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The Influence of the Electric Supply Industry on Economic Growth in Less Developed Countries

Edward Richard Bee
University of Southern Mississippi

THE INFLUENCE OF THE ELECTRIC SUPPLY INDUSTRY ON ECONOMIC

GROWTH IN LESS DEVELOPED COUNTRIES

by

Edward Richard Bee

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Approved:

____
Dr. Shahdad Naghshpour, Committee Chair
Professor, Political Science, International Development, and International Affairs

____
Dr. Robert Pauly, Committee Member
Associate Professor, Political Science, International Development, and International Affairs

____
Dr. Joseph St. Marie, Committee Member
Associate Professor, Political Science, International Development, and International Affairs

____
Dr. David Butler, Committee Member
Professor, Political Science, International Development, and International Affairs

____
Dr. Karen S. Coats
Dean of the Graduate School

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ABSTRACT

THE INFLUENCE OF THE ELECTRIC SUPPLY INDUSTRY ON ECONOMIC GROWTH IN LESS DEVELOPED COUNTRIES

by Edward Richard Bee

August 2016

This study measures the impact that electrical outages have on manufacturing production in 135 less developed countries using stochastic frontier analysis and data from World Bank's Investment Climate surveys. Outages of electricity, for firms with and without backup power sources, are the most frequently cited constraint on manufacturing growth in these surveys.

Outages are shown to reduce output below the production frontier by almost 5 percent in Africa and by a lower percentage in South Asia, Southeast Asia and the Middle East and North Africa. Production response to outages is quadratic in form. Outages also increase labor cost, reduce exports of manufacturing product and slightly increase imports of intermediate materials. The rate of inefficiency in manufacturing, however, is not higher in countries with state ownership of the transmission and distribution grids.

This research has implications for economic theory. The output elasticity of electricity is nearly triple its share of inputs in production. The marginal revenue product of electricity is nearly triple the marginal revenue products of labor and capital inputs at equilibrium. Electric supply, akin to R&D, has a much larger role in economic output than postulated in production theory. Differences in the output elasticities between firm-level and worker-level production functions raise additional questions about the adequacy of the human capital theory of wage differentials.

This research has several implications for development policy. First, unlike investments in human capital, stable electric supplies can deliver short-term improvements in living standards. Second, policies focused on small business development can inadvertently raise the level of inefficiency in manufacturing.

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Thanks are also due to the members of my committee, both as teachers and as reviewers. Dr. Pauly shaped my thinking about scientific inquiry by exposing me to Thomas Kuhn and the philosophy of science. Dr. St. Marie and Dr. Butler taught me the differences between sound and spurious scientific research. Committee members contributed many hours of their time to reviewing my work. The scientific insights in this work reflect as much on their expertise in teaching and research as on my scholarship.

I also owe a debt to Platt's UDI North America who contributed the raw data on the ownership of transmission and distribution grids in LDCs and to the Enterprise Survey program at the World Bank, who collected the cross sectional and panel data used to test my hypotheses.

I also owe thanks to my daughter Elizabeth, who transformed my raw work into the publishable dissertation accepted by the Graduate Reviewer, which was a task that exceeded my talents and abilities.

The faculty and students in the International Development program are truly exceptional. I have benefited immeasurably from my dialogue with this diverse and innovative group of people. I owe a collective dedication to the group for their role in my learning and research.

DEDICATION

I dedicate this work to the memory of William and Pauline Bee, my mother and father, and to my wife Carole. Each has been pivotal in shaping my intellectual life and career.

My father, who was a member of the Greatest Generation, taught me the importance of direct and clear writing: Any success I have achieved during my career is the direct result of his wisdom. My mother taught me the importance of perseverance, patience and avoidance of haste. These traits of hers, which I have never learned to emulate fully, were critical in the completion of this dissertation.

Carole White Bee, my wife of more than 30 years, convinced me that one is never too old to return to school. I would never have pursued this work without her active support and encouragement. She was the spark plug that ignited my passion for international development.

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CHAPTER I - INTRODUCTION

Electricity has not been recognized as a significant production factor in neoclassical growth models due to its small share of inputs into production. Research and development exhibit a similarly small role in production inputs, yet the contribution that research and development (R&D) has on economic development is no longer in dispute. R&D spending became an explicit production factor in endogenous growth models in the 1980's (Romer 1986; Lucas 1988). As Griliches notes: "The fact that the contribution of R&D is small does not mean that the contribution of R&D is small to our lives as they are lived. It is only small in the part that is recorded in the national income accounts" (Griliches 1983, 129).

World Bank Investment Climate Surveys of businesses in LDCs have consistently identified electric supply as the most common constraint on economic output (See Table 1). Electricity is identified as the most serious obstacle to operation and growth both by manufacturing companies with backup power generation and those without backup generators. Since the percent of respondents identifying grid electricity as an obstacle is twice as large for firms with generators, the importance of electricity as an obstacle to operations is not reduced by access to standby power.

This research investigates the impact of electricity supply on the per capita incomes of less developed countries (LDCs) through its macroeconomic effects on industrial production. It answers the questions of what and how strong are the substitution and complimentary effects between electricity and on imports and domestic production of intermediates, and on productivity enhancements due to investments in new technology by the industrial sector. The research further investigates whether the form of ownership and regulation of the electric generation and distribution industry influences the availability and efficiency of domestic electric supply. LDCs are those countries defined as middle or low income by the World Bank.

Significant externalities are a plausible explanation for the unmeasured importance of electricity for economic growth, especially in low income countries where the assumption of unconstrained availability of electricity and intermediate inputs are often violated. The presence of significant externalities provides an economic explanation of why knowledge and R&D were far more important than expected in traditional growth models (Klenow and Rodrigues-Clare 2005). Lucas (quoted in Klenow and Rodriguez-Clare 2005, 819) provides this explanation: “If ideas are the engine of growth and if an excess of social over private returns is an essential feature of the production of ideas, then we want to go out of our way to introduce external effects into growth theory, not try to do without them.”

The characteristics of electricity are a second plausible explanation for the unmeasured importance of electricity to growth. Unlike human or physical capital or other forms of energy, electricity cannot be stored. When electricity is embodied in an industry’s technology, which is pervasive in the 21st century, labor and capital produce zero marginal product during outages of electricity. Substitutions with other forms of energy are not possible in the short-term because of the often short duration of electrical outages and their unpredictability. Production technologies that embody electricity are not adaptable in the short-term to alternate forms of process energy.

A third plausible explanation for the unmeasured importance of electricity in economic growth is substitution of imported intermediates for domestically produced intermediates. Research conducted in the United States after the OPEC embargo (OTA 1990) indicated that a significant decline in direct energy imports had been partially offset by imports of energy-intensive intermediate products. The growth accounting literature of electricity in industrial production has universally assumed that production is autarchic, ignoring the possibility that imported intermediate inputs are substitutes for domestically produced intermediates. Also that export growth is not constrained by the availability of electricity.

This study will investigate the importance of these three plausible explanations. The specific research questions that I will explore are:

1. The degree that the electric supply industry constrains industrial exports in LDCs;
2. The degree that the electric supply industry constrains production of domestic intermediates and promotes imports of intermediate products in LDCs;
3. The degree that the electric supply industry constrains investment levels in LDC manufacturing and reallocates investment flows from production equipment to power generation equipment;
4. How the ownership and regulation of the transmission and distribution infrastructure affects the macroeconomic performance of manufacturing in LDCs

All of these research questions will measure the effects of these industrial shifts on the per capita income in LDCs.

Table 1

World Bank Enterprise Surveys 2007-2015

		Standby Generator	
	All	No	Yes
# Observations	57,410	37,087	19,745
Obstacle			
Electricity	17%	13%	25%
Access to finance	16%	18%	13%
Practices of informal competitors	12%	13%	8%
Tax rates	11%	12%	9%
Political instability	10%	10%	9%
Corruption	8%	6%	10%
Inadequately educated workforce	6%	7%	5%
Labor regulations	4%	4%	4%
Tax administration	3%	3%	3%
Transport	3%	2%	3%
Crime, theft, and disorder	3%	3%	2%
Access to land	3%	3%	3%
Customs and regulations	2%	2%	3%
Business licensing and permits	2%	2%	2%
Courts	1%	1%	1%

Note: Response to question: most serious obstacle affecting operation and growth of this establishment. Responses in Table 1 are limited to manufacturing companies.

CHAPTER II – LITERATURE REVIEW

Increased industrial production has been a central element of development theory since the introduction of Lewis's (1954) dual-sector theory and Prebisch's import substitution industrialization (Todaro and Smith 2011). Industrialization increases an underdeveloped country's per capita income.

Solow (1956) provides the first explanation of how the combination of factor inputs increases per capita income. The Solow model postulates that growth occurs through increased inputs of labor and capital in combination with technological progress. After the introduction of Solow's growth model, other scholars quickly argued that economic history demonstrated that additional inputs, such as electricity and fuels, contributed directly to production and therefore should also be included in growth models.

After the worldwide drop in total factor productivity (TFP) following the quadrupling of oil prices in 1973 (Jones 2002), economists examined the explanation of energy postulated in ecological economics. Ecological economics postulates that energy is the ultimate factor input and exhibits diminishing returns to transformation and substitution because energy is subject to the laws of thermodynamics (Ayres and Kneese 1969). In this view, Solow growth models provide misleading inferences about factor inputs and future economic growth.

Subsequent literature in economics explores the role of electricity as a paid factor input, with investigations of its importance in production and how it substitutes and complements other factor inputs. The most recent literatures in General Purpose

Technologies (GPTs) and in infrastructure argue that electricity is an unpaid but pivotal input in manufacturing production through interactions with capital investment and Total Factor Productivity.

An empirical literature simultaneously emerged to examine how variables in electricity generation, transmission and distribution constrain economic growth and on which variables explain variances in electricity and economic output across countries and industries.

The central research questions in the literature are the relationship between electricity production and economic productivity and on how to measure the effect of electricity on industrial production. The "infrastructure" literature focuses on the role of electricity as an unpaid factor of production that contributes to the productivity of other inputs. The empirical literature in revealed preference focuses specifically on the measurement of unsupplied electricity.

This literature review incorporates studies on the relationship between electricity and per capita income and on the relationship between electricity and industrial production; and pivotal studies on the macroeconomic characteristics of energy in industrial production. Pivotal studies are defined as those introducing new methods, variables, or data sources. Energy studies are included when they provide theory used in studies about electricity and industrial production. The revealed preference literature in this review is specific to the measurement of unsupplied electricity.

Only the articles deemed pivotal in ecological economics are included as the author rejects the axiom that industrial production stems from a single primary input.

The voluminous literature on bidirectional causality between electricity and economic growth is covered with summaries of causality findings from three recent literature surveys.

The literature on the characteristics of demand for industrial and commercial electricity is omitted since these attributes are well understood and not subject to dispute. Virtually all studies of electricity demand find inelastic price and income relationships in the short-run and unitary to elastic relationships in the long-run.

This chapter is divided as follows. The review begins with the dispute over the role of energy and electricity in economic growth that surfaced after the introduction of the Solow model, followed by the examination of the claims made by ecological economist over the role of energy in production after the OPEC price rise of 1973. The review next summarizes the literature on electricity as a paid factor of production before summarizing the recent work in General Purpose Technologies and in infrastructure on electricity as an "unpaid" factor of production. The chapter ends with the empirical literature on electricity and industrial production, including the literature on revealed preference and the cost of electrical outages.

The Role of Electricity in Economic History

Solow attributes economic growth to two factor inputs and Total Factor Productivity (TFP). Factor inputs of labor and capital explain less than half of growth in most countries (Ayres and Warr 2010). A persistent criticism of the Solow model is that TFP is nothing more than a miscellaneous category that captures the unexplained variance in growth (Ayres and Warr 2010). The Solow model provides a poor explanation of economic growth. Other factors of production, such as materials and energy, should be included as explanatory variables for economic growth.

Schurr (1983) investigates the historic role of electricity in productivity growth in the United States. The U.S. has witnessed a prolonged trend of declining energy intensity since WWI, where energy input per unit of output has declined. This contrasts with the earlier period when energy inputs increased faster than economic output. The U.S. economy since WW I has also witnessed simultaneous improvements in energy productivity, labor productivity, and Total Factor Productivity (TFP). TFP is the ratio of economic output to factor inputs.

The role of electricity requires particular attention since growth in electricity inputs between 1914 and 1929, on a kWh basis, were triple the change in hours of labor inputs, while the energy intensity of manufacturing output declined.

Schurr (1983) draws these conclusions about electricity's role in productivity from economic history:

1. Abundant availability of energy on favorable terms encouraged the spread and development of new technologies which favored the use of energy relative to labor and to a lesser extent energy relative to capital. These raised the combined productivity of capital and labor.
2. Increased use of electricity and fluid fuels explain much of the productivity improvements in manufacturing. Technical change that exploited the quality characteristics of these fuels explains the simultaneous improvements in TFP, labor productivity, and energy productivity. Innovations in technology

triggered by the adoption of new energy sources lowered total production costs. The improvement in productivity was not merely because of falling energy costs during the period.

3. Electricity did much more than replace human and animal muscles. It was a management tool for reorganization of production systems which provided precise control, highly focused application, fractional use and linkages to technological systems.

DuBoff (1966) further explores the connection between technology and energy inputs identified by Schurr and Netschert (1960). DuBoff argues that the effects of electricity on productivity growth are due to embodied technology. Embodied technology (new machines and processes) raises output relative to input. It is difficult, however, to measure the impact of embodied technology on productivity because output per unit of input only changes when industry invests in new equipment. Investments in technology are not captured in simple production function models of the economy.

The rapid electrification of manufacturing in the United States between 1914 and 1919 is a case where the effects of embodied electrical technology can be measured. The absolute horsepower of electric motors quintupled during the period. The embodied technology of electric power, with its smaller and more flexible power units, displaced older capital-intensive steam power systems. The percentage of energy in manufacturing from electricity jumped from 18.7 percent to 50.2 percent during the period.

After declining consistently for 35 years, the ratio of output/capital in U.S. manufacturing reversed trends in 1914. The reversion coincides with the rapid adoption of electric technologies in manufacturing, indicating that the adoption of electricity improved the productivity of capital. The change in the output/capital ratio does not fully capture productivity changes from electrification; however, since changes in power technologies can also affect productivity of labor and material inputs. DuBoff (1966) concludes that the evidence supports the view that electric technology simultaneously increased the productivity of capital, labor, and materials as well as TFP.

Schurr and DuBoff offer empirical evidence, in the specific case of the United States, that electricity explains the productivity jump in manufacturing after World War I. Since electricity inputs also affect the productivity of labor, capital, and intermediate materials in manufacturing, the effects are difficult to measure in production function models of the economy. Empirical evidence suggests that the Solow approach fails to capture fully the determinants of productivity growth.

The Critique of Solow by Ecological Economics

Theoretical investigations of the relationship between energy and economic growth intensified after the publication of Ehrlich's (1968) Population Bomb and Meadows et al. (1972) Limits to Growth. Ehrlich and Meadows et al. resurrected the economic theory of Malthus (1798) that population grows geometrically, while the means of sustenance grow arithmetically (Jones 2002). Finite resources inevitably lead to a sudden collapse in per capita incomes as resources are depleted. These ideas were in sharp contrast to assumptions in the growth models adopted in economics after Solow's work (1956).

The Neo-Malthusians argue that economic growth models ignore the prevalence of negative externalities in production (pollution in particular) and the laws of thermodynamics (Ayres and Kneese 1969). The first and second laws of thermodynamics impose physical constraints on the production of goods and services that are ignored in economic growth models. Since matter cannot be destroyed except by anti-matter, pollution and waste are inevitable in the production and consumption of goods and services (Ayres and Kneese 1969). The disposal of these wastes inevitably creates negative externalities that are not captured by resource markets.

The Review of Economic Studies produces a symposium on the economics of exhaustible resources to address the issues raised by Ayres and Kneese (Heal 1974). Stiglitz (1974) notes that three economic forces offset the limitations of natural resources: technical change; substitution of man-made factors of production (capital) for natural resources; and returns to scale. In the paper, Stiglitz develops a Solow growth model with inputs of exhaustible resources and demonstrates that economies with exhaustible resources can experience constant rates of growth of per capita income, but at lower rates than growth models with only labor and capital inputs. Beckmann (1974) derives another growth model with multiple inputs, products, and exhaustible resources that draws similar conclusions: Consumption rates are governed by technical progress and the aggregate output elasticities of exhaustible resources: higher technical progress or lower resource use induces growth. Solow (1974) observed that the drag on economic growth from exhaustible resources could be offset by technical progress, especially natural-resource saving technical progress, and by substitution of capital and labor for exhaustible resources.

Solow (1978) formalized these findings of resource drag on economic growth into a theory of production with finite resources using a Constant Elasticity of Substitution (CES) production function that allows input shares to change over time as stocks of resources decline. The CES production function, unlike the Cobb-Douglas production function, does not assume that inputs are perfect substitutes with an elasticity of substitution of 1.0. The CES function provides an elasticity of substitution of inputs that is the percent change in factor proportions divided by the percent change in the marginal rate of technical substitution. The elasticity of substitution within the CES function can be less than the 1.0, meaning that factor proportions can change over time (Beattie, Taylor, and Watts 2009). Solow expresses the growth in output as a function of the growth rates of resources and other inputs, of technical progresses in resource use and in capital and labor inputs, and the share of output from resources and from other factor inputs.

Solow tests the model with data from the U.S. economy supplied by Denison (1974). He finds little support for the assumption that the U.S. economy is becoming more vulnerable to resource drag over time.

Solow’s analysis does not incorporate the significant increase in energy prices after 1973. The data produced by Denison (1974) excludes imports, which had become a significant input into U.S. production by this date (EIA 2015). U.S. growth slowed substantially after the OPEC price increases in 1974. Multi-factor productivity dropped from 2.1 percent prior to the OPEC decision (1948-1973) to 0.6 percent afterward (1973-79) (Jones 2002, 46). The slowdown occurred throughout the developed world (Jones 2002), suggesting it was not an internal shock in the United States economy. The empirical evidence raises questions about Solow's model and its conclusions. National growth models that exclude imported resources suffer from measurement error due to missing variables (Woolridge 2009).

Berndt (1978) uses neoclassical production theory to study the issues of energy and economic efficiency. He demonstrates, using an augmented five-factor production function (labor, capital, energy, materials, and technology), that the minimum energy point is an asymptote to the isocost curve where the relative price of energy is infinite (see Figure 1). The point of minimum energy consumption traced by the asymptote cannot be the minimum cost point in industrial production as postulated by Ayres and Kneese (1969). The point where all inputs are minimized is where the budget curve is tangent to the isocost curve, as postulated in neoclassical production theory.

Stern (1993) re-investigates whether the biophysical model used by ecological economists or neoclassical economic theory provides the best explanation of the relationship between energy and productivity. Stern uses vector autoregression models to examine the interrelationships between labor, capital, energy, and GDP in the United States between 1947 and 1990.

Stern finds that energy does not Granger-cause economic growth. Lagged values of labor and capital are highly significant in explaining GDP. Changes in labor input induce changes in energy use but changes in capital input do not cause changes in energy use: “If both labor and capital and labor and energy are substitutes in production, there is an asymmetric substitution relationship between energy and labor” (Stern 1993, 143). In contrast to earlier findings of Berndt and Wood (1975), Stern finds that capital and labor are neither substitutes nor complements in production.

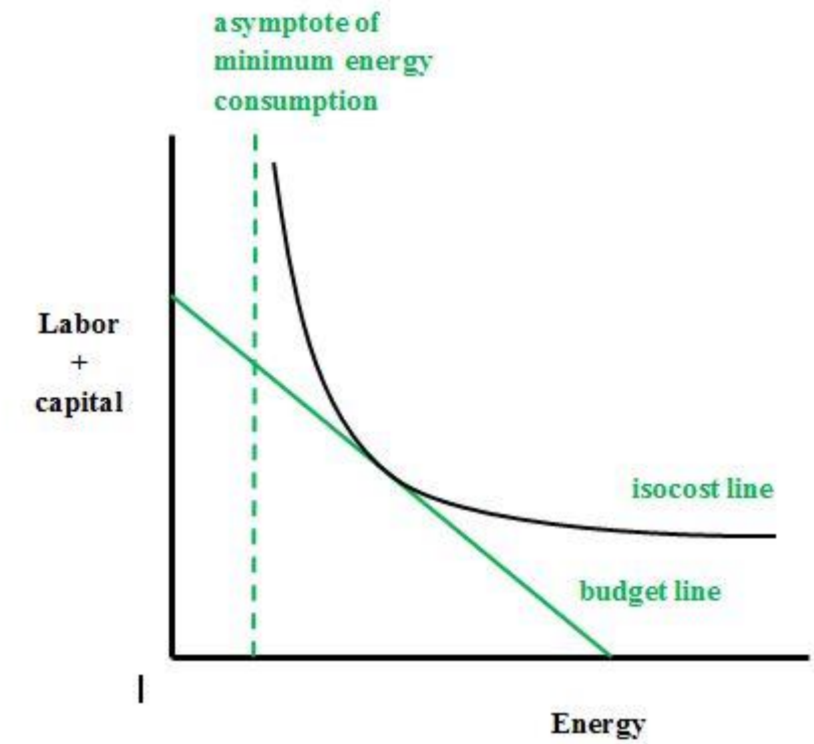

Figure 1. Contrast Between Production Theory and Ecological Economics

Stern's explanation of why his findings diverge from neoclassical production theory is because of measurement error. The measure of energy input in earlier studies include aggregate energy (for both industrial production and residential consumption), while the labor and capital components are only measuring production inputs. Another measurement error is the exclusion of energy embodied in imports. To accurately measure energy inputs, output should be redefined as domestic absorption plus exports or as the equivalent of GDP plus imports.

The most important measurement issues in neoclassic production theory, however, are the assumption of uniform quality of energy inputs. All forms of energy should not be considered of equal quality in production functions. Since the price of electricity is 10 times the price of coal on a BTU basis, one should assume that electricity is more productive than coal.

Stern (2003) summarizes why ecological economics and neoclassical economics differ in terms of energy's role in productivity. Ecological economics sees energy as a non-renewable factor of production whose use is governed by the first and second laws of thermodynamics. The first law requires that the material inputs into production must exceed the outputs of production with some residuals as waste or pollutants. The second law dictates that a minimum amount of energy is required to transform matter from one form to another. Other factors of production cannot therefore be perfect substitutes for energy. Since all industrial production involves transformation or movement of matter, production requires energy. In essence, energy is the only primary factor of production and all value added can be regarded as rent accruing to energy. In addition, since production organizes matter, knowledge can be considered a reproducible primary factor of production. Knowledge provides a biophysical justification for treating labor and capital as factors of production.

