving machine lie idle waiting for warp beams (weaving looms need warp beams from the warping looms). Previously looms would frequently lie idle waiting for beams, but advanced planning of warp beam delivery two weeks ahead means plants can exchange warp beams (even between different firms) to keep looms running at full capacity. Finally, keeping the factory floor clean and tidy reduces the number of accidents, for example reducing incidents like tools falling into machines or fires damaging equipment. Again the experience from Lean manufacturing is the collective impact of these procedures can lead to extremely large improvements in operating efficiency, raising output levels.

4d. Are the improvements in performance due to Hawthorne effects?

Hawthorne effects are named after the experiments carried out by industrial engineers in the Hawthorne Works in the 1920s and 1930s which attempted to raise productivity. The results apparently showed that simply running experiments led to an improvement in performance, with the most cited result being that both reducing and increasing light levels led to higher productivity. While these putative Hawthorne effects in the original experiments have long been disputed (e.g. Levitt and List, 2009), there is a serious potential concern that some form of the Hawthorne effect is causing our observed increase in plant performance.

However, we think this is unlikely for a series of reasons. First, our control plants also had the consultants on site over a similar period of time as the treatment firms. Both sets of plants got the initial diagnostic period and the follow-up measurement period, with the only difference being the treatment plants also got an intensive intermediate 4 month implementation stage. Hence, it cannot be simply the presence of the consultants or the measurement of performance generating the improvement in performance. Second, the improvements in performance take time to arise, and arose in quality, inventory and efficiency where the majority of the management changes took place (see Table 2). Third, these improvements persisted for many months after the implementation period, so are not some temporary phenomena due to increased attention. Finally, the firms themselves also believed these improvements arose from better management practices, which was the motivation for them spreading these practices out to their other plants not involved in the experiments.

5. The impact of management on organizational structure and computerization

5a. The impact of management practices on firm organization

Over the last thirty years a large theoretical literature on the organization of firms has developed, focusing on the decentralization of decision making within firms. The literature generally emphasizes optimal decentralization in one of two ways.[69] The first is in terms of minimizing information processing costs – trading off asking better informed senior managers versus the costs of communicating these requests and commands. In these models improving the availability information through out the organization would typically lead to greater decentralization as decisions can be taken more effectively locally. If plant managers are able to access daily information on quality, inventory and output, they should be more able to make effective management decisions without assistance from the directors. Hence, this literature would suggest that better management practices should lead to greater decentralization of decisions making. The second literature is in terms of principal-agent models emphasizing the trade-offs between incentives and information. The principal (in our case the directors) have the better incentives while the agents (in our case the plant managers) have the better production information. In these models improving management will have an ambiguous impact – on the one hand the principals become better informed, thereby increasing centralization, but on the other they can also more easily monitor their managers, reducing the misalignment of incentives. Hence, this literature is ambiguous on the impact of better management on firm decentralization.

While the theoretical literature is expansive the empirical literature on management and decentralization is extremely limited. Some survey and case-study evidence exists, but nothing with clean identification from natural or field experiments. So we collected extensive decentralization data from our management field experiment plants.

To measure decentralization we collected data on the locus of decision making for weaver hiring, manager hiring, spares purchases, maintenance planning, weaver bonuses, new product introductions, investment and departmental co-ordination. Because firm organization changes slowly over time we collected this data at lower frequencies – to date gathering data once from pre-intervention and once in March 2010. For every decision except investment we scored decentralization on a 1 to 5 scale, where 1 was defined as no authority of the plant manager over the decision and 5 as full authority (see Appendix Table B1 for the full survey and Table B3 for descriptive statistics). So, for example, we measured decentralization for the plant manager over weaver hiring from a scale of 1 defined as "*No authority – not even for replacement hires*" to 5 defined as "*Complete authority – it is his decision entirely*", with intermediate scores like 3 defined as "*Requires sign-off from the Director based on the business case. Typically agreed about 80% or 90% of the time*". These questions and scoring

[69] See, for example, Bolton and Dewatripont (1994), Garicano (2000) for examples of the first approach (information processing), and Aghion and Tirole (1997), Baker, Gibbons and Murphy (1999), Rajan and Zingales (2001), Hart and Moore (2005), Acemoglu et al. (2007) and Alonso et al. (2008) for examples of the second approach (principal-agent models).

were based on the survey methodology in Bloom, Sadun and Van Reenen (2009), which measured decentralization across countries and found developing countries like India typically have very centralized decision making within firms. The measure of the decentralization for investment was in terms of "The largest expenditure (in rupees) a plant manager (or other managers) could typically make without a Directors signature", which had an average of 12,608 rupees (about $250).

To combine all these eight decentralization measures into one index we took the principal factor component of the eight measures, which we called the decentralization index. Changes in this index were strongly and significantly correlated with changes in management across firms, as Figure 6 shows. Firms which had substantial improvements in management practices during the experiment also tended to have decentralize more production decisions to their plant managers.

Table 6 looks at this in a regression format by estimating the following specification

$$DECENTRALIZATION_{i,t} = a_i + b_t + cMANAGEMENT_{i,t} + e_{i,t} \quad (3)$$

where DECENTRALIZATION is our measure of plant decentralization, and a_i and b_t are plant fixed effects and time dummies. In column (1) we start with regressing our overall our decentralization index against management practices and find a statistically significant positive impact. Firms that improved their management practices during the experiment have also delegated more decisions to their plant managers. The magnitude of this effect appears reasonably large – the average change in management practices for the treatment firms (0.352) would be associated with about a 0.3 standard deviation change in the decentralization index. In columns (2) to (6) we examine the five individual components of the decentralization index that changed over the experimental time frame.[70] We see that all the individual sub-components also increased, although often this change is not statistically significant. The area where this most notable changed was directors coordination, which reflects the extent to which directors are involved in decision making between managers – for example, does a director need to get involved in decisions between the inventory manager and the production manager. Because of the improvements in production information it became easier for different section heads to coordinate directly rather than involve the directors.

To put these results in context, however, it is worth noting that even these decentralizing Indian factories are still extremely centralized compared to factories in Europe and the US. For example, using the Bloom, Sadun and Van Reenen (2009) data we know that plant managers in developed country are typically able to hire full-time employees with pretty minimal control from their headquarters (compared to very limited authority in our Indian factories), and can invest about $52,000 without central clearance (compared to about $250 in India). So, these improvements in management practices have increased decentralization, but still leave Indian factories very centralized compared to plants in developed countries.

[70] We saw no changes in the degree of decentralization over weaver employment, planning of maintenance schedules and introducing new products. These decisions did have cross-sectional variation in the extent of decentralization (as shown in Appendix B) but no time variation between pre-treatment and March 2010.