The criticisms of neoclassical growth theory by ecological economics focus on the limits to substitution of energy for other inputs and the limits of technological progress in mitigating the scarcity of resources. The thermodynamic limits on transformation result in diminishing marginal returns on transformation. The argument against technological change is that it is another example of the limits of substitution between "natural" and "manufactured" capital. Technological change is subject to diminishing returns from the transformation of "natural" capital, such as energy resources and wood pulp, into "manufactured" capital such as fuels and paper. Transformations at the intermediate stage are not captured in final demand or GDP.

Bivariate and Multivariate Causality Studies

Ecological economists have attempted since 1996 to establish the causality between energy consumption and economic growth using Granger causality and co-integration methods. The purpose of these studies is to establish the superiority of the theory of ecological economics over neoclassical theory. The results of the causality literature are inconclusive, however, with a nearly equal number of findings of bidirectional causality, no causality and unidirectional causality from energy to GDP and vice-versa. Several reviews of this extensive literature that look specifically at the relationship between electricity consumption and economic growth are informative for this dissertation.

Murry and Nan (1996) examine the link between economic growth and electricity consumption in 23 countries between 1970 and 1990. Using Granger-causality models, they find no statistically significant relationship in eight developed and three under-developed countries but a statistically significant relationship from GDP to electricity in Colombia, El Salvador, Indonesia, Kenya, and Mexico; a significant relationship from electricity to GDP in Canada, Hong Kong, Pakistan, Singapore, and Turkey; and a statistically significant bidirectional relationship in Malaysia and South Korea.

The eleven nations that lack a significant relationship have both low GDP and electricity demand growth. Countries with a significant relationship have both high GDP and high electric consumption growth rates. The authors conclude that investments in electrification have been growth drivers in Canada, Hong Kong, Pakistan, Singapore, and Turkey. The paper leaves unanswered why the direction of causality differs within the 12 countries.

Apergis and Payne (2011) use the Granger causality method to examine the relationship between GDP and electric power consumption among 88 countries grouped in high income, upper middle income, lower-middle income and low income panels. The study uses a multivariate production function with dependent variable of real GDP and independent variables of real gross fixed capital formation, total labor force, and electric power consumption. Causality is bidirectional in high, upper-middle, and lower-middle income countries but unidirectional, running from electricity consumption to GDP, in low income countries. The results support the electricity-growth hypothesis for low income countries. The authors conclude that the causal relationship between electricity consumption and economic growth may in part depend on the country's stage of development.

Ozturk (2010) and Payne (2010) summarize the results of more than 35 single and multi-country causality studies. The causal relationship between electricity and economic growth can be reduced to four hypotheses:

1. Growth hypothesis: unidirectional causality runs from electricity consumption to economic growth. Electricity demand drives economic growth.
2. Conservation hypothesis: unidirectional causality runs from economic growth to electricity consumption. Electricity demand is derived from economic growth.

3. Neutrality hypothesis: the absence of a causal relationship between economic growth and electricity consumption.
4. Feedback hypothesis: electricity consumption and economic growth are interdependent and causality is bi-directional.

The 35 studies in the O&P survey include 74 countries. The results by number of countries are as follows: Neutrality hypothesis (31 percent); Conservation hypothesis (28 percent); Growth hypothesis (23 percent); and Feedback hypothesis (18 percent). Payne attributes the variation to variable selection, model specifications, time periods of the studies, and econometric approaches. Suggestions for future research include: use multivariate production function techniques to eliminate omitted variable bias; incorporate per capita consumption and wealth data in panel error correction models to understand the impact of electricity consumption within stages of economic development; incorporate the possibility of structural breaks in the models; and finally, examine both the sign and magnitude of the coefficients on the causality tests.

The dispute in the literature between neoclassical production theory and ecological economics on the role of energy in production remains unresolved after forty years. The axiom of diminishing returns to transformation in ecological economics assumes that resources are fixed and finite. The recent discovery of shale technology and the rapid growth in U.S. oil production suggests that the availability and price of natural resources as factor inputs respond to technological progress, as espoused in neoclassical production theory (Verleger 2015). While the use of natural resources as factor inputs may reduce growth rates, technical progress and substitution of other factors of production can offset the effects of dwindling resource stocks on economic growth. Berndt (1978) offers a strong argument for why the point of maximum efficiency in production is not the point of minimum resource use.

Tests of Granger causality have also failed to resolve the dispute. A synthesis of this literature is that empirical tests of the causality between electricity and economic growth cannot be generalized. Measurement error in past studies, from omitted or imprecisely measured variables, has been posited as an explanation of the difference in results for different countries and time periods. An alternative explanation is that the direction of causality depends on the level of per capita income and the stage of development of countries.

Energy and Electricity as Paid Factors of Production

While ecological economics uses causality tests and new variables to measure the connection between electricity and industrial production, neoclassical economists attempt to measure its effects by including electricity as a paid input in production function models of the economy. If electricity is an important input into production, it will serve as a substitute or complement to other factors of production that can be measured in production function models. After the OPEC price increase in 1973, economists examined the role of energy and ultimately of electricity in industrial production using aggregate production functions.

Berndt (1978) observes that econometric studies on aggregate energy demand have consistently reported substantial energy-labor substitutability. Examples abound of motive power (a composite of energy and capital) being substituted for human toil in industrial production. If energy and labor are substitutable inputs, increases in relative energy prices lower labor productivity. So energy is a link between per capita income and labor productivity. Berndt finds that energy and capital are complements, not substitutes, in manufacturing in Canada, Germany, and the United States because the two are used as a bundle (which he calls the E-C bundle). When the price of energy rises, firms substitute away from the E-C bundle to labor. The share of labor in production increases and labor productivity growth slows. The effects of energy, therefore, cannot be totally separated from the effects of capital accumulation in production function models.

Berndt and Wood (1979) reconcile the disparate finding of E-K (energy-capital) complementarity found by Berndt and Wood (1975) and by Berndt and Jorgenson (1975) with the findings of E-K substitutability in Griffin and Gregory (1976) and in engineering studies.

The possibility of E-K complementarity cannot be demonstrated with a two input production function. Berndt and Wood therefore use a four-input production function (capital, labor, energy, materials) that is separated into two subfunctions G(E,K) and H(L,M). A shift in relative price of one of the inputs in a subfunction will have a combination of substitution effects and complementary effects on the share of each input in optimum production. Berndt and Wood find that energy and capital are gross substitutes but net complements. An empirical analysis of U.S. manufacturing during the 1970s confirms the relationship. They reconcile the findings of Gregory and Griffin (1976) by demonstrating that their three-input production function is biased upward as it omits material inputs and therefore the elasticities in their model are gross substitutes, not net substitutes. When this difference is recognized and output is held constant, the net elasticity estimates are consistent with net E-K complementarity.

Berndt (1983) adds an empirical explanation of why production function models have not accurately captured the impact of energy on production. The dramatic increase in energy prices in the 1970s reduced the capital stock through write-offs. The typical assumption in growth models of constant depreciation was violated in practice, which led to an overestimation of the impact of capital accumulation on economic growth and an underestimation of the impact of energy as a factor of production. Jorgenson (1984) adds a further explanation. When technical change is energy-using, increases in energy price will reduce the growth rate of TFP ceteris paribus.

Berndt and Kolstad (1993) develop a production function model to test for the productivity impacts of embodied and unembodied technical change in manufacturing. The analysis is for the United States, Canada and France. If technical progress is unembodied, its impacts on productivity will not vary with the level of capital investment. If embodied, productivity enhancements from technical progress are gradual as technical progress only augments the productivity of recent capital investment.

Berndt and Kolstad construct a production function that decomposes technical change into three components: unembodied technical change from changes in inputs of labor, electricity, and fuels; unembodied technical change from the quasi-fixed factors of buildings and equipment (the major components of capital stock in manufacturing); and embodied technical change associated with the same quasi-fixed factors of production.

Adjustment to equilibrium for quasi-fixed inputs is long-run because plant and equipment (capital inputs) are fixed in the short-run.

For the United States and France, the empirical results indicate a Hicks-neutral embodiment of capital equipment (Hicks-neutral change is when changes in TFP do not shift the shares of capital and labor in production). Embodiment played a modest role in explaining technical progress in the United States, Canada, and France between the 1960s and 1987. Berndt and Kolstad speculate that the finding could reflect the market power of innovators to capture potential rents, price deflators that account for differentials in input qualities, or output measures that fail to account for quality change. The Berndt and Kolstad findings confirm the link between capital investment and embodied technical change, and the measurement problem in cross-sectional production functions that omit changes in capital investment.

The investigation of energy as a paid factor input confirms that it exhibits substitution and complementary effects with other factor inputs (an attribute of a paid factor of production) but that its effects are difficult to measure because it is closely tied to investment and write-offs of capital equipment. In addition, the evidence suggests that energy plays an additional role in augmenting TFP. Energy, therefore, has properties of an unpaid and paid factor of production.

Electricity as an Unpaid Factor of Production

Much of the theoretical literature on energy and productivity investigates the presence of externalities that are not captured in neoclassical growth models due to measurement error or because electricity is an unpaid factor of production where the price is not set by market forces. The effects of electricity are captured largely in TFP rather than as a production input.

Carter (1983) observes that technological change does not resemble neoclassical substitution because the substitution of different energy forms leads to a chain reaction of other events. He uses the example of substitution of coal for charcoal in steel production: a) less energy, less labor, and less capital per unit of steel; b) location of industry shifts, which opens up new resources and improves efficiency of industrial production. The process is long-term and not captured in short-term production functions.

Norsworthy (1984) mirrors this finding when he explores forces that stimulate technical change in U.S. manufacturing resulting from higher energy prices between 1958 and 1977. Since investors require both time to recognize price trends plus time to replace capital equipment, reactions to energy shocks are long-term and tied to capital investment.

Waverman (1984) confirms Jorgenson's (1984) finding of technology complementarity with energy. Using a production function where fuel inputs of coal, natural gas, electricity, and oil are modeled individually in Canadian manufacturing, he finds that technical change in 19 of 20 industries is coal saving but electricity and natural gas using. Fuel substitutions are linked with capital spending.

Sonenblum, Schurr, and Wood (1983) examine the link between quality of energy and economic productivity. He identifies five quality properties of energy:

1. Ability to transfer heat and do useful work
2. Ability to be moved or stored economically in large amounts

3. Ability to transform production process and create new technology opportunities
4. Ability to affect the quality and variety of manufactured products
5. Ability to avoid excessive environmental damage

These properties vary by energy type. Quality properties of energy therefore translate into these economic outcomes:

1. Cost reductions of capital, labor and materials
2. Increases in speed and scale of production processes
3. Decreases in gross energy consumption
4. Improvements in quality of output
5. Development of new goods and services

While partial substitution of qualities is available between energy forms, producers cannot totally substitute one form for another due to differences in qualitative features. Economic history suggests that electricity and fluid fuels didn't stimulate technological advance by lowering energy costs but by savings in labor and capital attributed to their qualitative features. Examples include:

1. Electric power was superior to coal in production and control of heat, which created new products and production methods
2. Electric motors provided a small, fractionalized, interruptible power unit that wasn't available with mechanical and steam power

Rank order correlations show a strong link between growth rates in TFP with a simultaneous decline of energy inputs per unit of output. Two possible explanations for this pattern:

1. providing workers with more energy
2. providing workers with more tools

There is no empirical support for the first explanation because the energy/labor ratio was relatively static over the period of electrification in the U.S. Since the energy to capital ratio in the U.S. has grown since 1910, this lends support for the "more tools per worker" hypothesis. Electricity and capital investment are therefore complements.

Rosenberg (1983) examines the roles of energy supplies in economic growth. Throughout economic history, the energy source that offered the lowest fuel cost was not the technology that offered the lowest operating cost. An example is aluminum and electricity. Electricity was not as cheap an energy source as coal for producing aluminum but it provided the lowest cost of conversion.

Rosenberg argues that energy quality is as important an attribute as energy cost. Electricity has played important roles in improving industrial productivity because of its quality features. Electricity offers more precise control of heat and mechanical energy. Direct substitutes for electricity do not exist in many industries-communications and illumination are examples. Production function models that assume all energy forms are perfect substitutes are unable to accurately measure the role of electricity in productivity.

Schurr et al. (1990) examine the growth of productivity in U.S. manufacturing between 1899 and 1985, a period that includes the electrification of industrial production.

An examination of the data shows that half of growth in productivity during the period was due to increased inputs, while the other half occurred because of increases in multifactor productivity. Electricity inputs grew by 8 percent a year during the period, compared to increases of 1.5 percent for non-electric energy, 1.3 percent for labor and 3 percent for capital.

Capital growth in manufacturing during the 20th century (Schurr et al. 1990) has been strongly tied to electricity inputs in manufacturing. The energy intensity of manufacturing output, on a BTU basis, declined during the period, which is surprising since every BTU of electricity requires over three BTUs of primary energy to generate it. While inputs of electricity grew by more than 8 percent per year during the early twentieth century, the growth in electricity inputs was offset by a relative decline of other energy inputs, resulting in a net decrease in the share of energy in production.

The growth in TFP in the twentieth century can be divided into three epochs based on overall trends in manufacturing (Schurr et al. 1990). The first period, from 1899 to 1920, focused on increasing efficiency by increasing the scale of manufacturing (management focus on building scale economies in production). The second period from 1920 to 1948, when electric motors replaced steam power in factories, focused on increasing efficiency by accelerating the throughput in factories. The explanation of increased efficiency is that electric motors provided flexibility in workflow and factory design that was not available from steam power and shaft drive. Multifactor productivity grew rapidly during this period without increases in capital inputs. The third period from 1948 to 1985 was characterized by greater flexibility in operations through the automatic control of production. Electricity was an indispensable input into automation as alternative energy sources are not capable of powering electronic technologies used in instant communications and large-scale information management technologies that formed the cores of automation technology. In summary, electricity enabled the rapid growth of multifactor productivity during the second and third periods (the study does not explore the period since 1985).

General Purpose Technologies

Helpman (1998) examines the role of electricity in productivity through the concept of General Purpose Technologies (GPTs). Electricity is generally recognized as one of the oldest General Purpose Technologies. GPTs are disruptive innovations which find pervasive use in a wide range of industries. They radically change the mode of operations in the sectors that adopt them. They are the prime movers at the top of a tree-like structure of other technologies and hence have indirect influence on productivity across the economy. They enable a range of new technologies and lower the overall cost of production in a range of industries.

Because of pervasive externalities, GPT's are difficult to measure in production functions. Bresnahan and Trajtenberg (1995) identify two types of externalities due to GPTs: 1) between the GPT and its application sectors; and 2) across application sectors. The first type of externality is an appropriation problem akin to those in research and development. Because it is difficult for GPTs to appropriate all of the economic returns from their inventions, they are under-produced. In other words, social and private returns diverge in GPTs. The second type of externality in GPTs stems from coordination failures and network effects. All of the actors in a sector would benefit from the adoption of the GPT but none has sufficient level of incentives to adopt it individually.

Howitt (1998) identifies three measurement problems with GPTs: 1) As knowledge-generation activities, GPTs are not captured in GDP measures; 2) GPTs lead to new and improved products which are underestimated due to quality differences; and, 3) The introduction of a GPT leads to capital obsolescence. Howitt simulates the introduction of a GPT with a production model and finds that capital obsolescence is the most important of the measurement problems.

Lipsey, Bekar, and Crawley (1998) observe that GPTs are difficult to measure due to the presence of both Hicksian and Technological complementarities. Hicksian complementarities are changes in output that can be modeled as a change in the price of an input. Technological complementarities are defined as changes in output that cannot be modeled as changes in the price of an input because the technology leads to changes in other technologies. As an example, the substitution of electricity for steam power, as identified earlier by Schurr et al. (1990) could not be modeled as a change in the price of steam. Even if steam were priced at zero cost, it could not compete with electric power because of production externalities such as efficiency in factory layout from flexible electric power drive.

Technological complementarity is characterized by net substitutes and gross complements. The substitution effect is small in relation to the income effect. From a theoretical perspective, technological complementarity (as found in GPTs) cannot be modeled as the results of changes in the prices of factor services found in simple production functions. The changes due to technological complementarity stem from new products, new factors of production, and new production functions.

Infrastructure

Investment climate surveys by the World Bank identify infrastructure as a major barrier to economic growth yet the internal rates of return on infrastructure projects evaluated by the bank are often lower than threshold values (Hulten, Bennathan, and Srinivasan 2006). This disparity has led to a significant literature on the measurement of externalities from infrastructure.

Aschauer (1989) found that a decline in infrastructure investment in the U.S. was an important factor behind the productivity slowdown of the 1970s and 1980s. By specifying public capital as a separate input in an aggregate production function, Aschauer found that public infrastructure was significant in explaining the differentials over time in returns on private capital investment. When public infrastructure spending declines, total factor productivity also declines. The marginal product of core infrastructure, consisting of highways, airports, electrical and gas facilities, and public utilities, was two to four times higher than the return on private investment between 1949 and 1985. Munnell (1990) supports Aschauer's findings.

Duggal, Saltzman, and Klein (1999) find that infrastructure plays an important role in determining the level of productivity in the United States between 1960 and 1989. They argue that the treatment of infrastructure as a factor input in previous studies violates marginal productivity theory since its unit cost is not market determined. It is invalid to assume that infrastructure is remunerated based on its marginal product. It is also invalid to assume that the costs of infrastructure are calculable by individual firms nor that it is equal for each firm, as would be true if infrastructure prices were market determined.

Duggal, Saltzman, and Klein build an aggregate production function that incorporates infrastructure as part of the technology variable (so that infrastructure increases total productivity by lowering production costs) while also including it as a factor input. The aggregate production function in log form is:

(1)

$$lnY = lnA + \alpha(lnK) + \beta_1(lnL) + \beta_2 \left(\frac{1}{L} - \beta_3 \frac{K}{L^2}\right)$$

where Y = output, A= the technology index, K is the stock of nonresidential capital adjusted for capacity utilization and L is worker hours.

Infrastructure accumulation shifts the production function upward and enhances the marginal products of the other factor inputs. The marginal product of labor is a cubic function:

(2)

$$MP_L = Q\left(\frac{\beta_1}{L} - \frac{\beta_2}{L^2} + 2\beta_2\beta_3 \frac{K}{L^3}\right)$$

where MPL is the marginal product of labor and production inputs are the same as in the previous equation. Labor initially increases the marginal product of labor then decreases it. The marginal product eventually turns negative when excess labor is used with capital.

Duggal, Saltzman, and Klein (1999) find that the elasticities of output with respect to labor, private capital, and infrastructure are 0.25, 0.39, and 0.27 respectively. The elasticity of output for infrastructure is close to the 0.24 found by Aschauer. The composite index of technology (or Solow Residual) includes variables for infrastructure, and for other technology. The composite index increases more than the sum of the two variables, suggesting that the effects of infrastructure are not additive but interactive. The implication is that infrastructure becomes more important as it interacts with higher levels of technology. They conclude that their estimates "are not implausible if one stops thinking of infrastructure as a factor input that siphons off its factor share of income." (Duggal, Saltzman, and Klein 1999 72).

Canning and Bennathan (2000) estimate the social rates of return to electricity-generation and paved-road infrastructure (relative to the returns to other forms of capital) using an aggregate production function for a panel of countries from 1959 to 1999. Inputs are physical capital, human capital, and infrastructure.

Canning and Bennathan find that infrastructure, including electric generation capacity, is strongly complementary with both physical and human capital. For electricity generation, Canning and Bennathan find an inverted U-shaped relationship between the elasticity of electric infrastructure investment and per capita income. Middle-income countries have a higher elasticity between output and electricity investment than poor or rich countries. The elasticities for rich countries are more homogeneous than those of poor and middle-income countries, suggesting that the proportion of physical, human and, infrastructure capital vary more in lower-income countries than in richer countries.

Canning and Bennathan also estimate the relative cost of infrastructure using social rates of return. On average, the returns to investments in generating capacity exceed the returns to physical and human capital in poor countries. The social returns to these forms of capital exceed the private returns estimated in World Bank cost-benefit studies. Microeconomic tools, like cost/benefit analysis, miss benefits of infrastructure due to externalities.

Canning and Pedroni (2004) examine the long-run effects of infrastructure on per capita income in a panel of countries from 1950 to 1992. They imbed infrastructure spending in a Barro style growth model. A test of Granger causality demonstrates that causality is bi-directional with electricity infrastructure. They find a long-run impact from infrastructure to GDP per capita. C&P find that the long-run effects of investment in electric generation are positive in most countries and only negative in a few countries. Their findings suggest that on average electricity may be underprovided.

Hulten, Bennathan, and Srinivasan (2006) (HB&S hereafter) examine the spillover externalities of infrastructure in manufacturing industries in India between 1972 and 1992 using an aggregate production function with observations consisting of Indian states. HB&S place infrastructure directly in the production function for manufacturing output as an unpaid factor of production. The production function model is:

(3)

$$Q = A(B,t)F(K,L,M(B))$$

where Q is output, B is infrastructure stock, t is a time trend, K is privately-owned capital, L is labor, and M are intermediate inputs.

This formula inserts infrastructure into the manufacturing industry through direct or “market-mediated effects” (the M(B) variable) and indirect or “non-market mediated infrastructure” channels (the A(B,t) variable). Changes in infrastructure stock reduce the price of intermediate inputs, enhancing efficiency within the firm's operations. Changes in infrastructure stock also raise output from efficiency-promoting externalities which are captured in TFP. The explanation is that increased electric-generating capacity promotes continuous supply and allows the use of more sophisticated machinery and reduces the need for self-generation of electricity. The total effects of electricity infrastructure consist of the direct and indirect effects.

The estimated effects of electricity spillovers (the non-market mediated or TFP effects) are substantial, accounting for a third of TFP growth in Indian manufacturing between 1972 and 1992. The spillover is an indirect effect which does not include the marginal product contributed by the use of electricity in production (the market-mediated effect). The results contrast with the results for United States manufacturing in Hulten and Schwab (1991). The difference suggests that the effects of infrastructure investments could play a larger role in developing countries than in the developed world.

Straub (2008) surveys the literature on the relationship between productivity and electricity generation, transmission and distribution and other forms of infrastructure. The assumption behind these studies is that electricity networks with frequent outages and unstable voltage induce high costs and deter investment.

Straub uses a pair of aggregate production functions to frame the discussion of the literature. The two functions distinguish the different assumptions made in infrastructure studies by Hulten, Bennathan, and Srinivasan and Duggal, Saltzman, and Klein. The theoretical questions that the two approaches raise are listed below:

1. Comparison of output elasticities of capital and infrastructure;

2. Can direct and indirect effects of infrastructure be disentangled?
3. If indirect effects can be estimated, what are the contributions of generic versus infrastructure externalities to shifts in productivity? Are there interactions between them?
4. Is the effect of infrastructure investment permanent or transitory?
5. Can economists identify a country's optimal infrastructure stock?

In Straub's review of 80 empirical studies, he finds that 77 of the total studies focus exclusively on estimating the output or growth elasticity of infrastructure. Only five studies, such as HB&S, examine the disentangling of direct and indirect effects. Thirty-six studies distinguish between permanent and transitory effects. Just five studies estimate the optimal stocks of infrastructure.

Half of the studies find a positive and significant effect of infrastructure, while 38 percent find no effect, and 6 percent find a negative and significant effect. For electricity generation infrastructure, the results are 45 percent neutral effect and 55 percent positive effect. The results differ significantly when studies use fixed-effects panel data, probably due to unobserved endogeneity. The use of different instruments in studies also makes a significant difference in results.

Straub observes that Paraguay illustrates the need to look at electricity quality, as well as electricity price, as measures of electricity infrastructure. Paraguay generates 100 percent of its electricity from the Itaipu dam project, and sells the majority of production to Brazil. Electricity generation capacity greatly exceeds demand in Paraguay. Yet only 82 percent of rural households have electricity service and the system is plagued by frequent outages and voltage spikes. Electric generation capacity is not an adequate measure for capturing the quality characteristics of electricity service.

The few studies that have examined the indirect effects of electricity on productivity have come to different conclusions. Hulten and Schwab (1984) find no significant externalities from infrastructure on the growth of U.S. states while Hulten, Bennathan, and Schwab (2006) find highways and electricity account for half of TFP differences in Indian states between 1972 and 1992.

Straub concludes that the results of empirical research could simply vary by country or time period and therefore not be subject to generalization. The agenda for future investigation includes examination of whether the payoffs to infrastructure occur in interaction with other investment conditions. Other variables to consider in future research are regulatory frameworks and market structures. Finally, institutional quality deserves further investigation. The enforcement of contracts, efficiency of bureaucracy and regulation, and level of corruption, all could affect the returns to investments in infrastructure. The final avenue for further research is the role of political economy in returns on infrastructure investment. If decisions on infrastructure investment respond to political motives rather than economic efficiency, investments may deliver suboptimal returns. Policy endogeneity is a challenge for econometric studies.

Straub's conclusion is that insights into the effect of infrastructure investments on productivity require more theory and better data sets to combine macro with sector and project level studies.

The literature that examines electricity as an unpaid factor of production identifies multiple problems with the measurement of its effects on production consistently. The effects are not fully measured in contemporaneous models because improvements in production efficiency are tied to capital investment. Moreover, the effects are not fully captured due to unmeasured quality differences of different forms of energy. The GPT literature identifies additional problems with the measurement of electricity on TFP. Externalities in industrial production from electricity are mismeasured due to an appropriation problem akin to R&D. Additional measurement issues include coordination failures, network effects, and technological complementarity: the full effects of electricity stem from the stimulation of new products, new factor inputs, and new production processes that are not captured in aggregate production function models.

The later infrastructure literature captures more of the effects of electricity by modeling a combination of production and TFP effects. This literature models electricity as an input that is not compensated based on its marginal product. The aggregate production approach in this literature is unable to accurately model the production impacts of electricity, since the cost of electricity as a factor input is not uniform across firms as it would be if priced by market forces. The most recent studies in the infrastructure literature identify additional complications in measurement, such as interaction effects between technology and electricity and between human capital and electricity. Hulten, Bennathan, and Schwab (2006) conclude that electricity effects on output must be modeled as a combination of direct or "market mediated effects" and indirect or "non-market mediated effects." They conclude that the non-market mediated effects of electricity account for about a third of TFP effects in Indian manufacturing between 1972 and 1992. Straub's review of the literature suggests that the infrastructure literature is inconclusive in terms of infrastructure's effects on productivity. Half of the 77 studies he reviewed show a positive effect and half show a neutral effect. The evidence suggests that the effects could vary between developed and less-developed countries and might not be generalizable as a simple theory. The empirical literature that follows identifies additional variables that affect the relationship between electricity and industrial productivity.

Empirical Studies

The empirical literature is divided into studies that are specific to the relationship between electricity use and productivity in the industrial sector, and studies that examine the role of electricity in general productivity. The literature reviewed in this section documents the effects of power shortages on GDP, employment, and exports in country-level studies while documenting the pervasiveness of electricity outages on production in East Asia, Africa, and Latin America. It documents the relationship between electricity theft and economic distortions in LDCs. The literature also covers studies relevant to the research question in this dissertation about differences in efficiency from differences due to state and private ownership of electric supply assets and in trade in energy embodied in imports and exports.

Sectoral and Industrial Studies

Jorgenson (1984) examines the linkage between electricity, technical change, and capital investment in manufacturing. The relationship between capital investment and technical change can be divided into technologies that use capital to enhance productivity and those that save capital to enhance productivity. Technology can further be divided into those investments where electricity's share of production inputs increases and those in which electricity's share of production inputs decreases. These relationships are named "electricity using" and "electricity saving" technologies.

Jorgenson measures these forms of technical change in a multivariate model of manufacturing with variables for bias, substitution, and technical change. If productivity growth is linked with increases in electricity consumption, the increase must be offset by a decrease in another production input. An example would be a technology that is labor saving and energy using.

Jorgenson examines the results of these relationships in the US economy with a translog production function with variables for labor, capital, electricity, other energy forms, and materials. The period of analysis is 1958 to 1979. Jorgenson finds that the decline in the price of electricity stimulates technical change in 23 of 35 industries but dampens productivity growth in the remaining twelve. In other words, technical change results in an increase in the share of electricity in output in 23 of 35 industries, holding fixed the prices of other inputs. These results strongly confirm Schurr's (1983) finding that electrification and productivity growths are related in a wide range of industries. The decline in real electricity prices during the first half of the twentieth century substituted electricity for other inputs, especially labor.

Schurr's hypothesis that electrification is especially significant in productivity growth in manufacturing is also supported by Jorgenson's findings. Technical change in manufacturing increased the input share of electricity in 15 of 21 manufacturing industries and in eight of 14 non-manufacturing industries. Rosenberg's hypothesis that electricity-using technical change is the "other side of the coin" of labor-saving technical change is rejected by Jorgenson's research. Technical change is labor-saving for only nine of 35 industries and labor-using for 26. Since the coefficients of bias must sum to 1.0, labor using technologies must reduce other production inputs. Jorgenson finds that technical change is materials-saving in 17 of the 35 industries and materials-using in eight.

With the exception of the economic downtown from 1997 to 2001, China has experienced electricity shortages since 1960. Recent investigations of the causality between electricity and economic growth in China by Lin (2003) and Shiu and Lam (2004) have been contradictory. An explanation is that Granger causality tests are sensitive to the time period of investigation and the stationarity of the data. Tests for unit roots by Yuan et al. (2007) shown that the data for China are not stationary in levels. Tests of Granger causality using error correction models identified a short-run relationship running from electricity consumption to GDP. The results are in line with those of Shiu and Lam (2004). Industrialization in China explains the pattern. Industry output has increased from 29 percent of GDP in 1978 to 49 percent in 2004. Ferrous and nonferrous metals, chemicals and nonmetal mineral products account for more than 42 percent of electricity consumption in China. Tests of Granger causality between electricity consumption and industrial growth support the hypothesis of causality running from electricity to industrial growth for primary and secondary industry but not for tertiary industry.

Lack of electricity supply is considered one of the reasons for India's slow export growth during the 1990s. The shortage of electricity limited India's comparative advantage in labor intensive products. Rud (2012) uses the variation across regions and over time within India to investigate the hypothesis that electricity supply limited manufacturing growth. To control for reverse causality and unobserved variables, he uses an instrumental variable (groundwater availability) as an instrument for electrification. The introduction of the green revolution in India provides a natural experiment because of the need for irrigation to support high-yielding seeds.

Rud's panel of Indian states from 1965 to 1984 show that an increase of one standard deviation in the measure of electrification is associated with an increase of around 14 percent in manufacturing output within a state. Electrification also is associated with more factories and greater output by small firms.

General Studies

Darmstadter, Dunkerly, and Alterman (1977) examine the relationship between energy and output in OECD countries. D, D, &A find that the prices of fuel and power have considerable power in explaining variations in the energy/output ratio among countries. Differentials in the industrial structure of output explain much of the variation across countries with little variation within countries in industrial production. The composition of output depends on the relative costs of energy in production. These results indicate that energy is a substitute for other factors of production.

The Office of Technology Assessment (OTA 1990) studied changes in energy consumption in the U.S. economy between 1963 and 1985. One of the most significant shifts in the production recipe was the energy embodied in imports. OTA constructed an input-output table of the U.S. economy where they calculated the BTUs of energy embodied in every commodity from the direct requirements table. The consumption of energy in the U.S. economy in 1985 would have been nine percent higher if the energy embodied in non-energy imports such as autos and steel were included with direct energy imports. The OTA analysis indicates that indirect imports of energy had increased between 1977 and 1985, while direct imports of energy (primarily oil) had declined. The total decline in energy consumption in the economy (direct + indirect) was 21 percent while the direct decline was 39 percent, suggesting that indirect imports of energy had increased. The OTA analysis suggests that indirect and direct energy imports are substitutes in production.

Prescott (1998) argues that shortages of capital could not account for the large differences in productivity rates between developed and developing countries. Prescott's argument suggests that differences in incentives, when applied to infrastructure delivery and maintenance, could explain a significant portion of the productivity differences.

Ferguson, Wilkinson, and Hill (2000) examine the correlation between GDP and electricity consumption between 1960 and 1995 for 100 countries. The variables are expressed in per capita units with GDP measured for purchasing power parities (PPP).

Differences in the level of correlation are apparent in different world regions. The coefficients of correlation for the OECD countries between electricity consumption and GDP are often higher than 0.9. The direction of correlation for the large oil producers is negative, rather than positive. Ferguson speculates that oil and gas are so cheap in these countries that they are not efficiently used. Africa has a level of correlation between electricity and GDP that is so low that it is not statistically significant.

The following are the key findings in the study:

1. Wealthy countries have stronger correlations between electricity use and wealth creation than poor countries
2. The correlation between electricity use and wealth creation is stronger worldwide than the correlation between total energy use and wealth
3. In wealthy countries, increases in wealth over time correlate with an increased proportion of energy in the form of electricity (what Ferguson labels the e/E ratio).

Lean and Smyth (2010) study the causal relationships between electricity generation, exports, prices, and GDP in Malaysia. Time series of the study are for 1970 to 2008. Electricity generation is used rather than electricity consumption because of the high transmission and distribution losses in Malaysia. Theft of electricity is imbedded in these losses but theft still has an impact on GDP production while technical losses do not.

The consumer price index is the measure of prices. Exports, electricity generation, and GDP are in per capita figures. The paper uses the Autoregressive Distributed Lag (ARDL) model with a modified version of the Granger causality test proposed by Toda and Yamamoto.

The results of the causality test are that Granger causality runs unidirectionally from economic growth and prices to electricity generation and from electricity generation to exports. There is no causal relationship between prices and economic growth. The result of causality running from economic growth to electricity generation differs from previous studies of Malaysia. An explanation for the difference is that this study uses a longer time series; it uses electricity generation rather than consumption; it uses the Toda and Yamamoto approach to Granger causality rather than the conventional approach. One recommendation for future research is an examination of energy use and GDP at a disaggregated level.

Escribano and Guasch (2005) develop an econometric method to assess the impact of electricity shortages on firm-level productivity using variables from World Bank Investment Climate surveys. When applied to Guatemala, Honduras, and Nicaragua, they find that a 1 percent increase in the average duration of power outages decreases productivity by .02-.1 percent. Since electricity is strongly complementary to other production inputs, it constitutes a bottleneck to production if not available.

Marathe and Mozumder (2007) examine the causal relationship between per capita GDP and per capita electricity consumption in Bangladesh using error correction models. Bangladesh has a small electricity infrastructure. Only 20 percent of the population has access to electricity. Per capita consumption is one of the lowest in the world. Problems in the system impair its efficiency and effectiveness. Among the documented problems are high system losses, delays in generation plant completions, low efficiency, erratic supplies, theft blackouts, and shortages of capital to increase capacity. The system has been unable to meet demand for more than a decade. Mozumder and Marathe find that per capita electricity consumption does not cause GDP but that GDP growth causes electricity consumption.

Zachariadis and Pashourtidou (2007) examine electricity consumption in Cyprus from 1960 to 2004 using various econometric methods. Multivariate vector relationships were examined between residential and commercial energy use with weather degree days, economic variables, and prices. Residential and commercial electricity are examined separately.

Econometric tests indicated unit roots in both residential and commercial energy consumption, in value added, and in electricity prices in levels but the lack of unit roots in first differences. Tests for co-integration suggested the need for error correction models in causality testing. Degree days for heating and cooling were significant variables in explaining both residential and commercial electricity consumption. Weather patterns are significant in explaining short-run demand but not for long-run demand. No Granger causality is detected for commercial electricity in the short-term among price, income, or weather. Long-run demand is affected by economic activity and electricity prices. Commercial economic activity and prices are exogenous to electricity consumption. The causality results in this study about Cyprus could differ from those in other countries because of the large tourism sector in Cyprus and the lack of a large industrial sector.

Ghosh (2009) examines the role that electricity theft plays in reducing employment growth rates in India. Electricity supply in India has grown by 10 percent annually since 1970. Capacity additions have always lagged demand. Per capita consumption of electricity in India is one of the lowest in the world. In India, transmission and distribution losses are high due to pilferage and theft, therefore consumption figures are underestimated. Stolen electricity contributes to economic growth but technical losses do not. Electricity supply is a better variable for testing causal relationships than electricity consumption.

Ghosh uses a trivariate model to test the relationships between employment, electricity, and GDP from 1970 to 2005. The Pesaran procedure is adopted in this study for the reasons cited in Odhiambo (2009). The Pesaran bounds test indicates that cointegration is present only when employment is the dependent variable. Results indicate that both electricity supply and GDP Granger cause employment in the short-run. Real GDP Granger causes electricity supply in the short-run. The coefficient on the error correction term of -0.146 suggests that convergence to equilibrium takes seven years.

Nagayama (2010) provides a framework for testing market reforms that deliver increased generation capacity: entry of Independent Power Producers (IPPs), unbundling, establishing regulatory agencies, and introducing wholesale markets. The reforms in Pakistan since the 1990s have not increased generation capacity nor reduced the transmission and distribution losses that reforms should have produced. Causality modeling indicates that variations in electricity theft are corrected by countervailing changes in price and load shedding while the converse is not true. A joint significance test indicates that the combination of load shedding and electricity theft may instigate theft. The conclusion of the analysis, after examining the variance decomposition, is that electricity theft Granger causes outages and electricity price changes.

Dinkleman (2011) estimates the impact of electrification on employment growth in the KwaZulu-Natal state of South Africa following the end of apartheid. South Africa undertook a massive electrification project to provide electricity to Black villages and towns. Two-thirds of South African households in 1993 lacked electricity. A quarter of these unsupplied households were electrified by 2001.

The electrification program provided a natural experiment where community-level employment growth rates could be compared for communities that were electrified and those that remained without electricity. The study finds that electrification resulted in a substantial shift away from wood use at home to electric cooking and lighting.

The results demonstrate employment growth among women in communities that were electrified. Electrification changed the production technology of households, which had an effect on female labor supply. Electricity allowed South Africans in rural areas to increase their participation in modern labor markets. In terms of methodology, land gradient was used as an instrumental variable in modeling to isolate the reverse bias and endogeneity problem inherent in electrification studies.

Shahbaz and Lean (2012) examine the relationship between electricity consumption and economic growth in both short-term and long-run periods in Pakistan between 1972 and 1999. Power production has restrained economic activities in Pakistan. Load sheddings (intentional outages) are frequently used to curb the demand for electricity. Siddiqui et al. (2011) estimates that the electricity crisis since 2007 has caused a loss of output in the industrial sector of at least 12 percent.

The Shahbaz and Lean model incorporates labor and capital as well as electricity consumption to control for the effects of other factors of production. The method uses a Hicks-neutral Cobb-Douglas production function with per capita inputs of electricity, capital, and labor as independent variables. Capital stock is computed using the perpetual inventory method with annual depreciation rate of four percent. After unit root and ARDL bounds tests for cointegration, the coefficients in the model are estimated using an unrestricted error correction model (UECM).

The results indicate a significant long-run effect of electricity consumption on economic growth. A one percent per capita increase in electricity consumption stimulates per capita economic growth by 0.3 percent but the authors do not report the specific consumption and production levels for the relationship. The long-run coefficient on electricity is higher than the coefficients on capital stock and labor in the model. The results indicate that electricity and capital are statistically significant in explaining short-term economic growth but labor is not. The model does not incorporate exchange rates and international trade variables as suggested by Karanfil (2009) and Halcioglu (2009).

Puller and West (2013) study whether efficiency changed after Texas opened retail electricity markets to competition in 2002. The study examines electricity rates for two regulated and two unregulated utilities from 1997 to 2006. The marginal cost of retail power is estimated as the average monthly wholesale price of electricity in Texas under deregulation. The results show that marginal and average retail prices diverge from marginal cost both before and after retail deregulation. Distortions relative to marginal cost persist after retail competition was introduced in Texas.

Jamil (2013) examines the effect of electricity theft on the electric supply industry in Pakistan. A shortage of electricity has been a perennial constraint on economic growth in Pakistan. Like many developing countries, electricity supply in Pakistan is characterized by poor quality and frequent outages. Jamil uses an error correction model for testing the causal relationships between electricity theft, electricity price, and load shedding. Data are for Pakistan for 1985 to 2010. Transmission and distribution losses are a proxy for theft. The hypothesized model is that theft of electricity sends price signals to producers which promote inefficient use of electricity, since thieves lack price incentives to drive the efficient use of electricity. Theft also lowers revenues that producers need to expand capacity. The only way to increase revenues for capital investment is to raise tariffs on paying consumers.

When electricity producers react to shortages by shedding loads, industrial consumers react by installing generators and uninterruptible power supplies. These measures lower efficiency as fuel costs are much higher in small generators. Higher prices also lower industrial production and reduce consumer surplus. Higher prices in turn stimulate higher rates of theft.

Jamil observes that a significant share of the electricity shortages in Pakistan from 2006 to 2011 is due to shortages of natural gas to power generators. The share of electricity generation from natural gas has declined from 71 percent to 45 percent during that period. The reduced gas supply in turn is related to lack of incentives for natural gas production in Pakistan.

Electricity losses are a widespread and costly problem in Latin America (Jimenez, Serebrisky, and Mercado 2014). Electricity losses are a key measure of the efficiency of the power sector. Losses measure the productivity of the transmission and distribution system. Losses consist of two categories, technical and non-technical. The degree of technical losses is related to the characteristics of the electrical system. Technical losses increase as the load in the system increases. Technical losses also increase with the length of the transmission and distribution network. Rural areas with low population density exhibit more technical losses than high density urban areas. Non-technical losses consist of electricity that is delivered to customers but never billed to them. Principal categories of non-technical losses are theft, fraud, un-metered supply, and mismanagement of the system. Most of the losses in Latin America are non-technical.

About 17 percent of electricity produced in Latin American countries is lost in transmission and distribution. This compares to six percent in high-income OECD countries and 13 percent in middle-income countries. The level of losses in Latin America is higher than in Africa but still below the 22 percent level in India. The range of losses in Latin America and the Caribbean vary from six percent in Barbados to 56 percent in Haiti. Nine countries in Latin America and the Caribbean have losses exceeding 20 percent.

Most losses are in the Latin American distribution system. A survey of regulators and utilities performed by the IADB (Inter-American Development Bank) indicates that transmission losses in 15 Latin American countries averages 3.1 percent and ranges in a narrow band between 1.6 to 3.7 percent when Paraguay's 7.9 percent is excluded. The distribution losses average 10.7 percent and range from 1.3 percent in Peru to 30.8 percent in the Dominican Republic.

Regulatory and governance schemes are related to the level of electricity losses. Countries such as Chile, Colombia, Costa Rica, and Peru have pricing systems that cap the losses that can be passed on in electricity tariffs at seven percent. Companies must absorb losses in excess of the cap. Losses in Peru, the only country with this regulatory framework for which survey data are available, are 4.3 percent, the lowest reported loss rate in Latin America. The regulatory climate and the ownership of transmission and distribution assets appear to influence the efficiency of electricity supply through the reduction of electrical losses.

Chan, Cropper, and Malik (2014) examine the effects of ownership on the efficiency of electricity generation in India. India suffers serious deficits in the electrical power sector. Blackouts have become front-page news, generating capacity continues to lag targets set in government plans, and 400 million Indians still lack electricity.

The study compares the efficiencies of power plants in India and the United States from 1988 to 2009 based on the name plate specifications of the plants. This method allows the researchers to compare the efficiency of 406 coal plants of the same scale, vintage, and with the same heat rates. Dummy variables are included in the regression equations for investor-owned plants. The results demonstrate that state-owned plants in India are less efficient than publicly owned plants in the United States. Indian plants on average used 9.4 percent more coal per kWh than US plants of the same age, nameplate capacity, and heat rates. Differences are attributed to different maintenance practices in India and to the lower heat content of Indian coal.

McRae (2015) examines the impact that residential electricity subsidies for informal settlements have on capital allocation in the electricity supply industry in Colombia. Electricity distribution in Colombia is a private industry. The subsidy program in Colombia consists of a stepped level of subsidy to the firms distributing electricity based on the income level in neighborhoods they serve. McRae builds a model of residential demand with variables for outages, household income, household characteristics, price of electricity, and stock of appliances. The marginal price of electricity in most informal settlements, because of a lack of metering, is zero. The marginal cost of supplying electricity to buyers is the wholesale cost of power transmitted to the distribution company, net of losses. McRae finds an interaction between non-paying customers and outages. "Outages are stochastic events caused by the failure of poorly maintained and overloaded equipment, as well as environmental factors such as trees, animals, storm and lightning" (McRae 2015, 54). McRae demonstrates that the increase in producer surplus from increased customer revenue that accrues from the improvement of service in Colombia is not as large as the decrease in producer surplus due to the subsidy reduction from system improvements. Subsidies to maintain service for nonpaying, unmetered households displace long-term investment by creating disincentives for investment. A second observation is that the subsidy program in Colombia shifts resources from commercial and industrial uses, since tariff rates for commercial electricity were set at 120 percent of cost, to generate cash flow to pay for the informal settlement program. A similar finding emerges in the Dominican Republic for a subsidy program to provide service to informal settlements (Krishnaswamy and Stuggins 2007). The impacts of electricity subsidies predicted by economic theory are confirmed by McRae's study.

Revealed Preference and the Cost of Unsupplied Electricity

Economic theory suggests that the economic loss from outages of electricity could exceed the economic value of electricity in industrial production because of the need to scrap materials in process and because the marginal revenue product of labor and capital are both zero during outages. A literature has developed that looks specifically at the economic damages from electrical outages.