5b. The impact of management practices on computerization

One of the major topics over the last decade has been the relationship between IT and productivity. Until the 1990s convincing evidence on the aggregate impact of computers on productivity was so hard to find that Robert Solow famously quipped in 1987 that "you see computers everywhere but in the productivity statistics". In more recent periods, however, the paradox has reversed with a growing literature now finding that the productivity impact of IT is substantially larger than its cost share (e.g. Bresnahan, Brynjolfsson and Hitt, 2002, and Brynjolfsson and Hitt, 2003). The literature has argued this is because IT is complementary with modern management and organizational practices, so that as firms invest in IT they also improve their management practices. This leads to a positive bias on IT in productivity estimates as management and organizational practices are typically an unmeasured residual.[71] But none of this literature has any direct experimental evidence, instead relying on identification from observed changes in IT and management and organizational survey data.

So to investigate the complementarity between IT and management practices we collected computerization data on ten aspects of the plants, covering the use of Electronic Resource Planning (ERP) systems, the number of computers, the age of the computers, the number of computer users, the total hours of computer use, the connection of the plant to the internet, the use of e-mail by the plant manager and the director, the existence of a firm website and the depth of computerization of production decisions (see Appendix Table B2 for the full survey and Table B3 for descriptive statistics). As with decentralization we collected this data once from before the intervention and once in March 2010. Figure 7 plots the change in the principal component factor of these ten computer measures against the change in management practices across these plants. It is clear that as firms adopted more modern management practices they significantly increased the computerization of their production.

Table 6 looks at this in a regression form by estimating the following specification

$$\text{COMPUTERIZATION}_{i,t} = a_i + b_t + c\text{MANAGEMENT}_{i,t} + e_{i,t} \qquad (4)$$

where COMPUTERIZATION is various measures of computer use within plants, and a_i and b_t are plant fixed effects and time dummies. In column (7) we start with regressing our overall computer index on management practices and find a large significant positive coefficient. The magnitude of this at 0.423 suggests that for a firm changing management practices by the treatment average of 0.352 they would increase computerization use by about 0.15 of a standard deviation. In columns (8) to (10) we look at the three individual components of this measure that changed over the experimental period, and see all individually increased, most notably the number of hours of computer use and the number of computer users.

For context we should note, however, that Indian firms are very un-computerized in comparison to firms in Europe, the US and Japan. For example, comparing the numbers of the use of IT in European factories from Bloom, Sadun and Van Reenen (2007) we see that in all European firms plant managers and directors would use e-mail and plants some form of ERP system, compared to 25%, 83% and 79% respectively in India.

[71] See, for example, Bartel, Ichniowski and Shaw (2007) and Bloom, Sadun and van Reenen (2007).

6. Why are many Indian firms badly managed?

Given the evidence in section (IV) on the substantial impact of better management practices on plants quality, inventory and output, the obvious question is whether these management changes increased profitability, and if so why where these not introduced before.

6a. The estimated impact of management practices on profits and productivity

In Table 7 we provide some estimates of the magnitudes of the profitability and productivity impact of the interventions, with more details in Appendix A. Firms did not provide us with any profit and loss accounts, so we have estimated the impact on profitability from the quality, inventory and efficiency improvements.[72] Our methodology here is very simple: for example, if a given improvement in practices is estimated to reduce inventory stock by X tons of yarn, we map this into profits using conservative estimates of the cost of carrying X tons of yarn. Or if it reduces the numbers of hours required to mend defects we estimated this reduction in hours on the firms total wage bill. These estimates are medium-run because, for example, it will take a few months for the firms to reduce their mending manpower.

<u>Profits:</u>
The top panel of Table 7 focuses on profits. In the first row we see that the improvements in management practices should have increased profits via reducing mending costs by about $13,120 for the intervention. The reason is the reduction in quality defects should lead to a fall in the mending manpower, which has an annual average wage bill of $41,000. Mending is generally piece-work so that lower levels of defects lead directly to a lower mending wage bill. In the second row we see the reduction in defects also increased the level of fabric output by $178,800 by reducing the amount of fabric waste. Fabric defects leads to about a 7.5% loss of fabric sales because many defects cannot be repaired and have to be cut out, or are sold at large reductions.[73] Reducing the number of defects should lead directly to a reduction in the amount of wasted fabric, and thus an increase in output. In the third row we calculate that the reduction in inventory levels from the intervention reduced annual costs by about $8,045. This was because yarn costs about 22% a year to hold given the 15% nominal interest rates on bank loans, the 3% storage costs and 4% depreciation costs. In the fourth row we see the intervention and full-adoption increases in efficiency are estimated to increase profits by $122,180 because of the higher sales from the additional output. The total increase in profits was estimated to be around $322,145, which is about an increase in profits of about 11.4%.[74]

[72] We could obtain the public profit and loss accounts, but it was unclear how accurate these were. We did not ask firms for their private profit and loss accounts (if they even kept them) as they would have been likely to refuse given the fears over them leaking out to the Indian tax authorities.
[73] For example, one of the most common quality defects was color streaking in the fabric from different shades of yarn having been accidently used in the same piece of fabric. This fabric is unusable for most clothing so is typically sold at a 50% discount as lining material. Another common defect was dirt and grease stains, which are often impossible to remove in light-colored fabric.
[74] While we can not obtain the true profit and loss accounts for these firms, we do know the costs of capital for yarn within the textile industry (22%) and the firms capital stock ($13.3m on average), yielding annual profits of around $2.82m.

These increases in profits are potentially lower bounds in three senses. First, they take the firms' choice of capital, labor and product range as given. But in the long-run the firms can re-optimize. For example, with fewer machine breakdowns each weaver can manage more machines, so the number of weavers can be decreased. Second, many of the management practices are arguably complementary, so they are much more effective when introduced jointly (e.g. Milgrom and Roberts, 1990). However, the intervention time-horizon was too short to change many of the complementary human-resource practices, so the full rewards would not be realized. For example, providing employees with rewards for performance above their baseline requires defining the baseline – such as the average level of efficiency over the preceding year – but this is itself impacted by the operational management interventions. As a result many firms did not want to introduce the performance bonuses until after the other interventions had stabilized and they could calculate the appropriate baseline. As a result the full impact of the interventions will take time to accrue. Third, the intervention was narrow in focus in that other management practices around activities like finance, strategy, marketing and procurement were not been addressed.

On the other hand these increases in profits may overstate the long-run impact is once the consultants leave the factory the firms backslide on the management changes. We are currently planning to revisit these firms in Fall 2011, after a one year absence, to collect longer-run data to evaluate this.

To estimate the net increase in profit for these improvements in management practices we also need to calculate the costs of these changes (ignoring for now any costs of consulting). These costs were extremely small, averaging less than \$2000 per firm.[75] So in the absence of any costs of consulting to introduce these new management practices – which would have been substantial if firms had paid themselves – it would clearly be highly profitable to do so.

Productivity:
The bottom panel of Table 7 estimates the impact of the intervention on productivity. This is based on an assumed constant-returns-to-scale Cobb-Douglas production function:

$$Y=AL^{\alpha}K^{1-\alpha} \tag{1}$$

where Y is value-added (output – materials and energy costs), L is hours of work and K is the net capital stock. Under perfect competition the coefficient α is equal to the labor share of value-added, which is 0.59 in textiles in the 2003-04 Indian Annual Survey of Industries.