The economic damage from electrical outages is not directly observable and therefore is difficult to measure. The three methods in the literature for estimation are proxies, contingent valuation surveys using measures of willingness-to-pay and willingness-to-accept, and market-based estimates using revealed preference. Revealed preference eliminates the upward bias inherent in estimates of damages collected in customer surveys.

Bental and Ravid (1982) introduce a simple method of calculating the marginal cost of industrial power using revealed preference. Since firms acquire back-up power to hedge against power outages, the marginal cost of backup power is the marginal cost of a power cut. To maximize profits, a risk-neutral firm functioning in a competitive market will equate the marginal cost of self-generated power with the expected gain from using that power. The gain consists of the continued production during the outage plus the avoided damage to equipment from the power failure. At equilibrium, the expected gain from self-generated power will equal the expected loss from the power outage. In other words, revealed preference implies that the marginal cost of self-generated power is an accurate estimate of the marginal cost of electrical outages. The marginal cost of outages will change, however, as the level of outages increases or decreases because the unit cost of equipment changes. The Bental-Ravid method only provides an estimate of the marginal cost at the time of generator installation.

At an average duration of outages of 10 hours per year in Israel in 1982, the marginal cost of backup power consists largely of amortized capital costs (Bental and Ravid 1982). The marginal cost of backup power therefore rises when outage levels drop and falls when the aggregate duration of outages rises. This finding explains the significantly higher estimated cost of backup power in the United States, which has a much lower average level of aggregate outages. The marginal cost of backup power will vary between countries with the level of aggregate hours of power outages.

Gilmer and Mack (1986) develop a model of electricity reliability that equates changes in reliability with changes in the real price of electricity. Outage costs should be modeled using extremely short-run demand curves, since electricity customers have no time to adjust behavior to outages. Industrial demand for electricity is highly inelastic in the short-term. Changes in reliability shift the short-term demand curve upward, resulting in a reduction in electricity consumer surplus and a dead weight loss from a reduction in the consumption of industrial electricity. These shifts are equivalent to an increase in the price of electricity. The dead weight loss and shift in consumer surplus can be estimated from shifts in the price of electricity modeled from shifts in the reliability of electricity supply.

Caves, Herriges, and Windle (1990) review the literature on outage costs and the demand for power reliability. Most of the literature comes from empirical studies in developed economies. The authors caution that since customers in developed countries have limited experience with power outages, survey data only provide information on attitudes and opinions rather than data on actual behavior from interruptions. The conclusion of the CH&W review is:

1. Proxy methods provide average or upper bound rather than marginal costs
2. Survey methods, such as the World Bank Enterprise Survey, are the most accurate method for collecting data for industrial and commercial customers
3. Consumer surplus methods are valuable because they use customer responses to prices to infer the value of power reliability.

The price that customers pay for electricity reveals information about the lost value of electricity during power outages. The limitation of the consumer surplus method is that the value of lost electricity is conditioned on the amount of warning that customers have of outages, because warning time provides time for electricity customers to adapt their behavior to outages. The data used for calculation of surplus are based on estimated demand where customers have advance warning of price changes. These demand curves will underestimate the cost of outages when electrical outages are unannounced or random.

Proxy methods report lower costs of industrial outages when compared to survey methods. The explanation is that proxy methods omit costs of damaged equipment and materials and spillover effects on hours outside of the outage. Measurement error is an additional explanation, since researchers are unable to accurately calculate cost per unserved kWh when industries have backup generators that provide partial rather than full loads.

Survey data provides substantial information on the economic characteristics of outages. Data indicate that outages have a fixed and variable cost. The fixed cost is a substantial component of the total cost when outages are infrequent. Fixed costs represent 27 percent of total outage cost for a one-hour industrial outage (Billinton, Wacker, and Wojczynski 1982). Outage costs are not proportional to frequency of outage, suggesting that behavioral adaption to outages is likely. Industrial customers prefer fewer long outages to more frequent but short outages (Ontario Hydro 1980). The distribution of outage costs is bimodal, with many industrial customers assigning zero cost to outages and the balance having a log-normal distribution around a second peak (Billinton, Wacker, and Wojczynski 1982). Standby power generation is not found to reduce outage costs in the industrial sector since the primary reason for installation of equipment is to minimize hazard to personnel and to prevent damage to equipment, materials and finished product (Subramaniam, Billinton, and Wacker 1986). Woo and

Gray (1987) find the opposite effect, with industrial firms having standby power reporting lower outage costs than firms without standby generators.

Woo and Pupp (1991) recap five studies of the cost of electrical outages in the United States and Canada not covered by Caves, Herriges, and Windle. The study by Gilmer and Mack (1986) estimates the cost of outages using consumer surplus. The marginal cost of unserved electricity is lowest in the study by Bental and Ravid (1982) that uses the proxy cost of standby generation as the measure of revealed preference. The highest estimated costs are in studies by Fisher (1986, as quoted in Woo and Pupp 1991) and Woo and Gray (1987), which show outage costs that are 10 to 20 times as large per unserved kWh. The universal finding among all of the studies is that, the more electricity-intensive the production process, the higher the cost per interruption.

Caves, Herriges and Windle (1992) use revealed preference to infer the cost of electrical outages for large industrial consumers in the USA. These authors use the decisions of 19 large industrial firms to participate in load curtailment tariffs to estimate the cost of unsupplied power. The estimated parameters of their model are jointly, but not individually, significant. The model excludes information on the presence of back-up power. The limited sample size and the developed world observations are additional reasons why the study results are not definitive for modeling outage costs in less developed countries.

Tishler (1993) estimates the cost of electricity outages in Israel from unplanned interruptions in the supply of electricity. The study uses data for observed customer behavior to infer the cost of outages. Tishler identifies four sources of outage costs:

1. Foregone profits on output
2. Reduction in productivity from outages
3. Damage to materials due to outages
4. Payment to labor during the electricity outage

Among the adjustments that can reduce productivity after an outage are rescheduling of production, additional maintenance and clean-up, and replacement of damaged material. Tishler calculates that the price per served kWh in Israel in 1987 was $.053 to .067/kWh while the price per unserved kWh was $3.33 to $22.10. The cost of unsupplied electricity is 60 to 300 times the cost of supplied electricity.

The empirical data for Israel indicates that the composition of losses varies significantly by industrial sector. Lost profits from reduced output range from 20 percent of total losses in chemicals to 41 percent of total losses in electronics. Losses from productivity vary between 17 percent in continuous process industries like chemicals and plastics to 36 percent in mining. The vast majority of losses are in damaged materials and redundant labor. In most sectors, this component accounts for a third to two-thirds of total losses. In half of the sectors, redundant wages and wasted material are larger than the combination of lost profits and reduced productivity. The coefficient of variation is between 75 and 100 percent of the mean value for each component, suggesting that controls for industrial sector are important in empirical modeling.

Grosfeld-Nir and Tishler (1993) develop a two-factor stochastic model for the estimation of firm-level costs from electricity outages. Firm management is assumed to maximize expected discounted profits, or expected value of the firm, while responding to repeated random electricity outages. Outage costs include lost profits from lost output plus excess payments for labor and other inputs while production is zero. The damage function includes a fixed cost per outage, a cost that varies proportionally with output, and a cost that varies with the length of outage.

Grosfeld-Nir and Tishler find that losses from outages are equivalent to proportional increases in prices of electricity and of all other inputs. The model estimates that the cost per unserved kWh in 1987 varies from $4.04 in textiles to $20.31 in electronics and electric equipment for 11 industrial sectors in Israel. The cost per unserved kWh is a multiple of the cost of delivered kWhs, a confirmation of the earlier Tishler (1993) findings. The most significant components of total outage cost are for direct damage to materials and payments to labor during outages, rather than for lost profits. The cost per unserved kWh is inversely proportional to the share of electricity in production. Industries with low percentages of electricity inputs have proportionately higher losses per unserved kWh. Electricity is a complement to other inputs in all industries.

Beenstock, Goldin, and Haitovsky (1997) use the principle of revealed preference to estimate the cost of power outages in Israel. BG&H develop an economic model of the cost of mitigated and unmitigated cost of outages from economic theory and compare the results of the model against the losses calculated from a survey of business and institutional customers of the Israel Electricity Company. The survey data for Israel shows that the cost of outages varies substantially with the duration of the outage. The loss function has a u-shape. The cost for a 10 minute outage equals $10 per unsupplied kWh, which falls to $6 per unsupplied kWh at 45 minutes. Cost per unsupplied kWh increase from that point to $12.50 at 180 minutes. The components of cost vary with the duration of outage. For outages under 10 minutes, lost materials is the largest component of total cost, with virtually no loss in output. Lost output increases after 10 minutes and encompasses most of the cost in outages exceeding 30 minutes.

BG&H derive the optimum level of backup from theory. The optimal demand for back-up power, assuming an exponential function for losses, is:

(4)

$$G^{\wedge *} = E \times e^{\wedge}(-\frac{\lambda P}{\pi})$$

G* = optimum level of backup load, E= total electrical load, λ is the mean value of a loss, P is the price per kWh of unsupplied power, and π is the proportion of the year where power is not supplied.

According to the BG&H model, the demand for back-up power varies directly with load, directly with the unreliability of the power grid and inversely with the cost of back-up power.

The unmitigated loss may be inferred from the BG&H loss function:

(5)

$$L = \ln(\frac{E\_i}{G\_i}) \times 1/\lambda\_i$$

where variables are the same as in the previous equation.

(Note: BG&H fail to note that this function is undefined when the firm lacks backup power. Survey data collected by the World Bank indicate that two-thirds of manufacturing firms in LDCS lack backup power. The empirical data challenge the general validity of this BG&H finding.)

The variance of the electrical loss is a subset of the error term, just as in stochastic frontier models. The researchers estimate the loss function with a truncated probit model using outage data from the Israel Electric Company. Firms with zero outages are excluded from below and firms with complete backup are excluded from above. As a power system becomes less reliable, the demand for backup power increases, the total cost to the industrial firm increases, but the cost per unsupplied kWh drops. In other words, the loss function is not linear with respect to the aggregate duration of outages. The comparison of cost estimates from revealed preference and survey valuations shows that the estimates are comparable in sectors where output is measurable, such as industry, but diverge significantly in non-profit and government sectors where output cannot be easily measured.

Sullivan, Vardell, and Johnson (1997) report the results of a survey of 299 industrial customers of Duke Power on detailed costs incurred because of electrical outages. The survey documents the sources of outage costs and how they vary with the duration of outage. The outage scenarios are for a four-hour interruption, a one-hour interruption with and without notice, a momentary voltage sag and a one to two second momentary outage. The elements of costs include lost production, costs of ruined material and labor costs to restart and make-up production. The nine-percent of customers with backup power universally reported that they would not curtail output during an outage. The results of the survey are therefore characteristic of firms that lack backup power and not of all firms using electricity.

The Sullivan, Vardell, and Johnson survey data is relevant to modeling the costs of outages in this dissertation. Lost time in production exceeds the time of the outage. A four-hour outage results on average in 6.67 hours of lost production; a one-hour outage results on average in a 2.96 hour lost production. The most pronounced divergence is in one to two second outages, which results on average in a 0.7 hour loss in production. The loss per hour is inversely related to outage duration in a non-linear fashion. Moreover, most of the lost production is not recovered by overtime hours. Thirty-eight percent of firms reported they would recover all of production in outages exceeding one hour while 56 percent reported that none of the production would be recovered. A third of firms use overtime to recover production from a four-hour outage. The percent drops to 25 percent for a one-hour outage and further to 16 percent for a momentary voltage spike or outage. For momentary outages, none is recovered. The cost of outages is therefore inversely related to the cost of production labor in a declining non-linear fashion. The effects of outages on production labor are therefore difficult to measure in production functions.

Sullivan, Vardell, and Johnson find that the second largest cost of outages, after lost production, is from damaged materials. Damage costs are not proportional to the duration of outage. Fifteen percent of the material damage in a four-hour outage occurs within the first few seconds while 60 percent of the damage occurs within the first hour of the outage. Lost materials from outages decline inversely with the length of outages. The damage to equipment by duration is similar to the distribution of material damage. The smallest cost of electrical outages is for the production of backup power. Firms in the SV&J survey report that the cost of backup power operations is about 0.2 percent of the total cost of a one-hour outage.

Steinbuks and Foster (2010) examine the cost and benefit of standby power generation in 25 African countries using observations from the World Bank Enterprise

Survey and engineering data on the capital and operating costs of backup power systems. The cost of self-generation is reported as three times as high as the subsidized cost of grid power in Africa. Steinbuks and Foster find that the net cost of generator ownership is negative in all countries in the sample except for Nigeria and DRC, where outages are inordinately high. A binary choice model of generator ownership, using censored regression, shows that generator ownership would remain above 20 percent, even in the case of no power outages. Firm characteristics of size, sector, corporate structure, and export orientation explain generator ownership. Firms that have continuous operations are more likely to have standby generators than small firms that operate during daylight hours.

Using revealed preference, Steinbuks and Foster calculate the marginal cost of unserved power in Africa for both firms with generators and those without them. They find that the losses in output due to power outages are lower, but not completely avoided, for firms with generators. The average loss for firms without generators is $150/hour versus a loss of $50/hour for firms with generators. The marginal benefit of owning a generator was calculated from estimates of sales lost to outages. The regression model was statistically significant at the .001 level. The variables explaining the marginal benefit are ln of # days of power outages, generator ownership, sector of firm and country of firm. Dummy variables for sector and country are jointly but not individually significant.

Steinbuks and Foster have implications for the measurement of the cost of unsupplied power. Generator ownership does not completely control for the effects of outages on production. Firms with generators on average have net operating costs above firms without generators.

A summary of the revealed preference literature is that backup power is not an accurate proxy for the cost of power outages. Companies in Africa also install generators to meet International Organization for Standards (ISO) quality standards and to qualify for production contracts with .multinational companies. Surveys suggest that generator ownership would remain above 20 percent in Africa if outages were reduced to zero for these non-cost reasons. The literature suggests that the time of lost production exceeds the time of outages because additional time is needed for repairs and to reset machinery. The costs of losses exceed the marginal revenue production of labor and capital because of the scrapping of raw materials and finished products from outages. Economic losses from electricity outages with respect to productivity appear to have a quadratic rather than linear form.

Summary of Literature

A review of literature on the electric supply industry and industrial production leads to three conclusions. First, electricity is an important input in industrial production but its effects have been underestimated in aggregate production functions for many reasons. Second, the effects of unsupplied electricity from power outages are larger than the effects on production of supplied electricity. Estimating the cost of unsupplied power from the cost of standby power generation does not accurately measure the relationship. A new method is needed to estimate the relationship. Third, institutional variables, such as the level of theft and transmission-distribution losses in the electric supply industry, clearly influence the efficiency of the electric supply industry and hence are important variables to incorporate into explanations of electricity's overall effects on industrial production. These findings raise significant measurement issues that this research must incorporate into its methodology. New tools, such as Stochastic Frontier Analysis and production function models that incorporate intermediate inputs, potentially offer a more accurate method of measuring the relationships of supplied and unsupplied power on industrial production and per capita income in LDCs. Firm level cost and production data from LDC economies provide a means of measuring the production relationship of electricity as an unpaid factor of production where prices of the input are neither uniform nor determined by market forces. Finally, the understanding of the importance of institutional relationships offers an opportunity to determine whether the impacts of electric supply can be generalized for LDCs.

The following research questions related to electricity and industrial production, formulated after a review of the relevant literature, are hypotheses that this research will explore in the chapters that follow:

1. Shortages of electricity in LDCs lower labor productivity through effects on the marginal product of labor (the MPL is zero in the absence of electricity)
2. Shortages of electricity in LDCs lower the productivity of capital through effects on the marginal product of capital (the MPK is zero in the absence of electricity)
3. Shortages of electricity in LDCs reduce capital investment levels in industrial plant and equipment which lowers future industrial output

4. Shortages of electricity in LDCs reallocate capital investment in industry away from production equipment into power generation equipment, which lowers economic efficiency
5. Shortages of electricity in LDCs lower inputs of human capital into industrial production
6. Shortages of electricity in LDCs lower domestic production of intermediates and substitutes imported intermediates for domestic intermediates
7. Shortages of electricity in LDCs shifts production from modern to traditional production methods which lower labor productivity and total factor productivity
8. Shortages of electricity in LDCs lowers export production which retards the transition from labor intensive to capital intensive production
9. The ownership and regulatory system for electricity distribution influences the reallocation of resources in industrial production in LDCs.

CHAPTER III –METHODOLOGY

If the electric supply industry is important for a country's economic development, its effects should be evident in per capita income and in per capita industrial production. The dependent variable for most of this statistical testing in this dissertation is per capita industrial production.

This chapter discusses the data, statistical methodologies, and inference tests used in measuring the effects of electricity and of electricity shortages on manufacturing production in LDCs. The literature review uncovered a host of measurement issues involved in researching the subject. First, the measurement of the effects of electricity on industrial production and the measurement of the effects of electricity outages are different concepts that require different statistical techniques to accurately measure the effects. Second, electricity is both an input and an unpaid factor of production that shifts total factor productivity (TFP). Finally, based on survey research, shortages of electricity on output are likely to exhibit a quadratic rather than linear form.

This chapter is divided into three sections. The first section describes the data used in the statistical analysis. The second section describes the statistical and inference procedures used to test the research questions. The final section introduces each of the five research hypotheses and the specific statistical models and inference tests used in hypothesis testing.

Data Sources

The World Bank Enterprise Survey (ES) is the primary data source and the sole source of firm-level data in this study. Gravity model data is used to develop variables used in the trade-related research questions. Platts UDI and World Bank Development Indicators are the country-level data used for testing the research questions about the effects of electricity institutional characteristics on firm productivity. Data sources are presented in the order in which they are used in the hypotheses testing.

World Bank Enterprise Surveys

Enterprise Surveys conducted by the World Bank are the primary data source in this research. The results of the Enterprise Survey program are available in both cross-sectional and panel data. The World Bank ES program consists of over 117,000 survey responses from firms in 135 low and middle-income countries. Country-level surveys have been conducted since 2007. The World Bank aggregates the country-level responses into a master file of observations in Stata format.

The manufacturing observations in this research consist of 57,000 companies in 101 countries (See Figure 2). Many of the smaller economies in Africa and the Caribbean do not have manufacturing companies in their samples and therefore are excluded from this research.

The ES program has used a standardized questionnaire since 2007 to ensure that responses are uniform across countries. The survey design is a stratified random sample with the weighting of firms proportional to a sector's share of GDP. The sample size is sufficient to determine how investment climate variables such as corruption, political instability, labor regulation, or electrical outages affect productivity in the largest sectors of each economy (World Bank 2007). Sample sizes range from 480 in small economies with Gross National Income (GNI) below $25 billion to 1080 for large economies with

GNI above $200 billion. The manufacturing subset ranges from 33 cross-sectional observations in Gambia to 6474 observations in India. The large number of observations in large countries like India is due to large sample sizes and repeated surveys between 2006 and 2014.

Questionnaires are administered in-person by panels of trained surveyors working from standardized written instructions. The 144 questions in the core and manufacturing survey are divided into thirteen sections, shown in Table 2 below. The variables used in this study come largely from Sections A-D and Sections L-N.

Surveyors provided their opinions on the validity of the responses in two questions. Interviewers record the veracity of the interviewee. A compilation reports that answers were "truthful" (65 percent) or "somewhat truthful" (33 percent). Only three percent of responses were classified as "untruthful." Surveyors also recorded on the source and accuracy of the reference data that interviewees used in formulating responses. Surveyors reported that 34 percent of the total responses were taken from company records while an additional 56 percent were "estimates computed with some precision." The balance of responses was rated as "arbitrary and unreliable numbers." The inference from these two questions is that survey responses are nearly universally of a high precision for this kind of survey.

Table 2

Description of Enterprise Survey Questionnaire

Section	Description	Questions(#)
A	Control Information	14
B	General Info such as ownership and start-up	8
C	Infrastructure and services	30
D	Sales and Supplies	30
E	Degree of Competition	12
F	Capacity Utilization	2
G	Land: ownership and access	5
I	Crime: extent and losses	5
J	Business-Government Relations	16
M	Investment Climate Constraints	1
K	Finance: sources, terms and services	22
L	Labor: skills, training, availability & education	12
N	Productivity	17

Cross Sectional Observations. Tabulations of questions in Sections A-B provide a general description of the manufacturing firms in the sample (See Appendix A). Observations come largely from Latin America, South Asia, Africa, and East and Central Asia. Although samples in all sectors except leather goods are in excess of 1000 firms, the observations are largely from food, metals and machinery, and garment sectors. A third of firms have less than 20 employees, while a fourth have more than 100 employees. Firms on average operate 62 hours per week with a median work week of 48 hours. Only 10 percent of firms operate more than 120 hours per week.

Ninety-five percent of the companies in the sample are privately held. Most firms are controlled by a single individual or corporation, with the largest owner controlling 71 percent of stock on average. About 90 percent of firms in the sample are exclusively domestic owned with just seven percent, on average, with some foreign ownership. State-ownership is under one percent in the sample. Most sales are destined for national markets although 14 percent of sales on average are exported directly or indirectly. All countries in the sample have both direct and indirect exports (output exported by a third-party). The lowest percent of output that is exported, at one percent, is from Sudan, while the highest percent, at 82 percent, is from Chile. Seventy-one percent of intermediate materials on average are of domestic origin with 25 percent of foreign origin.

The survey includes four questions related to backup power and electrical outages. Descriptive statistics on responses to the electrical questions are shown in Appendix B. Sixty percent of companies had experienced electrical outages during the past fiscal year but the distribution varies from 34 percent in High-Income OECD countries to 80 percent in Africa. The average number of outages was 21/month for the companies experiencing outages. The distribution of number of outages has a large variance and a number of extreme outliers. The average length of outage is 5.1 hours, again with a large variance. Companies experiencing outages reported that on average they generated 25 percent of the electricity consumed from their own generators. The average estimated loss of sales from power outages is 9.1 percent for the half of companies providing an estimate.

Several new variables were calculated to combine responses for companies experiencing outages and those without outages (The WB file posts firms without outages are missing data, rather than as “zero” outages. FOutage was calculated by inputting “0” outages for companies not experiencing them and combining the number of outages for companies reporting them. Variable ALoss was calculated to capture annual outages by multiplying monthly outages by 12. The number of annual outages was changed to 1 in levels so that the observations with value of 0 would not become missing values when the natural log form was calculated (the natural log of zero is undefined). The same transformation was made for DLoss (duration of outage) by combining responses from companies with outages and those without them. Finally, variable AFnDLoss was constructed by multiplying the number of annual outages by the estimated duration of outages to provide a measure of the annual aggregate hours of electrical outages. Outliers in each series were assigned a missing value if the value exceeded the annual operating hours of the establishment. The transformed variables show a lower average number of hours, a shorter duration of outages, and lower aggregate hours of annual outages.