The first row in the bottom panel estimates the impact of quality improvements on the reduction in repair manpower. Repairing defects is done on a piece by piece basis, so that a reduction in the number of defects implies an equivalent reduction in the number of repair hours. Since repair hours represents 18.7% of all hours across the factory, the 31.9% reduction in QDI estimated from the intervention and full-adoption changes in management practices led to an estimated 3.5% increase in productivity. The second row in the bottom

[75] The \$35 of extra labor to help organize the stock rooms and clear the factory floor, about \$200 on plastic display boards, about \$200 for extra racking for stores rooms, and about \$1000 on rewards.

panel of Table 7 estimates the productivity impact of the lower waste of fabric in the quality repair process, with an estimated 2.4% for the intervention. The third row of the bottom panel estimates the impact of a lower capital stock from the lower inventory levels, which leads to a 0.5% estimated increase in productivity.

Finally, the fourth row in the bottom panel estimates of the impact of increased production on total factor productivity. This translates directly into an increase in output, and given the labor and capital inputs are fixed, into an equivalent increase in productivity.[76] Hence, the 4.1% increase in output from the intervention translates directly into proportional increases in productivity.

Overall these productivity numbers are quite substantial – a 10.5% increase from the intervention. And as discussed above we think these are lower bound figures, substantially below the long-run impact of firms improving their management practices. Hence, these numbers suggests that bad management does play an important role in explaining the productivity gap between India and the US.

6b. Why are firms badly managed?

Given the evidence in section (5a) above on the large increase in profitability from the introduction of these modern management practices, the obvious question is: why had firms not already adopted these before? To investigate this we asked our consultants to document every other month the reason for any non-adoption of the 38 practices in each plant. To do this consistently we developed a flow-chart (see Figure 8) which runs through a series of questions to understand the root cause for the non-adoption of each individual practice. They collected this data from extensive discussions with owners, managers and workers, plus their observations from working daily in the plants.

As an example of how this flow chart works, imagine a plant that does not record quality defects (the first practice in quality control in Table 2). The consultant would first ask if there was some external constraint, like labor regulations, preventing this, which we found never to be the case.[77] They would then ask if the plant was aware of this practice, which in the example of quality recording systems typically was the case as it's a well known practice. The consultants would then check if the plant could adopt the practice with the current staff and equipment, which again for quality recording systems was always true as it is a simple process. Then they would ask if the owner believed it would be profitable to record quality defects, which was often the constraint on adopting this practice. The owner often argued their quality was so good they did not need to record quality defects. This view was mistaken because while these plants' quality might have been good compared to other low-quality Indian textile plants, by international standards their quality was very poor. So, as shown in Figure 3, when they did adopt basic quality control practices they substantially improved their production quality. So, in this case the reason for non-adoption would be "incorrect

[76] In fact with higher efficiency lower labor is needed because if machines breakdown less frequently workers can supervise more machines, so that in the long-run these figures would be an underestimate of the impact.

[77] This does not mean labor regulations do not matter for some practices – for example firing underperforming employees – but they did not directly impinge adopt the immediate adoption of the 38 practices in Table 2.

information" as the CEO had incorrect information on the cost-benefit calculation for quality control processes.

The overall results for non-adoption of management practices are tabulated in Table 8, for the treatment plants, control plants and the non-experimental plants (the plants in the same firm as the treatment plants). This is tabulated at 2 monthly intervals starting the month before the intervention phase. The rows report the different reasons for non-adoption as a percentage of all practices. So that, for example, the top-left cell (value 38.6) states that in the treatment plants in the month before the intervention 38.6% of practices were not adopted because the plant was unaware of the existence of these practices (they lacked information on these). Looking across the table several results are apparent

First, a major initial barrier to the adoption of these modern management practices is a lack of information about their existence. About 30% of practices were not adopted because the firms were simply not aware of them. These practices tended to be the more advanced practices of regular quality, efficiency and inventory review meetings, posting standard-operating procedures and visual aids around the factory, the use of historical efficiency data for design pricing and scientific inventory methods. Many of these are derived from the Japanese inspired lean manufacturing revolution, and are common across Europe, Japan and the US but apparently have yet to permeate Indian manufacturing.

Second, another major initial barrier was incorrect information, in that firms may have heard of these practices but thought they did not apply profitably to them. For example, many of the firms were aware of preventive maintenance but few of them thought it was worth doing this. They preferred to keep their machines in operation until they broke down, and then repair them. But another lesson from the Lean manufacturing revolution is that preventive maintenance reduces long-run downtimes (as faults are typically easier to fix in advance) and also production variability. Production variability itself reduce productivity as it causes other problems along the supply chain – for example, unanticipated breakdowns increase the complexity of production scheduling, increasing the downtimes from mismatched resources.

Third, as the intervention progressed the lack of information constraint was rapidly addressed. It was easy for the consultants to inform the firms about modern management practices. However, the incorrect information constraints were harder to address. This was because the owners had their prior beliefs about the efficacy of a practice and it took time to change these. This was often done using pilot changes on a few machines in the plant or with evidence from other plants in the experiment. For example, the consultants often started by persuading the managers to undertake preventive maintenance on a set of trail machines, and once it was proven successful it was rolled out to the rest of the factory. And as the consultants demonstrated the positive impact of some of these initial practice changes, the owners increasingly trusted them and would adopt more of the more complex recommendations, like introducing performance incentives for managers.[78]

[78] These sticky priors highlight one reason why management practices appear to take several years to change in the US and Europe. The evidence on this is anecdotal, but for example, the private equity industry has a 3 year minimum for a management turn around. Similarly, consulting firms typically take at least 18 months to execute large change management programs.

Fourth, once the informational constraints were addressed other constraints arose. For example, even if the owners became convinced of the need to adopt a practice they would often take several months to execute these. This was particularly pertinent in the non-experimental plants where the consultants were not on-site to drive the changes. This matches up to the evidence on procrastination in other contexts, for example Kenyan farmers investing in fertilizer (Duflo, Kremer and Robinson, 2009) or farmers in Ghana adopting new technologies (Conley and Udry, 2010).

Fifth, manager incentives were also a cause of non-adoption of a few percent of these practices. In these firms mid-level managers did not receive any incentive pay, and they had very limited promotion incentives since the directors of all mid-size textiles firms were family members. Hence, their incentives to perform beyond the levels required to keep their jobs was muted. As a result many of the managers were happy to adopt management practices that were standard in the industry, but reluctant to do anything further if this involved additional effort. This highlights how the adoption of management practices is cross-linked, with poor human-resource management practices impeding the adoption of other management practices.