Section N contains production function inputs expressed in local currency units (LCUs) for the last fiscal year. The amounts were adjusted to US$ using average annual exchange rates from World Development Indicators lagged by one year (World Bank 2016). Additional adjustments were needed for Ghana and Zambia, which had undergone currency re-basements during the survey years. Many of the minor production function categories, such as miscellaneous expenses, communication costs, and water costs, contain large proportions of missing data and were eliminated from the production function models. Data on output and production inputs were converted into units per worker for model estimation using the sum of the number of permanent and temporary full-time workers in the last fiscal year as the denominator.

The production function variables exhibit substantial positive skew and extreme leptokurtosis in levels (Appendix C). The survey contains book values of equipment and buildings for approximately 36,000 firms in the sample, which limits the model observations. The variable for capital consumption is the calculated value of depreciation based on book value of assets and the Hulten and Wykoff (1981) formula that manufacturing equipment depreciates at the rate of 0.1108 per year and buildings used in manufacturing depreciate at the rate of 0.0314 per year. The production function variables used in modeling were transformed into natural logs of the per worker levels.

Inputs of labor and intermediate materials represent 60 percent of the value of output. Combined fuel and electricity represent almost seven percent of output, slightly more than the value of depreciation. Inputs represent 71 percent of the value of output, inferring that TFP averages 29 percent of output. All input shares except materials are skewed and leptokurtic.

Panel Data Panel data observations for 2007 to 2015 are available for 3,000 manufacturing firms in 52 countries when assembled into a master database. The time series lengths are quite limited. Nearly all of the firms in the panel have observations in only two time periods. A total of 119 of the 3,000 firms have observations in three time periods. Production function, control, and electrical outage variables were constructed in the same manner as the cross sectional variables.

The Chi-square contingency test indicates that the panel is statistically different from the cross section sample at the 0.001 level in terms of sector, region, and size. The panel data have higher proportions of observations in leather, wood and furniture, auto parts, and misc. manufacturing, and lower proportions in metals and machinery, non-metallic, and plastic materials (Table 3). The panel has a lower proportion of observations in Africa and East-Central Asia and a higher proportion in Latin America, Middle East and North Africa, and in High-Income countries (Table 4). In terms of size, the panel has a lower proportion of observations in small companies (under 20 employees) and a higher proportion in large companies (over 100 employees) (See Table 5).

Table 3

Comparison by Sector

	Cross Sec.		Panel	
	Obs	Pct	Obs	Pct
Textiles	4,734	8.3	788	8.9%
Leather	494	0.9	227	2.5%
Garments	7,073	12.4	1218	13.7%
Food	11,875	20.9	1831	20.6%
Metals and Machinery	9,520	16.8	1158	13%
Electronics	1,691	3.0	175	2%
Chemicals and Pharmaceuticals	5,018	8.8	759	8.5%
Wood and Furniture	2,457	4.3	590	6.6%
Non-metallic and plastic	6,584	11.6	698	7.8%
Auto and auto components	1,014	1.8	70	0.8%
Other Manufacturing	6,380	11.2	1389	15.6%
Total	56,840	100	8903	100%

P of Chi-square test 0.0000

Table 4

Comparison by Region

	Cross Section		Panel	
Region	Frequency	Percent	Frequency	Percent
AFR	10,734	18.9%	1409	15.8%
EAP	5,237	9.2%		0%
ECA	7,651	13.5%	930	10.4%
LAC	11,947	21%	2184	24.5%
MNA	3,486	6.1%	729	8.2%
SAR	11,243	19.8%	1766	19.8%
High Income	6,573	11.5%	1736	19.5%
Total	56,871	100%	8903	100%

P of Chi-square test 0.0000

Table 5

Comparison by Size

	Cross Section		Panel	
Size	Frequency	Percent	Frequency	Percent
Under 20 employees	22,373	39.3%	3,272	36.8%
20-99 employees	20,915	36.8%	3,219	36.2%
100+ employees	13,583	23.9%	2,412	27.1%
Total	56,871	100%	8,903	100%

P of Chi-square test 0.0000

Gravity Model

Several of the research questions involve tests of trade relationships. Trade equations require the addition of gravity model variables to avoid the omitted variable bias and endogeneity with the error term (Chaney 2013). Gravity models have been used in economic geography since 1931 (Reilly 1931) to model domestic trade.

Linnenmann(1966) was among the first to use gravity models to explain bilateral trade flows between countries. The gravity trade model states that trade between two countries is proportional to product of the two countries' sizes and inversely with the distance between countries.

The general form of the gravity model is:

(6)

$$T_{A,B} = (GDP_A \times GDP_B) \div Dist_{A,B}^{\gamma}$$

where TA,B, is trade between countries A&B, GDPA is GDP of country A, GDPB is the GDP of country B and DistA,B is the distance between countries A and B.

Empirical work shows that the distance exponent γ is typically near 1, as are the exponents on GDP of countries (Chaney 2013).

The gravity model data used in this study consists of the CEPII gravity dataset (Mayer and Zignago 2011). Distances between trading partners are measured between capital cities. The indices of mass in the model consist of GDP, GDP per capita, and population. The GDP variable was selected to represent the numerator in the gravity equation. The final gravity index for each country is the sum of indices for each county's trade partners:

(7)

$$IN_i = \sum_{j=1\ to\ n} T_{i,j}$$

where INi = trade index for country i and T is the index for trade between country i and its trade partners j.

Platt's UDI Data

Data on the institutional structure of electricity generation, transmission, and distribution companies is furnished by Platts (Platts 2014). The Platts data have been used by the World Bank in studies of the electricity sector in Africa (Eberhard et al. 2011). Platts provides reports for 200 countries, including all of the countries in the cross-sectional and panel data, which identifies the companies that provide generation, transmission, and distribution services in the country. The data identify whether a provider is government, private, or cooperative in ownership. Country profiles include information about privatization laws and privatization initiatives. In the case of countries with an earlier privatization, the date and nature of the privatization (complete, majority private stock, majority government stock after privatization) is included. The company data includes the number of customers, the number of transmission and distribution substations, kilometers of transmission and distribution lines, peak and installed Mw of generation capacity, and electricity sales in Gwh.

The Platts data are updated on a six year cycle. Emails were sent to the commercial attachés at embassies in Africa, Asia, and Latin America to confirm if privatizations had occurred since the year of the Platts last update. The 19 responses from these emails are used to update the Platts data. The Platts data include accurate data on the ownership of electric generation, transmission, and distribution assets as of 2012.

Indicator variables are constructed for each country to distinguish state-owned transmission and distribution assets from private or cooperative-owned assets. Little variation is found in the ownership of distribution assets. Government owned the distribution assets in 104 of the 111 countries in the database. Government ownership was less pervasive in transmission assets. Government owned the transmission assets in 89 of the 111 countries.

Statistical Methods

The measurement problem in quantifying the impact of electricity on manufacturing output is that changes in other inputs also change output per worker, the link with changes in per capita income. A production function is an equation that quantifies the impact of factor inputs on the output of a firm. An aggregate production function quantifies the impact of a country's inputs on national output. Production functions provide a method for measuring the impact of electricity on output per worker *ceteris paribus*.

As revealed in the literature review, measurement of the impact of electricity shortages on industrial output is more complex than the measurement of electricity's role as an input factor. Production function methods miss impacts due to complementarity between electricity and capital investment and due to shifts in TFP from electricity as an unpaid factor of production. Stochastic Frontier Analysis (SFA) provides a method to quantify the impacts of shortages of electricity on the efficiency of output at the firm level. SFA provides an improved tool for measuring the impact of electrical shortages on per capita output by measuring the potential output lost because of electrical outages.

The production function and SFA methodologies used to measure the effects of electricity are discussed in the subsections that follow.

Production Function Methods of Measuring the Importance of Input Factors

A production function models the relationships between outputs and factor inputs (Kumbhakar, Wang, and Horncastle 2015). The Cobb-Douglas (C-D) is the simplest production function that exhibits well-behaved preferences (Varian 2010). It is the most commonly used production function in economics. The translog function uses a multiplicative relationship among variables to explain the output. With two-factor inputs, translog functions have six input variables and an intercept. The six variables in the translog method consist of the logarithms of the two inputs, their cross products, and the square of the logarithms of each input. With the five factor inputs in this study, the number of variables in the translog method expands to 25, including the five inputs, their cross products and squares of the logarithms of each input. Econometric issues with multicollinearity increase substantially with the use of a translog form (Pavelescu 2016). The flexibility of modeling nonlinear returns to scale and different elasticities of substitution among inputs by the use of a translog form is traded for challenges in estimating parameters due to multicollinearity. Earlier research in Africa supported the use of the Cobb-Douglas form with WB Enterprise Survey data (Escribano, Guasch and Pena 2010).

The (C-D) production function is the preferred model for estimating shifts in productivity when using Enterprise Survey data due to the endogeneity between production inputs and investment climate variables (Escribano and Guasch 2008). Substitution and complementary effects between production inputs that have been identified in the literature can be incorporated into the C-D framework by the use of interaction terms. The known effects from the literature are: substitution of electricity and labor; complementarity of electricity and new capital investment with TFP; and substitution of non-electric energy and electricity. Empirical work from Ghana (Braimah and Amponsah 2012) suggests that substitutions of electrical machinery for manual labor, such as electric saws for hand saws, are common but that substitutions between electricity and non-electricity are almost nil (except in metallurgical industries where product heating is involved) and therefore are irrelevant.

The C-D function is linear in natural logarithm of variables and therefore can be estimated by least squares techniques:

(8)

$$Ln(y_i) = \beta_0 + \beta_1 \ln(k_i) + \beta_2 \ln(m_i) + \beta_3 \ln(el_i) + \beta_4 \ln(en_i) + \beta_5 \ln(l_i) + \varepsilon$$

where y_i= output per worker, k_i=capital per worker, m_i=materials/worker, el_i=electricity/workers, en_i=non-electricity energy/worker, l_i= labor costs/worker, ε is an error term and β are regression coefficients.

Since the Enterprise Survey data is at firm-level, firm TFP can be calculated directly from the survey data (output minus operating costs) or can be calculated as the regression residual plus the constant term of β_0.

Endogeneity and Estimation of Production Functions

One of the key challenges in estimating production functions is endogeneity in the independent variables known as "transmission bias" (Gandhi, Navarro and Rivers 2013). Transmission bias arises because the firm's productivity is transmitted to the choice of inputs. The observed inputs are correlated with unobserved productivity, which implies a correlation between the independent variables and the error term in the regression equation.

Recent literature imposes restrictions on the economic environment to allow estimation of equations using lagged inputs as instruments for current inputs, also called the proxy variable approach. The prevalent assumption is that flexible inputs are inputs that firms can adjust in each period without adjustment costs. They differ from quasi-fixed inputs such as new equipment or facilities, which incur costs such as new investment or hiring costs for new employees. Flexible inputs are static in that they do not affect the profitability of the firm in future periods. Consequently, the flexible inputs can be used as proxies for productivity as outlined in Ackerberg, Caves, and Frazer (2006) and Levinsohn and Petrin (2003). The equations are estimated with Generalized Method of Moments (GMM) and instrumental variables (IV), rather than with OLS methods. Gandhi, Navarro, and Rivers (2013) show that production functions that exclude intermediate materials provide coefficients that are even more biased than those that suffer from transmission bias. In an investigation using firm level data for Chile and Colombia, the value-added equations (capital and labor inputs only) uniformly overestimate the elasticity of labor and capital and distort the capital/labor ratio in contrast to production functions that include intermediate inputs. Omitting supply chain variables such as intermediates and energy provide an upward bias on the elasticities of labor and capital.

Kumbhakar (2012) shows that OLS yields consistent estimators for production parameters in the case of profit maximization. Other economic behaviors, such as cost minimization or maximization of returns, could vary from profit maximization but these behaviors are not examined by Kumbhakar. Returns to scale and input elasticities can be estimated consistently in a single equation model using instruments on only one regressor, if the data are normalized. Expressing the independent variables as numeraires of one of the other inputs is demonstrated as a valid way to normalize the data

(Kumbakhar 2012). This method simplifies the consistent estimation of production function variables. The numeraire method is employed in this study with IV estimation.

Dollar, Driemeier, and Mengistaue (2005) provide a method for measuring the effects of investment climate on TFP using the Levinsohn-Petrin (2003) error correction. The L-P correction provides a solution for endogeneity between production inputs and investment climate by conditioning out the effects of unobserved productivity shocks on TFP.

IV Methods

The use of instrumental variables is a well-recognized econometric method discussed in introductory textbooks (Woolridge 2009). Production inputs are estimated by finding instrumental variables that are strongly correlated with the input variable but are not correlated with the error term in the equation. Coefficients are estimated in two-stages. In the first stage, the endogenous independent variables are estimated in separate equations. The estimated coefficients of the first stage equation are used as independent variables in a second equation. While OLS is an accepted technique for estimation, general method of moments (GMM) and limited information maximum likelihood (LIML) methods are better for consistent estimation in the presence of econometric issues such as heteroscedasticity and non-i.i.d. errors (Baum 2006).

Estimation of production functions by IV is not consistent if the instruments lack orthogonality (variables that lack orthogonality are partially correlated with the error term) or if they are weakly correlated with the independent variables in the structural equation (Baum 2006). Baum (2006) provides tests for determining the strength of instruments and for orthogonality that are used in this study. The J statistic of Hansen provides a test of over identification of instruments and correct model specification. The null hypothesis is that the IV equation has sufficient valid instruments and is correctly specified. Failure to reject the null hypothesis is a test of the consistency of estimators (Baum 2006).

The Anderson Canonical Correlation LR test is a test of the identification of valid and relevant instrumental variables (Baum 2006). The null hypothesis of the Anderson test is that the instruments are not valid or relevant (Baum 2006). Rejection of the null hypothesis is an indication that the instrumental variables are sufficient for consistently estimating the input coefficients (Baum 2006). The interpretation of these tests is another measure used to determine the consistency of production function inputs in this study.

Stochastic Frontier Analysis

Inefficiency is recognized widely in the engineering and management literature as a constraint on manufacturing production but not in production theory. Production theory assumes that producers efficiently allocate inputs to maximize profits and therefore operate on the production possibilities frontier at equilibrium (Varian 2010). The exclusion of intermediate inputs from production theory eliminates the recognition of supply chain disruptions that provide inefficiencies in practice in manufacturing production. The claim in this dissertation is that disruptions in manufacturing production due to electrical outages and shortages are significant sources of inefficiency in manufacturing in LDCs. A further claim is that electrical outages decrease the net export component of GDP in LDCs by shifting supply chain and customer choices of manufacturers.

SFA provides an analytical tool for measuring inefficiency in manufacturing production. Estimates of production functions by OLS or IV regression assume that firms operate on the production possibilities frontier. Except in the cases of market failure, firms efficiently use production inputs to maximize profits or to minimize costs (Varian 2010). SFA assumes that production is not universally efficient and that individual firms may operate below the production possibilities frontier for a host of reasons. SFA provides a means of measuring the level of inefficiency at the firm level (Kumbhakar and Lovell 2000).

SFA models assume that production outputs are endogenous and inputs are exogenous (Kumbhakar 2015) because output is the choice variable in production while inputs are fixed in the short-term. Zellner et al. (1966) shows that OLS estimators are consistent in estimating production function inputs when the objective of the producer is profit maximization. Mundlak (1961) shows that OLS estimators are inconsistent with profit maximization if managerial input is unobserved by the researcher. If producers minimize cost, then output is exogenous and OLS estimators are consistent in an input distance function. The input distance function measures how much inputs could be reduced at frontier production for a firm rather than how much additional output could be produced using the firm's level of input factors. If producers maximize revenue, then inputs are exogenous. Kumbhakar (2012) shows that OLS estimates in either input or output distance functions are inconsistent if producers maximize return on investment because both inputs and outputs are endogenous.

The regression model for SFA is:

$$Ln(Y_i) = \beta_0 + \beta_1 \ln(l_i) + \beta_2 \ln(k_i) + \beta_3 \ln(m_i) + \beta_4 \ln(el_i) + \beta_5 \ln(en_i) + (\mu_i + v_i) \quad (9)$$

where variable names are the same as in equation (8). The error term ε in OLS regression equation (7) is divided in SFA regression into a stochastic component of υ_i and an inefficiency component of μ_i.

While the OLS estimators of inputs are consistent, the intercept term in the production function is downward biased because of inefficiency (Kumbhakar, Wang, and Horncastle 2015). The intercept in OLS measures actual output rather than output at the frontier. The bias in the intercept is contained in the μ_i portion of the error term. The bias in intercept is estimated from the unobserved portion of error using variables that measure the sources of inefficiency (Kumbhakar and Lovell 2000). In this study, the measures of inefficiency consist of the frequency and duration of electrical outages calculated from Enterprise Survey observations.

The first step in an SFA analysis is to test for the presence of inefficiency in the observations. The Likelihood Ratio test provides the tool for determining whether the SFA model provides a better explanation of the data than OLS regression (Kumbhakar, Wang, and Horncastle 2015). The differences in likelihood from the OLS and SFA equations are tested using the LR test. If the difference is statistically significant, the SFA equation provides a better explanation of production than the OLS equation.

The distribution of inefficiency is unknown in advance of the estimation of the SFA model by maximum likelihood. If inefficiency is present, it can exhibit half-normal, truncated normal, or exponential distributions (Kumbhakar, Wang, and Horncastle 2015). The exponential distribution is the appropriate model if most firms cluster near the PPF because the mode of the exponential distribution is zero (Kumbhakar, Wang and Horncastle 2015). The half-normal distribution "is a non-negative truncation of a zero-mean normal distribution (Kumbhakar, Wang, and Horncastle 2015, 59) where all z-scores in the distribution are positive." The half-normal model has the variance of a normal distribution before truncation with a mean of zero: $N^+ (0, \sigma_u{}^2)$. The truncated normal distribution has a mean above zero, indicating that most firms operate away from the PPF. The half-normal model is a restricted version of the truncated normal model with a mean of zero.

Good practice entails estimating the truncated model prior to the half-normal to ensure that the mean of the distribution is above zero (Kumbhakar, Wang, and Horncastle 2015). The statistical significance of the mean of the inefficiency term in the truncated model is tested against the null hypothesis that the mean of the distribution is zero. If mean in the truncated model are statistically significant, it is the preferred model for analysis because it explains more of the variance in the data (Kumbhakar, Wang, and Horncastle 2015). LR tests of the models with different error distributions to determine the model for SFA analysis with the best explanatory power (Kumbhakar, Wang, and Horncastle 2015). For the research questions in the dissertation, the average level of inefficiency for firms experiencing outages can be tested against firms that did not report outages using a t-test of means.

Research Questions and Hypotheses

Because electrical outages are random and unpredictable, firms cannot form rational expectations about power availability and therefore cannot allocate labor efficiently. The level of uncertainty varies with the frequency and duration of outages. The effects of electrical outages therefore are measurable in output per worker. The relationship between per capita income (output/person) and output per worker is shown in equation (10) below:

$$Y \div P = (Y \div E) \times (E \div P) \tag{10}$$

where Y = output, E= employment, P = population, Y/P = per capita income, and Y/E= output per worker.

Electricity outages can impact per capita income by reducing output/worker (Y/E), or by changing the labor force participation rate (E/P). Even if worker overtime restores lost output, labor productivity per hour declines as a result of outages.

The effects of electrical outages are most accurately measured on an output per worker hour basis. While the World Bank ES provides data for average hours of operation per week and numbers of workers the aggregate number of hours is not available. Continuous process industries that operate 24 hours per day divide the workforce into shifts so that the aggregate number of hours per firm cannot be calculated from the average hours of operation per week. The International Labor Organization has data on the length of workweek in OECD countries, but does not have data for most of the LDCs in this study. The most accurate series, therefore, are the per worker series.

The literature indicates that the economic effects of outages are non-linear. Beenstock, Goldin, and Haitovsky (1997) find that economic losses from outages in Israel are quadratic with a u-shaped distribution. Sullivan, Vardell, and Johnson (1997) find a non-linear inverse relationship between length of outage and economic losses in North Carolina.

Sullivan, Vardell, and Johnson (1997) demonstrate that firms with generators do not curtail operations while firms without backup power curtail operations and rarely extend hours to recover production. The effects of electricity outages are hypothesized to be different for firms with and without standby generators. For firms lacking standby power (about 2/3 of the ES observations), outages diminish the marginal revenue product while increasing labor costs per unit of output because firms compensate employees for both idle time waiting for power and for productive time. Firms with standby generators avoid the increases in labor costs and diminishment of marginal revenue product but increase their non-electricity energy costs (substitution of higher cost electricity generated onsite), reducing their TFP. Since the effects are mutually exclusive, they can be measured using dummy variables for generator ownership. The effects of electricity shortages for firms that own generators are captured within the production function while the effects for firms that lack a generator are captured in both firm-level total factor productivity (loss of MRP) plus in the production function (increases in unit labor costs from idle labor).

The section below presents the five research questions in this dissertation, the theory forming them, and the model specifications for testing them.

Research Question One: The degree that electrical outages constrain industrial production in LDCs

Theory

Since per capita income is directly related to per worker output in manufacturing, electricity outage reduce per capita incomes if they decrease manufacturing output per worker or if they decrease TFP though the misallocation of resources used for standby power generation. Adenikinju (2003) demonstrates that firms in Nigeria respond to electrical outages by buying standby generators, reducing output, and choosing products that are not energy intensive, all of which are claimed to misallocate resources in Nigeria. Since private infrastructure provision constitutes 15 percent of total machinery and equipment costs for large firms and 25 percent for small firms, the impacts are substantial (Adenikinju 2003). Reinikka and Svensson (2002) develop a model for measuring the impacts of electrical shortages on capital investment in manufacturing using production theory. They demonstrate, using firm level data, that private investment in generators crowds out private investment in manufacturing production in Uganda. Because the marginal cost of producing electricity using (small) private generators is triple the marginal cost of grid power, the production point for profit maximizing firms with generators shifts inward when operating on backup power. Reinikka and Svensson (2002) provide a methodology for measuring this effect and test it empirically in Uganda.

The challenge in testing this research question is in measuring potential GDP. Stochastic Frontier Analysis (SFA) provides an econometric method of consistently measuring the difference between potential and actual output at the level of a firm.

The intercept in the OLS model is downward biased when the firms operates below the PPF (Kumbhakar, Wang, and Horncastle 2015). An unbiased estimator can be obtained using SFA. If potential output is defined as output by the most efficient producer (the firm having the highest positive residual), the efficiency of individual firms can be measured by subtracting its regression residual from the largest positive residual (Kumbhakar and Lovell 2000). The statistical relationship between these adjusted residuals and the level of power outages measures the difference between potential output and actual output due to outages. Potential GDP therefore is the difference between potential and actual output per firm multiplied by the number of firms.

Hypothesis HA1a

Electricity outages reduce TFP and output per worker for firms without access to their own generation. SFA provides a method of comparing potential and actual output or the level of output-oriented technical inefficiency. The interaction term of labor cost times the binary variable equal to 1 if firm lacks a standby generator (Labor*NoGen) measures how output per worker shifts from labor inputs between firms with and without generators. If the coefficient of the interaction term is negative and statistically different from zero, output per worker is lower t for firms without generators (Kumbhakar Wang, and Horncastle 2015). The SFA Regression Equation to test TFP reduction and labor increase from outages:

(11)

$$Ln(y_i) = \beta_0 + \beta_1 \ln + \beta_2 \ln + \beta_3 \ln(el_i) + \beta_4 \ln(en_i) + \beta_5 \ln(l_i) + \beta_6 \ln(Labor * NoGen_i) + C + (v_i + u_i \,|Outages)$$

where the production function variables are the same as equation (9), Labor*NoGen is an interaction term between labor and NOGEN (dummy variable=1 if no generator), C a vector of control variables, ν_i is idiosyncratic error and (μ_i | Outages) is output oriented technical inefficiency due to outages. The μ_i term measures the error in the intercept, hence is a measure of the bias in TFP from inefficiency. Empirical research suggests that the μ_i term is quadratic in form. Quadratic error term implies the presence of heteroscedasticity so that tests of inference require the use of robust standard errors.

The production function variables in the equation are normalized by dividing all inputs by labor input so that the inputs become numeraires of labor. According to Kumbhakar (2012) the normalization reduces the endogeneity from multiple inputs to the numeraire input.

Specific hypotheses: H_{0A}: $\beta_6 = 0$, $\mu_i = 0$ where $\mu_i = f$ (outage + outage^2)

H_{1a}: $\beta_6 > 0$, $\mu_i > 0$

Hypothesis HA1b.

Electricity outages increase the energy content of firm output for firms with generators. Standby power provides electricity to run production machinery when grid electricity is unavailable, but it costs much more to generate standby power than grid power because of a) economies of scale in grid generation and b) fuel inefficiency of standby generators. The cost per kilowatt hour for standby power can be more than triple the cost of grid power.

Firms with standby power therefore have higher costs for total energy (sum of electricity+ fuels to generate electricity) than companies that lack generators. Energy comprises, on average, seven percent of production costs for the manufacturing firms in the sample while electricity comprises about four percent of production cost. The increase in output from standby power is offset partially by an increase in the cost of energy inputs into production.

If the increased energy content in output is strongly correlated with the level of outages, this provides evidence of a misallocation of energy resources due to electricity shortages. Because energy content of output can also vary with the level of capital and labor inputs, the relationship must be tested in a *ceteris paribus* fashion. A dummy variable for generator ownership will measure how much energy content varies between companies owning generators and those lacking them. The equation for measuring misallocation of process energy:

(12)

$$Ln(En/worker_i) = \beta_0 + \beta_1 \ln(k_i) + \beta_2 \ln(m_i) + \beta_5 \, ln(l_i) + \beta_6 Gen_i + C + \varepsilon$$

where En/Worker= (electricity+other energy)/output per worker, k, m, and l are as defined in equation (9) and Gen is a dummy variable=1 if a firm owns a generator, C is a vector of control variables and ε is the error term.

$H_{A}o$: B_6=0

H_{A1}: B_6 >0

Research Question Two: The degree that the electric supply industry constrains industrial exports in LDCs

Theory

Production function models of previous studies treat LDCs as autarkic. If LDCs export their manufacturing production, their inability to supply international customers due to power outages reduces export earnings, which restricts the country's ability to finance imports. The diminishment of international competitiveness from power outages therefore has an impact on per capita incomes not captured in previous studies.

Shifts from domestic to export markets can also be the result of shifts in relative prices. Relative prices are not available in the ES data set. The hypothesized relationship can be tested without the influence of relative price changes using pooled cross sectional regression models, if one assumes that relative prices do not shift in the short-term of a year. This assumption implies that exchange rates are relatively stable over the course of 12 months.

Hypothesis HA2

Increases in the aggregate length of electrical shortages decreases the ratio of exports to value added by the firm. Value added consists of outputs minus inputs. Because of missing data, the sample of observations for calculated value-added is half of the larger sample (n=28101). The equation combines production inputs into a value-added term to reduce the number of variables subject to endogeneity. The pooled cross-section regression equation is:

(13)

$$\ln(ye_i) = \beta_0 + \beta_2 \ln + \beta_{10} \ln((NOGENERATOR_i * Outage_i) + \beta_{11} \ln(NOGENERATOR_i * Outage^2) + Gravj + C + \varepsilon_i$$

where inputs are identical to equation (9). Value added is the sum of inputs. The interaction term NOGENERATOROUTAGE (Dummy variable for backup generator ownership x measures of aggregate electrical outages) measures the change in value added from outages. Production per worker y has been divided into domestic production (d) and export production (e). $Grav_j$ is the index of the gravity model for each country applied to each firm in the sample, C is a vector of control variables and ε_i is the error term.

Specific hypotheses: H_{0A2}: $\beta_{10} = 0$,

H_{OA2B}:$\beta_{11} = 0$;

H_{AA2}: $\beta_{10} < 0$,

H_{AA2B}:$\beta_{11} \neq 0$

β_{10} measures the partial effect of aggregate electrical outages on export production at the average ratio of export production.

Research Question Three: The degree that aggregate electrical outages substitute imported intermediate materials for domestic intermediate materials

Theory.

Research indicates that the United States, after the OPEC embargo, offset a significant share of its direct energy imports by substituting imports of intermediate materials (OTA 1990). The economic response to price increase caused by embargo was that imports of energy shifted from direct to indirect forms while output per worker declined in domestic industries supplying intermediate goods. Because the U.S. had price controls on domestic energy production during the period, shortages of energy for power and heat constrained domestic production of intermediate materials. Constraints on the supply of direct energy supplies due to price controls explain the substitution of imported intermediate materials.

This research question claims that shortages of domestic intermediates due to aggregate power outages results in a substitution of imported intermediates in production. The claim is supported by production theory since imported intermediates are a direct substitute for domestic intermediates. The diminishment of output in intermediate materials industries from power outages should have an impact on per capita incomes not captured in previous studies. A shift from domestic to imported intermediates decreases the net exports component of GDP which lowers GDP per worker.

Shifts from domestic to imported materials can also be the result of shifts in relative prices. Relative prices of materials are not available in the ES data set. If one assumes that relative prices do not shift in the short-term of a year, the hypothesized relationship can be tested with a pooled cross sectional regression model without noise from relative price changes.

Hypothesis HA3

Increases in aggregate electricity shortages reduce the domestic intermediate inputs. The pooled cross-section regression equation is:

(14)

$$\ln(MD_i) = \beta_0 + \beta_1 \ln(l_i) + \beta_2 \ln(k_i) + \beta_4 \ln(el_i) + \beta_5 \ln(en_i) + \beta_{10} \ln(Outages_i) + \beta_{11} \ln[(Outages_i^2)] + Grav_j + C + \varepsilon$$

where inputs are identical to equation (9) with the new dependent variable of ln (MDi), ln of imported intermediates per worker, $Grav_j$ is an index of trade for country j, **C** is a vector of control variables and ε_i is the error term in the model.

Specific hypotheses: H_{03A}: $\beta_{10} = 0$,

H_{O3B} : $\beta_{11} = 0$;

H_{A3A}: $\beta_{10} \neq 0$,

H_{A3B}: $\beta_{11} \neq 0$

Research Question Four: The degree that the electric supply industry constrains total investment levels in LDC manufacturing and reallocates investment flows from production equipment to power generation equipment

Theory

Previous studies support the Schurr and Netschert (1960) hypothesis that capital investment and electricity are used as a bundle and that a significant share of the TFP growth in the developed world since electrification has come from the use of electrically driven equipment. Shortages of electricity are claimed to reduce the incentives for capital investment in manufacturing in LDCs since the productivity enhancements of such investments are zero when electric power is not available. The incentive to invest in new machinery and equipment is therefore inversely related to the frequency and duration of power outages.

The data for testing this hypothesis is available from the Enterprise Survey program under the heading of "investment in plant and equipment during the prior fiscal year." The total investment is subdivided into: a) buildings and land, and b) machinery, equipment, and vehicles.

The testing of this research question is complicated by the presence of standby generators in firms. Firms that owned their own generator throughout the panel years and those that lacked a generator during the study period would exhibit different investment levels. Firms that switched from exclusive grid power to generator ownership between the study periods are claimed to have increased their investment levels. If investment levels are statistically different for those owning and not owning generations and have accelerated for those that bought standby generation, this provides evidence to confirm the hypothesis that outages reduce investment levels overall while misallocating investment away from production equipment to power generation equipment.

Investment levels are influenced by interest rates, the capacity utilization in the industry, sales growth, prices of industrial equipment, and foreign direct investment levels. These independent variables must be added to an investment equation to eliminate any bias in the estimate of investment levels due to changes in electricity outages. Country-level variables for interest rates, equipment prices and FDI levels are reported by the IMF in their International Financial Statistics (IMF 2016).

Investment levels are not uniform by year. The rate of change of investment should therefore be calculated as the change in total assets per worker in time periods t and t-1.

Hypothesis HA4a

Investment levels in machinery and equipment and total capital investment are higher for firms with generators.

Hypothesis HA4b

Investment levels in machinery and equipment and total capital investment increase when firms acquire standby power. The pooled cross sectional regression to test H_{A4A} is:

(15)

$$INVEST_i = \beta_0 + \beta_{12} INTEREST\%_j + \beta_{13} CAPTUIL_i + \beta_{14} \Delta Y_{I,t-t-1} + \beta_{15} P_{capj} + \beta_{15} P_{capj} + \beta_{16} FDI_j + \beta_{17} NOGENERATOR_i + \beta_{18} OUTAGE_i + C + \varepsilon$$

where $INVEST_i$ is investment per worker by firm I, $INTEREST\%_j$ is real lending interest rate in country j, $CAPTUIL_i$ is the capacity utilization of firm I calculated from ES data, $\Delta Y_{I,t-t-1}$ is the change in output of firm $_I$ over the last three years calculated from ES data. Variables PCap is an index of industrial equipment prices for country j, FDI is an index of inward foreign direct investment for country j, **C** is a vector of control variables and ε is the error term in the regression equation.

Specific hypotheses: H_{04AA}: $\beta_{17} = 0$

H_{O4BB}: $\beta_{18} = 0$

H_{A4AA}: $\beta_{17} < 0$,

H_{A4AB}: $\beta_{18} > 0$

The Panel (Fixed and Random Effects) Regression Equations to test H_{A4B} is:

(16)

$$\Delta INVEST_{i,t1-t0} = \beta_0 + \beta_{12} INTEREST\%_{i,t1-t0} + \Delta\beta_{13}\, CAPTUIL_{i,t1-t0} + \beta_{14}\, \Delta Y_{i,t1-t0} + \beta_{15}\, \Delta Pcap_j + \beta_{16}\, \Delta\, FDI_j + \beta_{18}\, \Delta\, NOGENERATOR_{i,t1-t0} + \beta_{19}\, GENERATOR_{it} + \beta_{20}\, \Delta\, OUTAGE_i + C + \varepsilon$$

where Δ INVEST $_{i,\ t1\text{-}t0}$ is the change in book value per employee between panel years, INTEREST% $_j$ is the real lending interest rate in country j, $\Delta\beta_{13}$CAPTUIL$_i$ is the change of capacity utilization of firm $_I$ between panel years, ΔPcap$_j$ is change in industrial equipment prices between panel years in country j, ΔFDI$_j$ is change in inward FDI investment in country j between panel years, ΔNOGENERATOR$_i$ is a dummy variable=1 if firm $_I$ acquired a generator between panel years, 0 otherwise, GENERATOR$_i$ is a dummy variable for firms with backup generators in both panel years, and ΔOUTAGE$_i$ is the change in outages experienced by firm i between panel years, C is a vector of control variables and ε is the error term for firm $_I$ in the regression equation.

Specific hypotheses: H_{04BA}: $\beta_{18} = 0$;

H_{04BB}:$\beta_{19} = 0$

H_{A4BA}:$\beta_{18} > 0$,

HA4BB: $\beta_{19} > 0$

Research Question Five: How the ownership and regulation of the transmission and distribution infrastructure affects the macroeconomic performance of manufacturing in African and Latin America LDCs

The data for ownership of transmission and distribution infrastructure is not in the Enterprise Survey data but can be assembled from Platts UDI International Electric Power Sourcebook (Platts 2014), World Bank, and regional development banks' reports.

Theory

Empirical evidence demonstrates that the efficiency of electricity generation does not vary significantly with ownership of assets (Chan, Cropper, and Malik 2014). State-owned companies and private firms using the same-age of equipment with identical heat rates are similar in the fuel efficiency of power generation (Chan, Cropper, and Malik 2014). The empirical evidence also demonstrates that the differentials in efficiency of power distribution are dramatically different between countries. Combined losses in transmission and distribution are typically in the range of 6 percent in the OECD countries but vary from 6 to 56 percent in Latin America and the Caribbean (Jimenez, Serebrisky, and Mercado 2014). Variation is even higher in Africa (Eberhard et al. 2011). The claim in this research question is that the lack of reliability of electricity distribution (frequency and duration of outages) and of lost output in manufacturing are directly related to the ownership of the transmission and distribution infrastructure.

According to Rao (2016) the appropriate procedure is the stochastic frontier production function. The Stochastic Frontier Model Regression Equation is:

(17)

$$Ln(Y_i) = \beta_0 + \beta_1 \ln(l_i) + \beta_2 \ln(k_i) + \beta_3 \ln(m_i) + \beta_4 \ln(el_i) + \beta_5 \ln(en_i) + (\mu_i | Outages + v_i)$$

where inputs are defined as in equation (9) with μ_i= inefficiency error term conditioned on outages and v_i= idiosyncratic error term.

The inefficiency error is conditioned on outages. The technical efficiency index for each firm (TE_i) can be calculated after the above equation is estimated. TE_i is used as the dependent variable in a second equation with country dummy variables for generation and distribution system ownership and colonial origin to test Hypothesis H_{A5}:

Hypothesis HA5

Technical efficiency of manufacturing production and aggregate electricity outages are directly influenced by the ownership structure of electric generation and distribution. The second stage regression equation to test the hypothesis is:

(18)

$$TE_i = \beta_0 + \beta_{21}OUTAGE_i + \beta_{23}DISTRIBUTION_j + \beta_{24}TRANS_j + \beta_{25} - \beta_{29}\left(COLONY_j\right) + C + \epsilon$$

where OUTAGE is a measure of outages experienced by firm i, **C** is a vector of control variables, DISTRIBUTION is a dummy variable for government ownership of electric distribution assets in Country j and TRANSj is a dummy variable for government ownership of transmission assets in country j, $COLONY_j$ is a series of dummy variables for colonization by Britain, France, Spain, Holland and Ottoman Empire.

Specific hypotheses: H_{05A}: $\beta_{21=0,}$

H_{05B}: $\beta_{23=0,}$

H_{05C}: $\beta_{24}=0$;

H_{A5A}: $\beta_{21} < 0$

H_{A5B}: $\beta_{22} < 0$,

H_{A5C}: $\beta_{23} < 0$;

H_{05B}: $\beta_{25}=0$, $\beta_{26}=0$, $\beta_{27}=0$, $\beta_{28}=0$, $\beta_{29}=0$;

H_A: At least one of coefficients is different from zero.

CHAPTER IV—RESULTS

Firm-level production functions for manufacturing in the underdeveloped world have not been constructed prior to the ES survey program due to the absence of data. While the production functions for hypothesis testing in this dissertation examine per worker inputs and outputs, the chapter begins with an examination of firm-level production. According to development theory, differences in human capital explain differences in productivity per worker and wages (Todaro and Smith 2011). A comparison of firm-level and per worker variables provides evidence of whether differences in human capital explain differences in wages and productivity. Variations in wages could also be due to institutional constraints, which will make the marginal revenue products of output and output/worker differ. The analysis will in fact show that marginal revenue products of inputs differ between firm-output and output/worker.

Stochastic Frontier Analysis

Stochastic Frontier Analysis (SFA) provides a tool for measuring inefficiency in manufacturing production. Estimates of production functions by OLS or IV regression assume that firms operate on the production possibilities frontier (PPF). Firms efficiently use production inputs to maximize profits or to minimize costs (Varian 2010). SFA assumes that individual firms may operate below the PPF for a host of reasons. SFA provides a means of measuring the level of inefficiency at the firm level. The first step in an SFA analysis is to test for the presence of inefficiency in the observations. The Likelihood Ratio test determines whether the SFA model provides a better explanation of the data than OLS regression (Kumbhakar, Wang, and Horncastle 2015).

If inefficiency is present, it can exhibit half-normal, truncated normal or exponential distributions. Likelihood Ratio (LR) tests shown in column (d) demonstrate that all versions of the SFA model provide statistically significant improvements over OLS estimation at the 0.001 level (See Table 6). The null hypothesis of no inefficiency in the data is rejected. The LR ratio tests for the half-normal and truncated-normal distribution shown in column (c) are identical because the mean of the truncated normal distribution is not statistically different from zero. Coelli (1995) shows that the test of the inefficiency term in SFA has a mixture of chi-square distributions. Kodde and Palm's (1986) critical values for a one-tailed mixed chi-square test, shown for the degrees of freedom in column (e) are in column (f). The degrees of freedom for the truncated normal distribution are larger because of the additional test of the distributional mean. The log-likelihoods and chi-square values for the half-normal and truncated-normal distributions are equal. The distributions are equal when the mean of inefficiency is not greater than zero. The exponential error model provides the best distribution for modeling the inefficiency term based on differences in the LR tests of the various models.

Table 6

Likelihood Ratio Test of SFA Inefficiency Distributions

Model	(a) Dist. of Inefficiency	(b) N	(c) Log Likelihood	(d) Chi-square	(e) Df	(f) critical p =.001
OLS		24643	-29386	0	0	
SFA	Exponential	24629	-29278	216.2	1	9.5
SFA	Half-normal	24629	-29292	188.2	1	9.5
SFA	Truncated-N	24629	-29292	188.2	2	12.81

Comparisons of OLS and SFA estimates of firm-level Productivity

The terms “firm-level TFP” and “firm-level productivity” are used interchangeably in the literature (See Olley and Pakes 1996 and Gal 2013). Both terms measure the ratio of firm-level output to firm-level inputs. The term “firm-level TFP” is used in this dissertation to measure the ratio of output to aggregate inputs at the firm level.

The coefficients of the SFA production inputs, estimated by maximum likelihood, are within 0.1 percent of the OLS coefficients (See Table 7). The coefficients for the OLS model are shown in column (a) with the robust standard errors of the OLS model shown in column (b). Stars in column (b) represent the three levels of significance shown in the table notes. The coefficients for the SFA model are shown in column (c) with the robust standard error and level of significance for SFA model shown in column (d). The returns-to-scale for the OLS model is 0.9885 while the returns-to-scale for the SFA model is 0.9889. The constant term in the SFA model is statistically greater than the constant in the OLS model (Z=2.98; P=0.0014) confirming the presence of a downward bias in the OLS estimate for TFP. The difference in constant terms is not statistically significant in the presence of dummy variables for region, year, and sector, which also shift the constant term.

The SFA model includes four statistics that measure the inefficiency error (u) and the idiosyncratic error (v). Each of the error variance functions has a constant term plus coefficients for each of the variables in the error function. The error functions in Table 7 only have constant terms, however. The U-sigma term shown in Table 7 is the variance of the inefficiency error term. U-sigma is the exponent of an exponential function: exp (-

u). The sigma-u statistic is the standard deviation of the inefficiency error term and also is the measure of inefficiency in the model. Sigma-u is the square root of the level value of U-sigma and is a measure of inefficiency in the model. V-sigma is the variance of the idiosyncratic error function and sigma-v is the standard deviation of the idiosyncratic error function. The Sigma-u coefficient indicates that the OLS equation underestimates TFP at the production frontier by 14.0 percent (significant at the 0.0001 level). The average efficiency of firms in the sample is 86.0 percent of the frontier level.

Because of the large sample of nearly 23,000 firms, the standard errors of variables are small. Since the Breusch Pagan test of constant variance is rejected at the 0.0001 level, tests of inference are based on the robust standard errors. A likelihood ratio test of the SFA model over OLS estimation (LR= 78.8, with mixed chi-square (1) at 0.01 level =5.412) is significant at the less than 0.01 level (Kumbhakar, Wang, and Horncastle 2015). The mixed chi-square distribution is the average of chi-square with zero degrees of freedom and chi-square with one degree of freedom (Coelli 1995). Since inefficiency errors in the SFA model are non-negative, the null hypothesis for the LR test is a one-way test rather than the conventional two-way test. Coelli (1995) demonstrates with Monte Carlo simulation that the mixed chi-square distribution provides a better distribution for inference testing in SFA because of the boundary property of the test statistic. The SFA model explains more of the variance in the data than the OLS model.

A fixed effects regression model is used to control for unobserved heterogeneity due to differences in geography, survey year and industry sector. Categorical variables for country are not jointly significant ($F_{92,124}$ =0.1396) at the 0.10 level. Categorical variables for time period are jointly significant at the 0.001 level (Chi-square(8)= 32.22).

Categorical variables for sector are jointly significant at the 0.001 level (Chi-square (10)=12.9), Categorical variables for World Bank region (Chi-square (7)=11.14) are jointly significant at the 0.001 level.

The control variable for firm size is significant at the 0.001 level. The firm-level production exhibits a significant economy of size. Large firms are more efficient than small firms.

Table 7

Comparison of Firm-Level OLS and SFA Production Functions

	OLS Model		SFA model	
Variable	(a) B	(b) RSE(B) p	(c) B	(d) RSE(B) p
ln of labor cost	0.3628	0.0091***	0.3634	0.0091***
ln of depreciation	0.0406	0.0033***	0.0414	0.0033***
ln of material cost	0.4221	0.0071***	0.4210	0.0071***
ln of electricity cost	0.0960	0.0048***	0.0960	0.0048***
ln of non-electricity fuel cost	0.0670	0.0043***	0.0671	0.0043***
ln of employment	0.1110	0.0080***	0.1122	0.0080***
Africa	-0.0737	0.0303	-0.0734	0.0292
East Asia & Pacific	-0.1726	0.0386	-0.1743	0.0365***
East & Central Europe	-0.0255	0.0331**	-0.0277	0.0328**
Latin America & Caribbean	-0.0243	0.0333**	-0.0230	0.0239
Middle East & North Africa	-0.1122	0.0353	-0.1153	0.0353
South Asia	-0.2010	0.0322**	-0.1978	0.0368***
High Income-Non OECD Countries	-0.0954	0.0355	-0.0965	0.0295***
Surveyed in 2006	-0.1013	0.0463	-0.0971	0.0351**
Surveyed in 2007	-0.2022	0.0441***	-0.2012	0.033***
Surveyed in 2008	-0.0347	0.0497	-0.0260	0.0497
Surveyed in 2009	-0.0267	0.0433	-0.0216	0.0341
Surveyed in 2010	-0.2132	0.0463***	-0.2113	0.0334***
Surveyed in 2011	0.1780	0.0508***	0.1821	0.0361***
Surveyed in 2012	0.0153	0.0504	0.0193	0.0407
Surveyed in 2013	0.0138	0.0446	0.0236	0.0258
Textile Sector	-0.1654	0.1419	-0.1654	0.1429
Garment Sector	-0.1322	0.1418	-0.1338	0.1428
Food Sector	-0.0789	0.1417	-0.0782	0.1427

Table 7 (continued).