Finally, somewhat surprisingly we did not find evidence for the direct impact of a set of other factors highlighted in the literature on capital investment. One such factor is capital constraints, which are a significant obstacle to the expansion of micro-enterprises (e.g. De Mel, McKenzie and Woodruff, 2008). Our evidence suggested that the medium to large firms involved in our experiment were not cash-constrained. We collected data on all the investments for our 17 firms over the period April 2008 until April 2010 and found the firms invested a mean (median) of \$880,000 (\$140,000). For example, several of the firms were setting up new factories or adding machines, apparently often financed by bank loans. Certainly, this scale of investment suggests that investment on the scale of \$2000 (the first-year costs of these management changes, ignoring the consultants' fees) to improve the factories' management practices is unlikely to be directly impeded by financial constraints.

Of course financial constraints could impede hiring in international consultants. The market cost of our free consulting would be at least \$500,000, and as an intangible investment it would be difficult to collateralize.[79] Hence, while financial constraints do not appear to directly block the implantation of better management practices, they may hinder firms' ability to improve their current management practices using external consultants. On the other hand, our estimates of the incremental profitability from adopting modern management practices suggest cost recovery in as little as one year.

Another factor we that played a limited direct role was poor infrastructure. For example, unreliable electricity provision is a major impediment to productivity in developing countries (e.g. World Bank, 2004). We certainly saw evidence of this in that, for example, Tarapur and Umbergaon had weekly electricity blackouts which lowered production levels on the blackout

[79] Our international consulting firm estimated that to offer a standard consulting team to these firms at market rates would cost at least \$500,000. This is much more expensive than our costs per firm because: (I) we achieved substantial scale economies from working with a large number of firms simultaneously; and (II) we had 50% rates on the consultants and no partner charges.

days (most firms had generators that could cover only about 50% of their electricity needs). However, this did not appear to explain firms' bad management, since they successfully adopted many of the 38 key textile practices during the intervention period, over the course of which the infrastructure was not improved. This reflects that fact these practices change the way firms internally operate and are relatively independent from infrastructure or external problems.

The same reasoning also applies to corruption, since again there is no evidence the levels of potential corruption changed over the intervention period. Also, looking at the list of individual practices it is hard to identify many that would be constrained by corruption.

6c. How do badly managed firms survive?

We have shown that management matters, with improvements in management practices improving plant-level outcomes. One response from economists might then be to argue that poor management can at most be a short-run problem, since in the long run better managed firms should take over the market. Yet many of our firms have been in business for 20 years and more.

One reason why better run firms do not dominate the market is constraints on growth through managerial span of control. In every firm in our sample, only members of the owning family are company directors – that is in managerial positions with major decision-making power over finances, purchases, operations or employment. paper. Non-family members are given junior managerial positions that have power only over low-level, day-to-day activities. The reason is the family members do not trust the non-family members not to steal from the firm. For example, they are concerned if they let their plant managers run procurement they might buy yarn at inflated rates from friends and receive kick-backs.

A key reason for this inability to decentralize is the poor rule of law in India. Even if directors found managers stealing their ability to successfully prosecute them and recover the assets is minimal because of the inefficiency of Indian courts. In contrast, in the US if a manager was found stealing from a firm it is likely they could be successfully prosecuted and much of the assets recovered. A compounding reason for the inability to decentralize in Indian firms is bad management, as this means they cannot keep good track of materials and finance, so may not even able to identify theft within their firms. [80]

[80] Another compounding factor is these firms had poor human resources management practices. None of the firms had a formalized development or training plan for their managers, and managers could not be promoted because only family members could become directors. As a result managers lacked career motivation within the firm. In contrast in the Indian software and finance industries firms place a huge emphasis on development and training to motivate employees and build trust, which is essential for delegation in the absence of a strong level system (see also Banerjee and Duflo (2000)).

As a result of this inability to decentralize every factory in the firm requires a family member on-site to manage it. This means firms can only expand if male family members are available to take up plant manager positions. Thus, an important correlate of firm size in our firms was the number of male family members of the owners. For example, the number of brothers and sons of the leading director has a correlation of 0.689 with the total employment size of the firm, compared to 0.223 for their average management score. In fact the best managed firm in our sample – which was also a publicly quoted firm and apparently extremely profitable – had only one (large) production plant, in large part because the owner had no brothers or sons to run additional plants. This matches the ideas of the Lucas (1978) span of control model, that there are diminishing returns to how much additional productivity better management technology can generate from a single manager. In this model the limits to firm growth restrict the ability of highly productive firms to drive out the lower productivity firms from the market. In our India firms this span of control restriction is extremely binding so productive firms do not grow large and drive unproductive firms out from the market. This matches plant-level productivity data from China and India (Hsieh and Klenow, 2009) as well as firm-level organizational survey data (Bloom, Sadun and Van Reenen, 2009).

Entry also appears limited by the difficulty of separating ownership from control. The supply of new firms is limited by the numbers of wealthy families with finance and male family members available to run textiles plants. Given the rapid growth of other industries in India – like software and real-estate – entry into textile manufacturing is limited. Even our firms were often taking cash from their textile businesses to invest in other businesses, like real-estate and retail. And even if an entrant had funding there is no obvious guarantee their management practices would be better than the incumbent firms.

Hence, the equilibrium appears to be that Indian wage rates are extremely low so that firms can survive while operating with poor management practices. Because spans of control are constrained productive incumbent firms are limited from expanding and so do not drive out the badly run firms. And because entry is limited new firms do not enter rapidly. As a result the situation approximates a Melitz (2003) style model where firms have very high decreasing returns to scale, entry rates are low, and initial productivity draws are low (because good management practices are not widespread). The resultant equilibrium has a low average level of productivity, a low wage level, a low average firm-size, and a large dispersion of firm-level productivities.

6d. Why do firms not use more management consulting?

Finally, why these firms not hire consultants given the large gains from better management? The primary reason is these firms are not aware they are badly managed, as illustrated in Table 9. In the pre-intervention state for the treatment firms 93% (93%=(38.6+29.3)/73) of the non-adoption reasons were due to a "lack of information" or "incorrect information".

Of course consulting firms could still tout round firms for business, pointing out that their practices were bad and offering to fix them. But Indian firms, much like US firms, are bombarded with solicitations from businesses offering to save them money on everything from telephone bills to raw materials, so are unlikely to be particularly receptive (see Fuchs and Garicano 2010 for a theoretical model of these types of problems in selling advice). Of course consulting firms could go further, and offer to provide their advice for free with an ex post profit sharing deal. But monitoring this would be hard – many Indian are heavily under reporting profits to the tax authorities, and would be likely to do the same with partnering consulting firm.[81] Moreover, numerous Indian firms are breaching tax, labor and health-and-safety laws (see Exhibits 3 to 7), and so are reluctant to let unknown outsiders into their firms. Our project benefited from the endorsement of Stanford and the World Bank, but a local firm offering free consulting would probably find it much harder to gain the trust of firms.