	OLS Model		SFA model	
Variable	(a) B	(b) RSE(B) p	(c) B	(d) RSE(B) p
Metals and machinery sector	-0.0478	0.1415	-0.0474	0.1424
Electronics sector	-0.0027	0.1437	-0.0018	0.1447
Chemicals and pharma sector	0.0271	0.1419	0.0284	0.1428
Wood and furniture sector	-0.1443	0.1439	-0.1411	0.1446
Non-metallic and plastic mat. Sector	-0.1217	0.1416	-0.1190	0.1425
Auto and auto parts sector	-0.0488	0.1457	-0.0495	0.1468
Other manufacturing sector	-0.1455	0.1418	-0.1460	0.1428
constant or TFP	3.4890	0.1530***	3.6254	0.1628***
U-sigma constant			-3.922	0.4301***
V-sigma constant			-0.7102	0.0352***
sigma-u			0.1407	0.0303***
sigma-v			0.7011	0.0124***

Note: *p < 0.05, **p<0.01, ***p<0.001, two-tailed tests. Bruesch-Pagan test of heteroscedasticity of the OLS model was significant at the .0001, with Chi-square(1) of 683.5. Number of observations in both OLS and SFA equations is 22,887. R^2 of OLS equation is .9094. F(31, 22,855) of 6,817.3 Log likelihood of OLS equation with Wald Chi-square (30) of 200,483. Log likelihood of SFA equation is -24,855. The likelihood ratio Chi-square (½) is 108.0, indicating that the SFA equation explains more of the variance at the .001 level of significance.

Categorical variables are binary variables that shift the intercept or firm-level TFP term up or down from the base region, sector and period. The binary variables are important for generalizing the data across regions, years, and sectors.

The High-Income OECD countries have TFP that averages 10 percent above the High-Income non-OECD countries. The lowest TFP occurs in South Asia, which is 20 percent below the High-Income OECD countries.

The ES survey responses are recorded over eight years. The controls for year of survey are important since they shift the intercept as much as 39 percent. The control variables for sector also exhibit a range of 17 percent in TFP, with chemicals and pharmaceuticals having the highest TFP and 'Other manufacturing' the lowest.

Marginal Revenue Product of Inputs at Firm-Level

Marginal product is a measure of the amount of output contributed by the last unit of each factor input. Marginal revenue product (MRP) is marginal product expressed in revenue generated by the sale of the last unit of output. In this study marginal revenue product is expressed in dollars of output per dollar of factor input because the survey data collects information on factor costs in currency units.

In microeconomic theory, the MRP of each factor should be equal, since profit maximizers and cost minimizers will substitute cheaper factors for more expensive factors until the MRPs are equal (Varian 2010). This assumption is true only if factors are perfect substitutes. Stern (2003) argues that substitutability is limited in the case of energy. Berndt (1978), Jorgenson (1984) and Waverman (1984) find that electricity is a complement rather than substitute for capital. Schurr, Sonenblum, and Wood (1983) find that electricity is at best a partial substitute for other factors, including other forms of energy. Duggal, Saltzman and Klein (1999) argue that electricity and other infrastructure violates marginal productivity theory since its unit cost is not market determined. The electricity literature indicates that electricity is at best an imperfect substitute for other factors. The recent literature, such as Duggal, Saltzman, and Klein indicate that one expects differences in MRP between electricity and other factors in empirical studies. MRP measures the relative contribution of each factor input on a firm's output. It, therefore, is a measure of the importance of a factor input in a firm's technology.

The formula for computing marginal revenue product of a Cobb-Douglas production function is (Beattie, Taylor, and Watts 2009):

(19)

$$MRP_i = \frac{\partial Y}{\partial x_i} = \beta_i \times \frac{Y}{x_i}$$

Note: where MRP_i = marginal revenue product of factor input i, β_i = C-D regression coefficient for factor i, Y=output and x_i= input i

Marginal revenue product is equal to the partial derivative of output with respect to the factor input. It is calculated empirically by multiplying the regression coefficient from the natural logarithm form of the C-D equation by the output/factor input ratio.

As can be seen from the formula, MRP approaches infinity as the output/factor input ratio approaches zero, resulting in a highly skewed distribution. The median of the distribution and the truncated mean of MRP are better measures of central tendency than the distributional mean. The truncated mean is calculated by eliminating the bottom and top five percent of the distribution. The number of observations in the distribution is shown in column (a) of Table 8 while the number in the truncated distribution is shown in column (d). The truncated mean in column (e) is more than 10,000 times smaller than the mean for the sample shown in column (c) (See Table 8). The truncated means for the 90 percent of observations outside of the distribution tails are approximately twice the median value, suggesting a negative skew in the data. The truncated standard deviation shown in column (g) provides data for inference testing of differences in means. The confidence interval for the truncated mean is shown in column (f). The confidence intervals are within a narrow band of plus or minus 1.5 percent.

Table 8

Median, Means, and Truncated Means of Firm-Level MRP

MRP of:	(a) Obs	(b) Median	(c) Mean	(d) Obs	(e) Truncated Mean*	(f) Confidence interval (95%)	(g) Trun. S.D.*
Labor	29830	2.22	48767	27177	3.41	3.37-3.45	3.20
Capital	30201	1.52	8234	25929	3.38	3.33-3.44	4.78
Materials	28919	1.00	29264	26294	1.57	1.54-1.59	1.35
Electricity	29143	6.00	1288	26294	10.71	10.56-10.87	12.32
Fuel	23897	5.36	31831	21504	11.07	10.87-11.26	14.48

The median of MRP for electricity is higher than the median MRP of the other factor inputs (See Table 8). Half of the firms in the sample produce more than $6 of output for every $1 of electricity and half produce less than $6.00. The truncated means of the MRP of labor and capital are equal. The MRP of materials is lower than the means of labor and capital and the differences are significant at the 0.0001 level based on a difference of mean test with Welch's degrees of freedom and a standard error based on the pooled variance (t=89.95 with 36807 df; P=.0001). The mean MRP of electricity and fuels are significantly larger than the mean MRP of labor and capital (t=-80.08 with 25950 df; P=.0000), reinforcing the findings of Duggal, Saltzman, and Klein (1999). Shortages of electricity and fuels have more pronounced influences on output than shortages of capital or labor. The mean MRP of electricity by sector ranges from $8.65 in non-metallic and plastic materials to $13.93 in chemicals and pharmaceuticals (Table 9).

Table 9

Truncated Mean of Marginal Revenue Product of Inputs by Sector

Sector	(a) Obs.	(b) Labor	(c) Capital	(d) Mat.	(e) Elect.	(f) Fuels
Textiles	2,253	3.38	2.86	1.44	9.28	12.28
Leather	304	2.99	5.01	1.15	13.09	15.03
Garments	3,334	2.6	3.8	1.65	10.71	12.09
Food	5,479	3.72	3.18	1.51	10.22	9.00
Metals and Machinery	4,546	3.44	3.63	1.4	10.97	11.76
Electronics	848	3.98	3.97	1.42	11.58	13.86
Chemicals and Pharmaceuticals	2,498	3.8	3.58	1.44	13.93	12.92
Wood and Furniture	961	2.96	3.2	1.48	10.85	11.89
Non-metallic and Plastic Materials	2,940	3.65	2.81	1.54	8.65	9.68
Auto and Auto Components	524	4.35	3.52	1.32	9.03	14.01
Other Manufacturing	3,222	2.81	3.41	1.46	10.75	10.28

The mean MRP of inputs varies significantly from the share of inputs in production, with labor and materials representing a much higher proportion of output costs and energy a much lower proportion. (The mean share of labor in output is 16 percent, the median share of capital is 2.2 percent, the median share of materials is 40 percent, the median share of electricity is 1.67 percent, and the median share of fuels is 1 percent).

Per Worker Equations

The OLS and SFA models in output/worker exhibit returns to scale (RTS) of 0.95 rather than 0.RTS of 0.99 at the firm level (See Table 10). The coefficients for the OLS model with output/worker are shown in column (a) with the robust standard errors and levels of significance shown in column (b). The significance level is indicated by stars (*=.05 **=.01 and ***= 0.001 level). The coefficients, robust standard errors and significance levels of the SFA equation are shown in columns (c) and (d). The model with dependent variable of output/worker explains significantly less of the variance in the survey data than the model with dependent variable of firm output (R^2 of 0.91 versus R^2 of 81 percent). The average inefficiency for the firm-level and per worker level SFA models, however, does not differ. Firms, on average, operate at 86 percent efficiency, or 14 percent below the production frontier, whether measured at firm or per worker levels.

The differences in returns to scale between firm-level and worker-level models are from different coefficients on the labor, capital, and electricity inputs (See Table 11). The coefficients for the OLS and SFA models are shown in columns (a) and (c) with the robust standard errors and significance levels shown in columns (b) and (d). The differences for labor and capital are statistically significant at the 0.01 level using a Z test of the equality of regression coefficients (Brame et al. 1998 in Paternoster, Mazerolle and Piquero 1998). The test uses the pooled variance (Naghshpour 2012) to calculate standard errors. The differences in coefficients for materials, electricity, fuels, and the constant term are not statistically significant at the 0.10 level. The differential in economies of size is lower when measured on a per-worker level at the 0.01 level.

Table 10

Comparison of OLS and SFA Models

	OLS Model		SFA model	
Variable	(a) B	(b) RSE(B) p	(c) B	(d) RSE(B) p
ln of labor cost	0.3061	0.0057***	0.3057	0.0057***
ln of depreciation	0.0772	0.0038***	0.0783	0.0038***
ln of material cost	0.4142	0.0071***	0.4130	0.0071***
ln of electricity cost	0.0847	0.0050***	0.0847	0.0050***
ln of non-electricity fuel cost	0.0651	0.0043***	0.0652	0.0043***
ln of employment	0.0602	0.0042***	0.0609	0.0042***
Africa	-0.0777	0.0290**	-0.0775	0.0290**
East Asia & Pacific	-0.1894	0.0360***	-0.1913	0.0360***
East & Central Europe	-0.0404	0.0325	-0.0428	0.0325
Latin America & Caribbean	-0.0378	0.0237	-0.0367	0.0237
Middle East & North Africa	-0.1332	0.0353***	-0.1364	0.0353***
South Asia	-0.2150	0.0377***	-0.2118	0.0377***
High Income-Non OECD Countries	-0.1093	0.0291***	-0.1104	0.0291***
Surveyed in 2006	-0.1103	0.036**	-0.1059	0.036**
Surveyed in 2007	-0.1315	0.0347***	-0.1296	0.0347***
Surveyed in 2008	-0.0508	0.0504	-0.0423	0.0498
Surveyed in 2009	-0.0328	0.0353	-0.0278	0.0344

Table 10 (continued).

	OLS Model		SFA model	
Variable	(a) B	(b) RSE(B) p	(c) B	(d) RSE(B) p
Surveyed in 2010	-0.2128	0.0346***	-0.2107	0.0346***
Surveyed in 2011	0.1433	0.0370***	0.1471	0.0370***
Surveyed in 2012	0.0237	0.0415	0.0280	0.0409
Surveyed in 2013	-0.0113	0.0283	-0.0019	0.0261
Textile Sector	-0.1682	0.1418	-0.1682	0.1426
Garment Sector	-0.1154	0.1417	-0.1169	0.1426
Food Sector	-0.0707	0.1415	-0.0702	0.1424
Metals and machinery sector	-0.0507	0.1413	-0.0504	0.1422
Electronics sector	-0.0076	0.1436	-0.0068	0.1445
Chemicals and pharma sector	0.0245	0.1417	0.0256	0.1426
Wood and furniture sector	-0.1543	0.1438	-0.1512	0.1444
Non-metallic and plastic mat. Sector	-0.1179	0.1415	-0.1153	0.1423
Auto and auto parts sector	-0.0479	0.1456	-0.0486	0.1466
Other manufacturing sector	-0.1410	0.1417	-0.1415	0.1426
constant or TFP	3.5288	0.1584***	3.6666	0.1631***
U-sigma constant			-3.9074	0.4481***

Table 10 (continued).

	OLS Model		SFA model	
Variable	(a) B	(b) RSE(B) p	(c) B	(d) RSE(B) p
V-sigma constant			-.6752	0.0343***
sigma-u			0.1417	0.0317***
sigma-v			0.7135	0.0122***
N	22887		22887	

Note: Breusch-Pagan test for heteroscedasticity of the OLS model was significant at the .00001 level with Chi-square(1) of 2313.71. Dependent variable of natural logarithm of output/worker. Number of observations=22,887. R^2 of OLS equation of .8175. OLS equation is significant at .00001 level with F(31,22855) of 2218.2. SFA equation is significant at .0001 level with Wald(30) Chi-square of 67918.5. Log likelihood of OLS equation of -25,296.1 with log likelihood of SFA equation of -25,245.1.

Table 11

Z-tests of Differences in Firm-Level and Worker-Level Coefficients

	Firm-Level		Per worker-level			
Variable	(a) Beta	(b) SE	(c) Beta	(d) SE	(e) Pooled SE	(f) Z
Labor	0.3628	0.0091	0.3061	0.0057	0.011	5.28
Depreciation	0.0406	0.0033	0.0772	0.0038	0.005	-7.27
Materials	0.4221	0.0071	0.4142	0.0071	0.010	0.79
Electricity	0.096	0.0048	0.0847	0.005	0.007	1.63
Fuel	0.067	0.0043	0.0651	0.0043	0.006	0.31
ln Emp.	0.111	0.008	0.0602	0.0042	0.009	5.62
Constant OLS	3.489	0.1531	3.5288	0.1584	0.220	-0.18
Constant SFA	3.6254	0.1628	3.666	0.1631	0.230	-0.18

Note: t-test uses the average of SE of the two models, since the cases and number of obs. Are identical in each model

Labor costs constitute a higher share of output in advanced countries. A plausible explanation of the differences in the coefficients for labor inputs is that wage differentials between regions reflect more than differences in human capital. Regions with higher wages do not exhibit proportionally higher rates of labor productivity. Differentials between regions are smaller when measured in per-worker output. This is a research question that bears further investigation.

Marginal Revenue Product of Inputs at Per Worker Levels

Marginal revenue product of inputs measured at per worker levels exhibit a stronger influence on output of capital and a weaker influence of labor (Table 12). Column (a) of Table 12 includes the median and truncated mean of the MRP of labor. The mean figure is enclosed in parentheses. Column (b) through column (e) contain the corresponding statistics for capital, materials, electricity and fuels. Electricity and fuels have the highest marginal influence on output of any of the inputs. Every $1 of electricity on average produces $10 of output at the margin. The median MRP of electricity varies from $3.56 in non-metallic and plastic materials to $7.62 in chemicals and pharmaceuticals. The average MRP of electricity varies from $7.90 in on-metallic and plastic materials to $12.66 in chemicals and pharmaceuticals.

Table 12

Median Marginal Revenue Product of Inputs at Per Worker Levels

	Median (truncated mean) Marginal Revenue Product				
Sector	(a) Labor	(b) Capital	(c) Materials	(d) Electricity	(e) Fuels
ALL	1.9 (2.92)	2.9 (6.44)	1.05(1.53)	5.08 (9.78)	4.99 (11.04)
Textiles	1.83 (2.86)	2.44 (5.45)	1.04 (1.47)	3.91 (8.42)	5.88 (12.2)
Leather	1.52 (2.52)	3.92 (9.53)	0.86 (1.13)	6.07 (11.62)	6.51 (14.6)
Garments	1.33 (2.38)	3.44 (7.23)	1.24 (1.68)	5.55 (10.1)	5.81 (12.13)

Table 12 (continued).

	Median (truncated mean) Marginal Revenue Product				
Sector	(a) Labor	(b) Capital	(c) Materials	(d) Electricity	(e) Fuels
Food	2.16 (3.23)	2.74 (6.07)	1.04 (1.53)	4.80 (9.46)	3.62 (9.1)
Metals and machinery	2.04 (2.95)	3.18 (6.9)	1.04 (1.47)	5.29 (9.99)	5.73 (11.73)
Electronics	2.38 (3.38)	3.59 (7.55)	0.93 (1.51)	5.65 (10.63)	7.60 (13.58)
Chemicals and pharmaceuticals	2.25 (3.24)	3.36 (6.82)	1.01 (1.46)	7.62 (12.66)	6.51 (12.85)
Wood and furniture	1.60 (2.49)	2.65 (6.07)	1.10 (1.49)	5.36 (9.79)	5.21 (11.76)
Non-metallic and plastic materials	2.10 (3.09)	2.39 (5.34)	1.05 (1.64)	3.56 (7.9)	3.80 (9.67)
Auto and auto components	2.55 (3.67)	3.10 (6.7)	0.95 (1.51)	4.24 (8.19)	7.32 (13.78)
Other manufacturing	1.53 (2.44)	2.91 (6.49)	1.04 (1.46)	5.65 (9.87)	4.78 (10.33)

Inference tests confirm that the differences between firm and worker levels of the truncated means of the marginal revenue products of labor, capital, electricity, and materials are statistically significant at the 0.001 level (See Table 12). The number of observations is shown in column (a), the truncated means of the firm level in column (b), the truncated means of the worker level in column (c), the pooled standard error in column (d), the t statistics in column (e) and the probability of the t test in column (f). The marginal revenue product of labor is larger at the worker level while the MRP of labor, materials, and electricity are lower (See Table 13). The median difference in MRP of materials is not statistically significant at conventional levels.

Table 13

Test of Differences of Truncated Means for MRP at Firm and Worker Levels

MRP	(a) Obs	Truncated mean (b) Firm	(c) Worker	(d) SE	(e) T	(f) P
Labor	29811	3.38	2.92	0.0245	18.73	0.00001
Capital	30182	3.38	6.44	0.059	-51.76	0.0001
Materials	26194	1.48	1.53	0.0118	-4.22	0.00001
Electricity	29125	10.64	9.78	0.102	8.41	0.0001
Fuel	23884	11.04	11.04	0.1299	0.00	1.00000

Research Question One: The degree that electrical outages constrain industrial production in LDCs

Inefficiency is recognized widely in the engineering and management literature as a constraint on manufacturing production. Production theory in economics, however, assumes that producers efficiently allocate inputs to maximize profits and therefore operate on the production possibilities frontier at equilibrium (Varian 2010). The exclusion of intermediate inputs from production theory eliminates the supply chain disruptions that provide inefficiencies in practice in manufacturing production. The claim in this dissertation is that disruptions in manufacturing production due to electrical outages and shortages are significant sources of inefficiency in manufacturing in LDCs. A further claim is that electrical outages decrease the net export component of GDP in LDCs by shifting supply chain choices of manufacturers.

Electrical Outages in LDCs

The frequency of outages varies substantially by region (See Appendix B) with firms in Africa, Middle East, North Africa, and South Asia experiencing 22-75 times the outages reported in the high income countries in the sample. The duration of losses in hours also varies significantly, with Africa and the Middle East experiencing average outages that are 404 hours per year, which is 12-14 times as long as those in high-income countries.

The pattern differs substantially when responses are rated by output level rather than by frequency. The estimated loss of output in aggregate is 1.5 percent. The average weighted by sales is lower in all regions except for Africa. The losses from electrical outages are clearly moderated by the prevalence of standby generators. One-third of firms in the sample own generators with a much higher percentage of ownership in Africa and South Asia than elsewhere (Appendix Table B.2). Firms report that 6.1 percent of their power is self-generated. The value, weighed by output, is 2.1 percent, which is 10 fold higher than for firms in the OECD countries. The weighted figures by region range from 0.13 percent in East & Central Asia (ECA) to 13.5 percent in Africa, more than 50 times the figure for the OECD countries in the sample.

Inefficiency in manufacturing production due to electrical outages

SFA estimates the sources as well as the level of inefficiency for every observation in a sample. The regression model for estimating the production frontier using SFA is:

$$Ln(Y_i) = \beta_0 + \beta_1 \ln(l_i) + \beta_2 \ln(k_i) + \beta_3 \ln(m_i) + \beta_4 \ln(el_i) + \beta_5 \ln(en_i) + (\mu_i + v_i) \quad (20)$$

Note: where production inputs are l=labor/worker, k=depreciation/worker, m=materials/worker, el=electricity/worker and en=energy, other than electricity, per worker. Y is output per worker. The subscript of i represents firm i in the sample. 0. The error term ε in the equation is divided into a stochastic component of υ_i and a technical inefficiency component of μ_i.

Output-oriented technical inefficiency (lost output below the PPF) is calculated from the inefficiency portion of the error term (Kumbhakar, Wang, and Horncastle 2015):

(21)

$$\ln(y_i) = lny_i^* - u_i \text{ where } lny_i^* = f(\boldsymbol{x_i};\, \boldsymbol{\beta}) + v_i$$

The u_i term is a firm-level measure of inefficiency. The negative exponential form is a firm-level measure of efficiency: exp $(-u_i)$.

Jondrow et al. (1982) derive a formula for calculating the technical inefficiency of each observation in the sample using the expected value of u_i conditional on the composed error of the model: $E(u_i|\varepsilon_i)$) (in KWH 2015). Battese and Coelli (1988) derive a formula for calculating the technical efficiency of each observation using the expected value of the exponential value of $-u_i$ conditional on the composed error of the model: $E(\exp(-u_i|\varepsilon_i))$ (in KWH 2015). The Jondrow et al. (1982) and Battese and Coelli (1988) indices measure the observation-specific output-oriented technical efficiency and inefficiency of industrial production in this dissertation.

The classic SFA model assumes homoscedasticity in both the idiosyncratic and inefficiency error terms (Kumbhakar and Lovell 2000). Heteroscedasticity in the idiosyncratic error still provides consistent estimates of the frontier function parameters. The intercept term, however, exhibits a downward bias (Kumbhakar, Wang, and Horncastle 2015). Heteroscedasticity in the inefficiency error term of u_i, however, causes bias in both the frontier function parameters and the technical inefficiency term. Caudill and Ford (1993); Caudill, Ford, and Gropper (1995); and Hadri (1999) introduce adjustments, using exogenous determinants of heteroscedasticity that provide consistent estimates of frontier parameters and inefficiency under the condition of heteroscedasticity (in Kumbhakar, Wang, and Horncastle 2015). The marginal effects of each of the variables determining heteroscedasticity measure the partial effects of the variable on inefficiency.