7. Conclusions

Management does matter. We have implemented a randomized experiment which gave managerial consulting services to textile plants in India. This experiment led to improvements in basic management practices, with plants adopting lean manufacturing techniques which have been standard for decades in the developed world. These improvements in management practice led to plants improving the quality of their production, reducing excess inventory levels, and improving efficiency. The result was an improvement in profitability and productivity. Firms also decentralized their production decisions as a result of better management practices, because the improved monitoring reduced the potential for plant managers to expropriate firm resources and increased their ability to effectively manage the plant. At the same time computer use increased substantially, driven by the need to collect, process and disseminate data as required by modern management practices.

What are the implications of this for public policy? First, our results suggest that firms were not implementing the better practices on their own because of lack of information and knowledge, and that to really improve quality firms needed detailed instruction in how to implement better practices. This suggests a need for better knowledge and training programs in India, and in developing countries more generally. This would include high quality business school education to teach managers better management practices, and a more vibrant local consulting industry with the ability to signal quality through reputation building. While both these are private sector activities, they depend on the government for a regulatory environment which makes entry easy and which allows quality to be the main determinant of success. A second method for knowledge transference comes from the presence of multinationals. Indeed, many of the consultants working for the international consulting firm hired by our project had worked for multinationals in India, learning from their state-of-the-art manufacturing management processes. Yet a variety of legal, institutional, and infrastructure barriers have limited the extent of multinational expansion within India, limiting the spread of knowledge on better manufacturing among the Indian managerial labor force. Finally, our results also suggest that a weak legal environment has limited the scope for

[81] Because of this ex-post profit sharing consulting arrangements are almost unheard of even in the US and Europe. Consulting firms do occasionally consult in return for small equity stakes – as occurred during the dot-com boom for high tech firms. But this ties revenues to the sale price of the firm, which is a much more verifiable measure of performance than annual profits with less conflicting incentives since this is also the main route for the owners to extract profits from the business.

well-managed firms to grow. So that improving the legal environment should encourage productivity enhancing reallocation, helping to drive out badly managed firms.

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APPENDIX

A. Estimations of profitability and productivity impacts.

We first generate the estimated impacts on quality, inventory and efficiency. To do this we take the Intention to Treat (ITT) numbers from Table 5, which shows a reduction of quality defects of 31.9% (exp(-0.385)-1), a reduction in inventory of 15.9% (exp(-0.173)-1) and an increase in output of 4.1% (exp(0.04)-1).

Mending wage bill:
Estimated by recording the total mending hours, which is 71,700 per year on average, times the mending wage bill which is 36 rupees (about $0.72) per hour. Since mending is undertaken on a piece-wise basis – so defects are repaired individually – a reduction the severity weighted defects should lead to a proportionate reduction in required mending hours.

Fabric revenue loss from non grade-A fabric:
Waste fabric estimated at 7.5% in the baseline, arising from cutting our defect areas and destroying and/or selling at a discount fabric with unfixable defects. Assume increase in quality leads to a proportionate reduction in waste fabric.

Inventory carrying costs:
Total carrying costs of 22% calculated as interest charges of 15% (average prime lending rate of 12% over 2008-2010 plus 3% as firm-size lending premium – see for example http://www.sme.icicibank.com/Business_WCF.aspx?pid), 3% storage costs (rent, electricity, manpower and insurance) and 4% costs for physical depreciation and obsolescence (yarn rots over time and fashions change).

Increased profits from higher output
Increasing output is assumed to lead to an equi-proportionate increase in sales because these firms are small in their output markets, but would also increase variable costs of energy and raw-materials since the machines would be running. The average ratio of (energy + raw materials costs)/sales is 62%, so the profit margin on increased efficiency is 38%.

Labor and capital factor shares:
Labor factor share of 0.58 calculated as total labor costs over total value added using the "wearing apparel" industry in the most recent (2004-05) year of the Indian Annual Survey of industry. Capital factor share defined as 1-labor factor share, based on an assumed constant returns to scale production function and perfectly competitive output markets.

Table B1: The decentralization survey:

For all questions except D7 any score can be given, but the scoring guide is only provided for scores of 1, 3 and 5.			
Question D1: “*What authority does the plant manager(or other managers) have to hire a WEAVER (e.g. a worker supplied by a contractor)?*”			
	Score 1	Score 3	Score 5
Scoring grid:	No authority – even for replacement hires	Requires sign-off from the Director based on the business case. Typically agreed	Complete authority – it is my decision entirely
Question D2: “*What authority does the plant manager(or other managers) have to hire a junior Manager (e.g. somebody hired by the firm)?*”			
	Score 1	Score 3	Score 5
Scoring grid:	No authority – even for replacement hires	Requires sign-off from the Director based on the business case. Typically agreed	Complete authority – it is my decision entirely
Question D3: “*What authority does the plant manager (or other managers) have to purchase spare parts?*”?			
Probe until you can accurately score the question. Also take an average score for sales and marketing if they are taken at different levels.			
	Score 1	Score 3	Score 5
Scoring grid:	No authority	Requires sign-off from the Director based on the business case. Typically agreed	Complete authority – it is my decision entirely
Question D4: “*What authority does the plant manager (or other managers) have to plan maintenance schedules?*”			
	Score 1	Score 3	Score 5
Scoring grid:	No authority	Requires sign-off from the Director based on the business case. Typically agreed	Complete authority – it is my decision entirely
Question D5: “*What authority does the plant manager (or other managers) have to award small (<10% of salary) bonuses to workers?*”			
	Score 1	Score 3	Score 5
Scoring grid:	No authority	Requires sign-off from the Director based on the business case. Typically agreed	Complete authority – it is my decision entirely
Question D6: “*What authority does the plant manager (or other managers) have to introduce new products*”			
	Score 1	Score 3	Score 5
Scoring grid:	No authority	Requires sign-off from the Director based on the business case. Typically agreed	Complete authority – it is my decision entirely
Question D7: “*What is the largest expenditure (in rupees) a plant manager (or other managers) could typically make without your signature?*”			
Question D8: “*What is the extent of follow-up required to be done by the directors?*”			
	Score 1	Score 3	Score 5
Scoring grid:	The Directors are the primary point of contact for exchange of all information between managers	Frequent follow ups on about half of the decisions made by managers	Minimal follow-ups on decisions taken between managers. Only dispute resolution.

Table B2: The computerization survey:

For question D9 any score can be given, but the scoring guide is only provided for scores of 1, 3 and 5.

Question C1: “Does the plant have an Electronic resource planning system?”

Question C2: “How many computers does the plant have?”

Question C3: “How many of these computers are less than 2 years old”

Question C4: “How many people in the factory typically use computers for at least 10 minutes day?”

Question C5: “How many cumulative hours per week are computers used in the plant”?

Question C6: “Does the plant have an internet connection”

Question C7: “Does the firm (or plant) have a website?”

Question C8: “Does the plant manager use e-mail (for work purposes)?”

Question C9: “Does the plant manager use e-mail (for work purposes)?”

Question C10: “*What is the extent of computer use in operational performance management?*”

	Score 1	Score 3	Score 5
Scoring grid:	Computers not used in operational performance management	Around 50% of operational performance metrics (efficiency, inventory, quality and output) are tracked & analyzed through computer/ERP generated reports.	All main operational performance metrics (efficiency, inventory, quality and output) are tracked & analyzed through computer/ERP generated reports.

Table B3: Descriptive statistics for the Decentralization and Computerization survey

Decentralization questions					Computerization questions				
	Mean	**Min**	**Max**	**SD**		**Mean**	**Min**	**Max**	**SD**
D1 (weaver hiring)	4.71	3	5	0.683	**C1 (ERP)**	0.79	0	1	0.41
D2 (manager hiring)	2.19	1	4	1.19	**C2 (number computers)**	2.79	0	8	2
D3 (spares purchases)	2.78	1	5	0.87	**C3 (number new computers)**	0.54	0	8	1.65
D4 (maintenance planning)	4.69	2	5	0.76	**C4 (computer users)**	3	0	10	2.28
D5 (worker bonus pay)	2.54	1	5	1.22	**C5 (computer hours)**				
D6 (new products)	2.04	1	4	1.17	**C6 (internet connection)**	0.69	0	1	0.47
D7 (investment limit, rupees)	12608	1000	60000	12610	**C7 (website)**	0.33	0	1	0.48
D8 (director coordination)	3.20	2	5	0.88	**C8 (plant manager e-mail)**	0.25	0	1	0.44
Decentralization index	0	-2.07	1.53	1	**C9 (directors e-mail)**	0.83	0	1	0.38
					C10 (production computerization)	3.29	1	5	1.27
					Computer index	0	-1.52	2.45	1

Notes: There are about 50 rupees to the dollar.

Table 1: The field experiment sample

	All				Treatment	Control	Diff
	Mean	Median	Min	Max	Mean	Mean	p-value
Sample sizes:							
Number of plants	28	n/a	n/a	n/a	19	9	n/a
Number of experimental plants	20	n/a	n/a	n/a	14	6	n/a
Number of firms	17	n/a	n/a	n/a	11	6	n/a
Plants per firm	1.65	2	1	4	1.73	1.5	0.393
Firm/plant sizes:							
Employees per firm	273	250	70	500	291	236	0.454
Employees, experimental plants	134	132	60	250	144	114	0.161
Hierarchical levels	4.4	4	3	7	4.4	4.4	0.935
Annual sales $m per firm	7.45	6	1.4	15.6	7.06	8.37	0.598
Current assets $m per firm	12.8	7.9	2.85	44.2	13.3	12.0	0.837
Daily mtrs, experimental plants	5560	5130	2260	13000	5,757	5,091	0.602
Management and plant ages:							
BVR Management score	2.60	2.61	1.89	3.28	2.50	2.75	0.203
Management adoption rates	0.274	0.260	0.08	0.553	0.255	0.328	0.248
Age, experimental plant (years)	19.4	16.5	2	46	20.5	16.8	0.662
Performance measures							
Operating efficiency (%)	70.77	72.8	26.2	90.4	70.2	71.99	0.758
Raw materials inventory (kg)	59,497	61,198	6,721	149,513	59,222	60,002	0.957
Quality (% A-grade fabric)	40.12	34.03	9.88	87.11	39.04	41.76	0.629

Notes: Data provided at the plant and/or firm level depending on availability. **Number of plants** is the total number of textile plants per firm including the non-experimental plants. **Number of experimental plants** is the total number of treatment and control plants. **Number of firms** is the number of treatment and control firms. **Plants per firm** reports the total number of other textiles plants per firm. Several of these firms have other businesses – for example retail units and real-estate arms – which are not included in any of the figures here. **Employees per firm** reports the number of employees across all the textile production plants, the corporate headquarters and sales office. **Employees per experiment plant** reports the number of employees in the experiment plants. **Hierarchical levels** displays the number of reporting levels in the experimental plants – for example a firm with workers reporting to foreman, foreman to operations manager, operations manager to the general manager and general manager to the managing director would have 4 hierarchical levels. **BVR Management score** is the Bloom and Van Reenen (2007) management score for the experiment plants. **Management adoption rates** are the adoption rates of the management practices listed in Table 2 in the experimental plants. **Annual sales ($m)** and **Current assets ($m)** are both in 2009 US $million values, exchanged at 50 rupees = 1 US Dollar. **Daily mtrs, experimental plants** reports the daily meters of fabric woven in the experiment plants. Note that about 3.5 meters is required for a full suit with jacket and trousers, so the mean plant produces enough for about 1600 suits daily. **Age of experimental plant (years)** reports the age of the plant for the experimental plants. Note that none of the differences between the means of the treatment and control plants are significant. **Raw materials inventory** is the stock of yarn per intervention. **Operating efficiency** is the percentage of the time the machines are producing fabric per intervention. **Quality (% A-grade fabric)** is the percentage of fabric each plant defines as A-grade, which is the top quality grade.

Table 2: The textile management practices adoption rates

Area	Specific practice	Pre-intervention *level* of adoption: Treatment	Pre-intervention *level* of adoption: Control	Post-intervention *change* in adoption: Treatment	Post-intervention *change* in adoption: Control
Factory Operations	Preventive maintenance is carried out for the machines	0.429	0.667	0.214	0
	Preventive maintenance is carried out per manufacturer's recommendations	0.071	0	0.142	0.167
	The shop floor is marked clearly for where each machine should be	0.071	0.333	0.142	0
	The shop floor is clear of waste and obstacles	0	0.167	0.142	0
	Machine downtime is recorded	0.571	0.667	0.357	0.167
	Machine downtime reasons are monitored daily	0.429	0.167	0.5	0.167
	Machine downtime analyzed at least fortnightly & action plans implemented to try to reduce this	0	0.167	0.571	0
	Daily meetings take place that discuss efficiency with the production team	0	0.167	0.857	0.500
	Written procedures for warping, drawing, weaving & beam gaiting are displayed	0.071	0.167	0.500	0
	Visual aids display daily efficiency loomwise and weaverwise	0.214	0.167	0.571	0.167
	These visual aids are updated on a daily basis	0.143	0	0.643	0.167
	Spares stored in a systematic basis (labeling and demarked locations)	0.143	0.333	0.143	0
	Spares purchases and consumption are recorded and monitored	0.571	0833	0	0
	Scientific methods are used to define inventory norms for spares	0	0.167	0	0
Quality Control	Quality defects are recorded	0.929	1	0.071	0
	Quality defects are recorded defect wise	0.286	0.167	0.714	0.833
	Quality defects are monitored on a daily basis	0.286	0.333	0.714	0.333
	There is an analysis and action plan based on defects data	0	0.167	0.714	0
	There is a fabric gradation system	0.571	0.833	0.357	0
	The gradation system is well defined	0.500	0.667	0.429	0
	Daily meetings take place that discuss defects and gradation	0.071	0.167	0.786	0
	Standard operating procedures are displayed for quality supervisors & checkers	0	0	0.643	0
Inventory Control	Yarn transactions (receipt, issues, returns) are recorded daily	0.928	1	0.071	0
	The closing stock is monitored at least weekly	0.214	0.167	0.571	0.333
	Scientific methods are used to define inventory norms for yarn	0	0	0.167	0
	There is a process for monitoring the aging of yarn stock	0.231	0	0.538	0
	There is a system for using and disposing of old stock	0	.2	0.692	0.600
	There is location wise entry maintained for yarn storage	0.357	0.167	0.143	0
Loom Planning	Advance loom planning is undertaken	0.429	0.833	0.143	0
	There is a regular meeting between sales and operational management	0.429	0.500	0.214	0.167

Human Resources	There is a reward system for non-managerial staff based on performance	0.571	0.667	0.071	0
	There is a reward system for managerial staff based on performance	0.214	0.167	0.214	0
	There is a reward system for non-managerial staff based on attendance	0.214	0.333	0.214	0
	Top performers among factory staff are publicly identified each month	0.071	0	0.143	0
	Roles & responsibilities are displayed for managers and supervisors	0	0	0.500	0
Sales and Orders	Customers are segmented for order prioritization	0	0	0	0
	Orderwise production planning is undertaken	0.692	1	0.231	0
	Historical efficiency data is analyzed for business decisions regarding designs	0	0	0.143	0
All	Average of all practices	0.255	0.328	0.352	0.093
p-value for the difference between the average of all practices		0.248		0.000	

Notes: Reports the 38 individual management practices measured before, during and after the management intervention. The columns **Pre Intervention *level* of Adoption** report the pre-intervention share of plants adopting this practice for the 14 treatment and 6 control plants. The columns **Post Intervention *increase* in Adoption** report the changes in adoption rates between the pre-intervention period and 4 months after the end of the diagnostic phase (so right after the end of the implementation phase for the treatment plants) for the treatment and control plants. The **p-value for the difference between the average of all practices** reports the significance of the difference in the average level of adoption and the increase in adoption between the treatment and control groups.

Table 3: The structure of the experiment

Plant sample:		**Treatment**	**Control**
On-site	Number:	14 plants (across 11 firms)	6 plants (across 6 firms)
	Intervention:	1 month diagnostic, 4 months implementation, and measurement until August 2010	1 month diagnostic and measurement until August 2010
	Timing:	Two waves – first wave diagnostic began in September 2008 and second wave in April 2009.	One wave - diagnostic began in July 2009.
	Data:	Performance, management, organizational and IT	Performance, management, organizational and IT
Off-site	Number:	5 plants (across 4 firms)	3 plants (across 3 firms)
	Intervention:	None directly – but potential spillovers from interventions on other plants within the same firm	None directly – but potential spillovers from interventions on other plants within the same firm
	Timing:	No direct intervention – for analytical purposes timing defined as relative to the diagnostic phase for the on-site plants within the same firm	No direct intervention – for analytical purposes timing defined as relative to the diagnostic phase for the on-site plants within the same firm
	Data:	Management, organizational and IT	Management, organizational and IT

Notes: The table describes the structure of the management experiment. "On-site" plants are those in which the consultants spent time on-site each week to collect detailed performance data and ran the diagnostic phase. "Off-site" plants are those the consultants only visited bi-monthly to collect management, organizational and IT data.

Table 4: The impact of the treatment on management practices within and across plants

Dependent Variable	Overall Management	Overall Management	Overall Management	Inventory Management	Quality Management	Operations Management	Loom Planning	HR Management	Sales & Orders
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Own plant treatment$_{i,t}$	0.121***	0.122***	0.122***	0.117***	0.184***	0.098**	0.044	0.148***	0.031
Months consulting in own plant	(0.015)	(0.017)	(0.017)	(0.026)	(0.042)	(0.039)	(0.035)	(0.035)	(0.019)
Spillover treatment$_{i,t}$	0.039**	-0.006							
Months consulting in other plants within the same firm	(0.017)	(0.023)							
Lag spillover treatment$_{i,t-3}$		0.055**	0.050**	0.045**	0.074	0.049*	0.014	0.098***	-0.012
Lagged months consulting in other plants within the same firm		(0.024)	(0.019)	(0.021)	(0.045)	(0.027)	(0.029)	(0.031)	(0.013)
Time FEs	10	9	9	9	9	9	9	9	9
Plant FEs	28	28	28	26	28	28	28	28	28
Observations	280	252	252	252	252	234	252	252	252
R-squared	0.904	0.909	0.909	0.889	0.820	0.807	0.883	0.885	0.747

Notes: The dependent variable is the share of the 38 management practices adopted in each plant (in columns (1) to (3)) and within sub-groups of practices in columns (4) to (9). This is regressed against the cumulative weeks of intervention in the own plant ("Own plant treatment"), the cumulative weeks of treatment in other plants within the same firm ("Spillover treatment"), and this variable lagged three months ("Lag spillover treatment"). The data is quarterly until April 2009 and bi-monthly thereafter, reflecting the frequency of measurement of management practices. A full set of time-dummies and plant dummies is included. Standard errors are clustered at the plant level.

Table 5: The impact of management practices on performance

Dependent Variable	Quality (log QDI)			Inventory (log tons)			Output (log picks)		
Specification	OLS	IV	ITT	OLS	IV	ITT	OLS	IV	ITT
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\text{Management}_{i,t}$	-0.753*	-2.031***		-0.707***	-0.939***		0.125	0.239***	
Adoption of mgmt practices	(0.434)	(0.696)		(0.221)	(0.357)		(0.090)	(0.079)	
$\text{Intervention}_{i,t}$			-0.385**			-0.173**			0.040
Intervention stage initiated			(0.158)			(0.080)			(0.026)
Instrument	Log (1+ months of treatment)			Log (1+ months of treatment)			Log (1+ months of treatment)		
Time FEs	106	106	106	104	104	104	104	104	104
Plant FEs	20	20	20	18	18	18	20	20	20
Observations	1366	1366	1366	1690	1690	1690	1862	1862	1862

Notes: All regressions use a full set of plant and calendar week dummies. Standard errors bootstrap clustered at the firm level. **Quality (log QDI)** is a log of the quality defects index (QDI), which is a weighted average score of quality defects, so higher numbers imply worse quality products (more quality defects). **Inventory (log tons)** is the log of the tons of yarn inventory in the plant. **Output (log picks)** is the log of the sale quality production picks. **Management** is the adoption of the 38 management practices listed in table 2. **Intervention (implementation)** is a plant level indicator taking a value of 1 after the implementation phase has started at a treatment plant. **Log(1+months of treatment)** is the log of one plus the cumulative count of the weeks since the start of the implementation in each plant (treatment plants only), and value zero before. **OLS** reports results with plant estimations. **IV** reports the results where the management variable has been instrumented with log(1+ cumulative intervention weeks). **ITT** reports the intention to treat results from regressing the dependent variable directly on the 1/0 intervention indicator. **Time FEs** report the number of calendar week time fixed effects. **Plant FEs** reports the number of plant-level fixed effects. Two plants do not have any inventory on site, so no inventory data is available.

Table 6: The impact of management practices on organization and computerization

Measure:	Organization							Computerization		
Dependent variable:	Decentra-lization index	Manager employ-ment	Spares purch-asing	Worker bonuses	Invest-ment limits	Director coordin-ation	Computer-ization index	Computer intensity	Computin g hours	Computer users
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Management$_{i,t}$	0.833***	1.226*	0.127	1.660**	0.162	2.458***	0.423***	2.736***	11.320**	
	(0.187)	(0.702)	(0.268)	(0.717)	(0.235)	(0.813)	(0.119)	(0.668)	(4.108)	
Standard dev. of dependent var.	1.000	1.367	1.331	1.481	3.591	1.537	1.000	1.327	10.425	
Time FEs	2	2	2	2	2	2	2	2	2	2
Plant FEs	28	28	28	28	28	28	28	28	28	28
Observations	56	56	56	56	56	56	56	56	56	56

Notes: All regressions use two observations per firm (per intervention and March 2010), and a full set of plant dummies and time dummies. Standard errors bootstrap clustered at the firm level. **Management** is the adoption of the 38 management practices listed in table 2. **Decentralization index** is the principal component factor of 8 measures of decentralization around weaver hiring, manager hiring, spares purchases, maintenance planning, weaver bonuses, new products, investment, and departmental co-ordination. The other decentralization columns show the results for the individual components of this index which change over time (the omitted components do not change). **Manager employment** is the measure of the decentralization of employment decisions on hiring new junior managers. **Spares purchasing** is the measure of the decentralization over the purchasing of spare parts. **Worker bonuses** is the measure of decentralization over the ability to pay small worker bonuses. **Investment limits** is the log of the capital investment limit of plant managers. **Director co-ordination** is the extent of follow-up by directors in decision making between managers. **Computerization index** is the principal component factor of 10 measures around computerization, which are the use of an ERP system, the number of computers in the plant, the number of computers less than 2 years old, the number of employees using computers for at least 10 minutes per day, and the cumulative number of hours of computer use per week, an internet connection at the plant, the a firm web-site, if the plant-manager uses e-mail, if the directors use of e-mail, and the intensity of computerization in production. The other computerization columns show the results for the individual components of this index that changed over time (the omitted components did not change). **Computer intensity** is a measure of the extent of computers in the production management process. **Computing hours** is the number of cumulative hours per week that plant workers use computers. **Computer users** is the number of plant workers using computers for at least 10 minutes per week. **Plant FEs** reports the number of plant-level fixed effects.

Table 7: Estimated average impact of improved quality, inventory and efficiency

Change	Impact	Estimation approach	Estimated impact
Profits (annual in $)			
Improvement in quality	Reduction in repair manpower	Reduction in defects (31.9%) times average mending manpower wage bill of $41,000.	$13,120
	Reduction in waste fabric	Reduction in defects times (31.9%) the average yearly waste fabric (7.5%) times annual average sales of $7.45m.	$178,800
Reduction in inventory	Reduction in inventory carrying costs	Reduction in inventory (15.9%) times carrying cost of 22% times $230,000 average inventory	$8,045
Increased efficiency	Increased sales	Increase in output of 4.1% times 40% margin times $7.45m sales	$122,180
Total			$322,145
Productivity (%)			
Improvement in quality	Reduction in repair manpower	Reduction in defects (31.9%) times share of repair manpower in total manpower (18.7%) times labor share (0.58) in output	3.5%
	Reduction in waste fabric	Reduction in defects (31.9%) times the average yearly waste fabric (5%)	2.4%
Reduction in inventory	Reduction in capital stock	Reduction in inventory (15.9%) times inventory share in capital (8%) times capital factor share (0.42)	0.5%
Increased efficiency	Increased output	Increase in output (4.1%) without any change in labor or capital	4.1%
Total			10.5%

Notes: Estimated impact of the improvements in the management intervention on firms profitability and productivity through quality, inventory and efficiency using the estimates in Table 5. Figure calculated for the average firm. See Appendix A for details of calculations for inventory carrying costs, fabric waste, repair manpower and factor shares.

Table 8: Reasons for bad management, as a percentage (%) of all practices, before and after treatment

Non-adoption reason	Firm group	1 month before	1 month after	3 months after	5 months after	7 months after	9 months after
Lack of information (plants not aware of the practice)	Treatment	38.6	12.8	2.2	0.5	0.4	0.3
	Control	32.1	13.7	8.4	8.4	8.4	n/a
	Non-experimental	30.4	13.0	2.1	0.5	0.5	0.3
Incorrect information (plants incorrect on cost-benefit calculation)	Treatment	29.3	33.3	31.9	29.2	28.5	27.5
	Control	27.6	36.1	38.4	37.9	37.9	n/a
	Non-experimental	34.2	33.2	31.3	28.7	24.7	23.2
Low ability or procrastination of owner (the owner is the reason for non adoption)	Treatment	3.8	9.1	7.2	7.5	7	6.7
	Control	5.8	9.5	9.2	8.4	8.4	n/a
	Non-experimental	5.3	23.4	31.8	35.5	33.2	33.7
Limited manager incentives or authority (plant manager is the reason for non-adoption)	Treatment	1.3	2.1	2.4	3.0	3	3.2
	Control	1.6	1.6	1.6	1.6	1.6	n/a
	Non-experimental	2.4	2.6	2.6	2.6	2.6	2.6
Not profitable (the consultants agree non-adoption is correct)	Treatment	0	0.2	0.4	0.5	0.5	0.5
	Control	0	0	0	0	0	n/a
	Non-experimental	0	0	0	0	0.5	0.5
Other (variety of other reasons for non-adoption)	Treatment	0	0.2	0.4	0.2	0.5	0.5
	Control	0	0	0	0	0	n/a
	Non-experimental	0	0	0	0	0	0
Total	Treatment	73	57.7	44.3	40.9	39.8	38.6
	Control	67.1	60.8	57.6	56.3	56.3	n/a
	Non-experimental	72.3	72.1	67.9	67.3	61.6	60.3

Notes: Show the percentages (%) of practices not adopted by reason for non-adoption, in the treatment plants, control plants and non-experimental plants (belonging to firms with a treatment plant). Timing is relative to the start of the treatment phase (the end of the diagnostic phase for the control group and the start of the treatment phase for the other plant in their firm for the non-experimental plants). Covers 532 practices in treatment plants (38 practices in 14 plants), 228 practices in the control plants (38 practices in 6 plants) and 190 practices in the non-experimental plants (38 practices in 5 plants). Non adoption was monitored every other month using the tool shown in Figure 4, based on discussions with the firms' directors, managers, workers, plus regular consulting work in the factories. Note that data is only currently available up to 7 months after the end of diagnostic phase in the control firms.