The marginal effect of a variable [k] on inefficiency $E(u_i)$ that is exponentially distributed is:

(22)

$$\frac{\partial E(u_i)}{\partial z[k]} = {}^{1}\!/_{2}\, \delta[k] \exp(\frac{1}{2} z_i \delta)$$

Note: δ is the coefficient of k estimated by maximum likelihood, z is the observation-specific value of the exogenous variable determining heteroscedasticity

Both the idiosyncratic and inefficiency error in the SFA equation demonstrate statistically significant levels of heteroscedasticity from differences in firm size, as measured by the natural logarithm of firm employment (See Table 14). Column (a) of Table 14 shows the coefficients in the SFA model, column (b) shows the robust standard errors, column (c) shows the two test statistics and column (d) is the significance level of the two tests. The coefficient of variable LLabwk, the numeraire of the factor inputs, is also the return to scale. The coefficient of labor is 0.2985, calculated by subtracting the coefficients for the other factor inputs from the numeraire. Size of firm is both an exogenous determinant of inefficiency and an endogenous determinant of efficiency. The average firm in the sample has an employment of 36 employees (lsize=3.58). Firms with 98 employees (lsize=4.58) generate output/worker that is 9.2 percent above the average size firm. Firms that are 1 standard deviation above the mean size (natural logarithm of 4.997 or anti-log of 148 employees) produce output/worker that is 13 percent above the average size firm. The response of firm size to inefficiency is even more pronounced. The marginal effects of size on inefficiency, calculated from the marginal effects formula

$\partial E(u_i)/\partial z[k]$, is 19.6 percent lower inefficiency when moving from average size (36 employees) to 98 employees.

The variables measuring natural logarithm of annual hours of electrical outages and the square of natural logarithm of annual hours of electrical outages are individually insignificant at the 0.05 level but jointly significant at the 0.001 level (Chi-square(2)=25.72, p value less than 0.0001). Electrical outages are an exogenous determinant of firm inefficiency and exhibit a quadratic relationship with inefficiency, in conformance with the findings reported by Beenstock, Goldin, and Haitovsky (1997) in Israel and by Sullivan, Vardell, and Johnson (1997) in the United States.

Table 14

Test of Electrical Outages on Inefficiency in LDC Manufacturing

Variable Name	(a) Coef.	(b) Robust SE	(c) z	(d) P>z
ln of labor cost	0.9462	0.0063	244.09	0.000
ln of depreciation	0.0810	0.0039	29.32	0.000
ln of material cost	0.4175	0.0075	101.98	0.000
ln of electricity cost	0.0830	0.0054	19.61	0.000
ln of non-electricity fuel cost	0.0662	0.0047	17.76	0.000
ln of employment	0.0921	0.0077	16.03	0.000
Africa	-0.0785	0.0347	-2.67	0.008
East Asia & Pacific	-0.1941	0.0409	-5.47	0.000
East & Central Europe	-0.0495	0.0362	-1.54	0.122
Latin America & Caribbean	-0.0302	0.0270	-1.17	0.243
Middle East & North Africa	-0.1273	0.0417	-3.64	0.000
South Asia	-0.2043	0.0470	-5.41	0.000
High Income-Non OECD Countries	-0.1205	0.0342	-3.5	0.000
Surveyed in 2006	-0.0875	0.0433	-2.37	0.018
Surveyed in 2007	-0.1102	0.0410	-3.16	0.002
Surveyed in 2008	-0.0130	0.0557	-0.3	0.766
Surveyed in 2009	-0.0212	0.0416	-0.61	0.544
Surveyed in 2010	-0.2098	0.0423	-5.56	0.000
Surveyed in 2011	0.1696	0.0413	4.71	0.000
Surveyed in 2012	0.0397	0.0493	0.87	0.387
Surveyed in 2013	0.0110	0.0301	0.39	0.694
Textile Sector	-0.2158	0.1608	-1.83	0.067
Garment Sector	-0.1621	0.1608	-1.38	0.167
Food Sector	-0.1184	0.1608	-1.01	0.311
Metals and machinery sector	-0.0899	0.1606	-0.77	0.442
Electronics sector	-0.0615	0.1631	-0.51	0.61
Chemicals and pharma sector	-0.0296	0.1610	-0.25	0.801
Wood and furniture sector	-0.1935	0.1625	-1.62	0.105
Non-metallic and plastic mat. Sector	-0.1582	0.1606	-1.35	0.178
Auto and auto parts	-0.0896	0.1653	-0.73	0.464

Table 14 (continued).

Variable Name	(a) Coef.	(b) Robust SE	(c) z	(d) P>z
Other manufacturing sector	-0.1889	0.1608	-1.61	0.108
ln Aggregate annual outages	0.3634	0.2006	3.69	0.000
square of ln Agg. Ann. Outates	-0.0341	0.0356	-2.58	0.01
ln of employment	0.5206	0.1023	6.39	0.000
constant	-6.9935	0.8089	-13.32	0.000
Idiosyncratic error				
ln of employment	0.0537	0.0227	7.32	0.000
constant	-0.8543	0.0901	-29.54	0.000

Note: Equation included 20,519 observations. Wald Chi-square(31) of 84348.7 is significant at .0001 level.

The expected effect of outages on inefficiency, or lost output, can be calculated for each observation using the coefficients for each variable in the inefficiency term and the values of observations for each producer.

The average efficiency level of firms, in the sample, weighted by output, is 0.9215 and the average inefficiency level is 0.0906, with a large standard deviation (See Table 15). The weighted average is much lower than the unweighted average of 14.6 percent.

Table 15

Indices of Average Levels of Output-oriented Efficiency and Inefficiency

Index	(a) Observations	(b) Mean	(c) Std. Deviation
Battese-Coelli eff.	20472	0.9215	0.0657
Jondrow ineff.	20472	0.0907	0.0930

Note: Statistics are weighted by output/firm

The average level of efficiency, weighted by output level, varies significantly by region (See Table 16). Column (a) of Table 16 is the number of observations in the region, column (b) is the mean of the efficiency index, column (c) is the standard deviation of the inefficiency index, column (d) is the median efficiency of each region and column (e) is the standard error of the mean. The highest levels of efficiency are in East and Central Asia and the lowest in East Asia and the Pacific.

The Jondrow et al. (1982) index of inefficiency demonstrates a similar pattern (See Table 17). The column headings are identical to those in Table 16.

Table 16

Average Efficiency by Region

Region	(a) Obs.	(b) Mean	(c) Std. Dev	(d) Median	(e) SE Mean
Africa	4,698	0.913	0.061	0.953	0.001
East Asia & Pacific	1,616	0.843	0.093	0.869	0.002
East & Central Asia	2,118	0.953	0.020	0.956	0.000
Latin America & Caribbean	4,810	0.855	0.082	0.877	0.001
Middle East& North Africa	1,562	0.854	0.055	0.864	0.001
South Asia Region	3,747	0.861	0.049	0.867	0.001
High income: OECD	1,061	0.880	0.051	0.886	0.002
High income: nonOECD	907	0.876	0.045	0.881	0.002

Note: Statistics are weighted by output/firm

Table 17

Average Inefficiency by Region

Region	(a) Obs.	(b) Mean	(c) Std. Dev	(d) Median	(e) SE Mean
Africa	4,698	0.100	0.080	0.050	0.001
East Asia & Pacific	1,616	0.197	0.146	0.151	0.004
East & Central Asia	2,118	0.050	0.026	0.046	0.001
Latin America & Caribbean	4,810	0.178	0.126	0.140	0.002
Middle East& North Africa	1,562	0.173	0.080	0.156	0.002
South Asia Region	3,747	0.164	0.071	0.153	0.001
High income: OECD	1,061	0.139	0.067	0.128	0.002
High income: nonOECD	907	0.144	0.062	0.135	0.002

Note: Statistics are weighted by output/firm

The percent of output by region lost from electrical outages is a significant share of inefficiency in the less developed regions (See Table 18). The column headings are identical to those in Table 16. The mean percent of inefficiency from outages, shown in column (b), is 9 percent across regions. The percent is highest in Africa at 48 percent and lowest in the High-Income Non-OECD countries at 8.5 percent. The high percentages in Africa, Middle East, and South Asia reinforce the Likert-scale ratings of the severity of electricity as an obstacle to business operations reported in the ES survey. More than half of firms in Africa and the MENA regions rated electricity supply as a major or severe obstacle to operations while 45 percent assigned the same ratings in South Asia.

Table 18

Mean Technical Inefficiency Due to Electrical Outages by Region

Region	(a) Freq.	(b) Mean	(c) Median	(d) Std. Dev.	(e) SE | mean
Africa	4,697	0.483	0.533	0.278	0.004
East Asia & Pacific	1,615	0.209	0.000	0.323	0.008
East & Central Asia	2,107	0.211	0.000	0.294	0.006
Latin America & Caribbean	4,792	0.165	0.000	0.257	0.004
Middle East& North Africa	1,560	0.274	0.178	0.295	0.008
South Asia Region	3,747	0.358	0.454	0.294	0.005
High income: OECD	1,057	0.142	0.000	0.242	0.007
High income: nonOECD	897	0.085	0.000	0.186	0.006
Total	20,472	0.091	0.045	0.093	0.001

Note: Statistics are weighted by output/firm

Effects of Generator Ownership on Productivity of Labor

Electrical outages are hypothesized to affect industrial production differently for firms with standby power and those without standby power. For firms without generators, the hypothesized effects are increased labor costs plus reduced TFP. An interaction term of Labor*NoGen (labor cost x dummy variable=1 if firm lacks a generator) captures this effect. For firms with generators, the hypothesized effects are increased amounts of process energy in production. Process energy is the combination of electricity and non-electric fuels consumption.

The equation below tests whether firms lacking generators use more labor in production than firms with generators:

(23)

$$\ln(y_i) = \beta_0 + \beta_1 \ln(k_i) + \beta_2 \ln(m_i) + \beta_3 \ln(el_i) + \beta_4 \ln(en_i) + \beta_5 \ln(l_i) + \beta_6 \ln(Labor * NoGen_i) + C + (v_i + u_i \mid Outages)$$

Note: production function inputs are the same as equation (9), Labor*NoGen is an interaction term of labor & NOGEN (dummy variable=1 if no generator), C a vector of control variables, ν_i is idiosyncratic error and (μ_i | Outages) is output oriented technical inefficiency due to outages. The μ_i term measures the error in the intercept, hence is a measure of the bias in TFP from inefficiency.

If the interaction term is negative and significantly different from zero, firms lacking generators produce less output per dollar of labor, *ceteris paribus,* than firms with generators.

We reject the null hypothesis of no difference in labor content at the 0.0001 level (See Table 19). Column (a) of Table 19 are the SFA regression coefficients, column (b) the robust standard error, column (c) the z-test statistics, and column (d) the significance level of the z-test. The sign of the interaction term (Labor*NoGen) is negative. Firms lacking generators on average have a return to labor that is 0.6 percent less than firms with generators. Firms with generators have a return on labor of 0.302. The differential in returns represents a 2 percent increase in labor costs per unit of output for firms lacking generators.

The null hypothesis of no difference in inefficiency from outages is also rejected at the 0.001 level of significance. The natural logarithm of aggregate annual hours of outages and its square are jointly significant at the 0.001 level (Chi-square (2)=29.19; p=0.00001). The relationship between outages and inefficiency is quadratic with a u-shaped distribution. The marginal effect of outages decreases until 458 hours, after which the marginal effects increase. The effect at the mean of 270 hours is an increase in inefficiency of 1.192 percent. The effect at +1 standard deviation changes slightly to 1.189 percent.

Table 19

SFA Model Testing Increased Labor by Generator Ownership

Variable	(a) Coef.	(b) Robust SE.	(c) z	(d) P>z
ln of labor cost	0.302*	0.007*	45.66*	0.000
ln of depreciation	0.082	0.004	21.03	0.000
ln of material cost	0.416	0.007	55.67	0.000
ln of electricity cost	0.083	0.005	15.25	0.000
ln of non-electricity fuel cost	0.065	0.005	13.91	0.000
ln of employment	0.091	0.007	11.73	0.000
Interaction Labor*NoGen	-0.006	0.001	-5.04	0.000
Africa	-0.089	0.035	-2.58	0.010
East Asia & Pacific	-0.204	0.041	-4.96	0.000
East & Central Europe	-0.047	0.036	-1.29	0.198
Latin America & Caribbean	-0.023	0.027	-0.85	0.397
Middle East & North Africa	-0.130	0.042	-3.07	0.002
South Asia	-0.222	0.047	-4.73	0.000
High Income-Non OECD Countries	-0.116	0.034	-3.37	0.001
Surveyed in 2006	-0.082	0.043	-1.88	0.059
Surveyed in 2007	-0.106	0.041	-2.57	0.010
Surveyed in 2008	0.007	0.056	0.12	0.907
Surveyed in 2009	-0.009	0.042	-0.21	0.830
Surveyed in 2010	-0.207	0.042	-4.87	0.000
Surveyed in 2011	0.161	0.041	3.89	0.000
Surveyed in 2012	0.064	0.049	1.29	0.198

Table 19 (continued).

Variable	(e) Coef.	(f) Robust SE.	(g) z	(h) P>z
Surveyed in 2013	0.019	0.030	0.64	0.524
Textile Sector	-0.208	0.160	-1.30	0.194
Garment Sector	-0.157	0.160	-0.98	0.326
Food Sector	-0.120	0.160	-0.75	0.452
Metals and machinery sector	-0.087	0.160	-0.55	0.585
Electronics sector	-0.063	0.162	-0.39	0.697
Chemicals and pharma sector	-0.029	0.160	-0.18	0.855
Wood and furniture sector	-0.197	0.162	-1.22	0.222
Non-metallic and plastic mat.	-0.158	0.160	-0.99	0.324
Auto and auto parts sector	-0.095	0.165	-0.58	0.562
Other manufacturing sector	-0.186	0.160	-1.16	0.244
constant or TFP	3.573	0.179	19.93	0.000
U-sigma (inefficiency)				
ln of annual hours of el. Outages	0.391	0.226	1.73	0.084
Square of ln of annual hours of outage	-0.032	0.039	-0.81	0.418
Constant of inefficiency	-7.305	0.764	-9.56	0.000
V-Sigma				
ln of Employment	0.054	0.023	2.36	0.018
constant	-0.854	0.090	-9.51	0.000
Inefficiency level (Avg)	0.139			
variance of idiosyncratic error	0.719			

Test of Misallocation of Process Energy

The fuel efficiency of self-generation is low compared to grid power due to economies of scale in electricity generation. Significant amounts of self-generation of power in LDC manufacturing should result in excess consumption of process energy. The pattern of energy consumption should therefore vary between companies that own their own generators and those that rely solely on grid power. Companies relying on grid power will have lower energy consumption.

Two variables in the Enterprise Surveys capture the effects of non-grid power generation on firm productivity: 1) percent of electricity generated in-house by firms (NOGRID); and 2) An indicator variable that identifies firms with standby generators (GEN). The interval scaled variable of NOGRID is preferred in the hypothesis test to the binary variable of GEN.

The model is estimated with instrumental variables to control for the correlation between independent variables and the error term. The simultaneity bias is handled by adding output/worker to the right hand side of the equation and transforming the remaining independent variables into a numeraire format with labor/worker as the denominator (Kumbhakar, Wang, and Horncastle 2015). Labor/worker is the single endogenous variable in the equation. The dependent variable in the equation is energy/worker.

(24)

$$lnEnerWorker = NoGrid + lsize + Nlabor + NlMat + LNKdepworker + C + \varepsilon$$

H_{oA}: B_6=0 H_{1A}: B_6 >0

Note: lnEnerWorker= natural logarithm of energy (fuels+ electricity) per worker; NoGrid is the percent of a firm's power generated in-house, Nlabor= natural logarithm of numeraire of labor/worker; lsize= natural logarithm of firm employees; NlMat=numeraire of natural logarithm of materials per worker; LNKdepworker t= numeraire of natural logarithm depreciation/worker – natural logarithm labor/worker, ε is a stochastic error term

The variable for natural logarithm of employment size controls for economies of scale in self-generation. Larger generators use less energy per kilowatt-hour of generation than smaller-sized generators.

Due to the correlation between labor and the error term, the equation is tested in IV form with instruments of lage (natural logarithm of age of business) and natural logarithm of investment level in last fiscal year. While the coefficients between the IV and OLS models do not vary by more than 0.3 percent, the dissertation interprets the IV equation, which is the theoretically correct procedure.

The Hansen J statistic for the IV equation indicates that it is fully identified at the 0.01 level of significance. The Kleinbergen-Wald F statistic indicates that the independent variables are estimated with a 10 percent or less margin of error. The level of significance of the null hypothesis of full identification is marginal at conventional levels of inference. Because the observations are firm-level rather than aggregate, potential instruments are restricted to other survey questions. An examination of more than 30 potential instruments did not produce instruments with better identification properties.

Variable NoGrid (percent of electricity generated in-house by firm) is statistically different from 0 at the 0.0001 level (Table 20). The column headings of Table 20 are identical to those in Table 16. Every one percent increase in power generated internally, on average, increases energy/worker by 0.0034 percent. Firms in the sample, on average, generate 25 percent of their power in-house, so the average firm in the sample uses 0.1 percent more energy/worker than would be expected if outages are reduced to zero.

The efficiency of energy usage increases with firm size as expected due to economies of scale in generation. The median size firm has 30 employees (natural logarithm of 3.37). A firm with 79 employees (natural logarithm of 4.37) will use 4.7 percent less energy/worker than a firm with 30 employees.

These findings confirm the alternative hypothesis that firms that self-generate electricity have a higher energy content in output/worker, in monetary terms, than firms that have access to uninterrupted grid power. The regression estimates indicate that the differences are minor in practice.

The absence of electric price data in the survey does not allow a test of whether quantities of energy differ between firms with generators and those lacking them. The price of industrial electricity from the grid could be far above the cost of production of self-generated electricity in some countries because of substantial subsidies on diesel fuel used to generate electricity in-house (Kitson, Wooders, and Moerenhout 2011). The energy content of industrial output, on a quantity basis, could differ from these findings based on firm-level cost data.

Table 20

IV Equation Testing Differences in Energy Use by Generator Ownership

Variable	(a) Coef.	(b) Robust SE.	(c) z	(d) P
Numeraire of labor	0.9458	0.1133	8.34	0.000
Percent of power self-generated	0.0033	0.0006	5.02	0.000
Numeraire of materials	0.2463	0.0116	21.2	0.000
Numeraire of depreciation	0.1544	0.0158	9.74	0.000
ln of firm employment	-0.0477	0.0161	-2.96	0.003
Africa	-0.0573	0.1678	-0.34	0.733
East Asia & Pacific	0.2720	0.1873	1.45	0.147
East & Central Europe	0.3895	0.1396	2.79	0.005
Latin America & Caribbean	-0.0564	0.1432	-0.39	0.694
Middle East & North Africa	-0.1812	0.1396	-1.3	0.194
South Asia	-0.1134	0.2429	-0.47	0.64
High Income-Non OECD Countries	-0.0062	0.0679	-0.09	0.927
Surveyed in 2006	-0.4843	0.1534	-3.16	0.002
Surveyed in 2007	-0.7997	0.0643	-12.43	0.000
Surveyed in 2008	-0.6727	0.0756	-8.89	0.000
Surveyed in 2009	-0.3509	0.0874	-4.01	0.000
Surveyed in 2010	-0.3365	0.0550	-6.11	0.000
Surveyed in 2011	-0.3211	0.0559	-5.74	0.000
Surveyed in 2012	-0.2332	0.0651	-3.58	0.000
Surveyed in 2013	-0.2144	0.0742	-2.89	0.004
Textile Sector	0.1602	0.1393	1.15	0.25
Garment Sector	-0.0841	0.1353	-0.62	0.534
Food Sector	0.5014	0.1368	3.66	0.000
Metals and machinery sector	0.1388	0.1491	0.93	0.352
Electronics sector	0.0710	0.1572	0.45	0.651
Chemicals and pharma sector	0.0574	0.1497	0.38	0.701
Wood and furniture sector	-0.1430	0.1390	-1.03	0.303
Non-metallic and plastic mat. Sector	0.4887	0.1413	3.46	0.001
Auto and auto parts sector	0.1472	0.1570	0.94	0.348
Other manufacturing sector	0.1369	0.1385	0.99	0.323
_cons	-0.1984	0.9651	-0.21	0.837

Note: Dependent variable is in energy (fuels and electricity) per worker. Number of observations=25,535. Equation is significant at <.00001 level with F(30,25504) of 395.75. R^2 (centered)=.571. Variable in numeraire of labor is instrumented with natural logarithm of age of firm and natural log of investment by firm in last fiscal year. Hansen J-statistic of 3.939 has P-value of .0472, indicating instruments are orthogonal at .01 level. Kleibergen Paap rk LM statistic of 51.328 rejects null hypothesis of underidentification at .0001 level.

Research Question Two: The degree that electrical outages constrain industrial exports in LDCs

Production function models used in previous studies treat LDCs as autarkic. If LDCs export manufacturing products, their inability to supply international customers due to power outages reduces export earnings and diminishes the international competitiveness of LDCs.

The pooled cross-sectional equation for testing the influence of electrical outages on exports per worker is given below:

(25)

$$Ln(ye_i) = \beta_0 + \beta_2 \ln(k_i) + \beta_3 \ln(m_i) + \beta_4 \ln(elec_i) + \beta_5 \ln(fuel_i) + \beta_{10}(Gen) + \beta_{11} \ln(aggregate\ losses) + \beta_{12}(gravgdp) + C + \mu_i$$

Note: where Ye is export output per worker, k is capital per worker, m is intermediate materials per worker, elect=electricity per worker, fuel=non-electric energy per worker, Gen= a dummy variable=1 for firms with generators, aggregate losses are hours of electrical outages per year, gravgdp is a gravity model index for each of the countries in the model using GDP as the numerator and the square of distance between capital cities in export and import countries as the denomination. The gravity index is in natural logarithms. C is a vector of control variables and u is the error term in the equation. All variables except the intercept term are specific to firm i. The control variables in this equation consisted of dummy variables for the 11 manufacturing sectors in the sample.

The control variables in the model consist of a size parameter and dummy variables for manufacturing sector. The model coefficients cannot be estimated consistently with OLS due to correlation between the independent variables and the error term. The production function variables are converted to numeraires with exports/worker as the denominator in an endogeneity treatment advocated by Kumbhakar (2015). The subsequent IV equation estimated with the GMM method, using 5 excluded instruments, to produce consistent estimates at the 0.05 or less level, based on the Hansen J Statistic for the model (Table 21). The column headings in Table 21 are identical to those in Table 16. The Kleibergen-Paap Chi-square and Cragg-Donald Wald tests reject the nulls of under-identification and presence of weak instruments.

The number of observations in the equation is reduced by 50 percent due to the limited number of observations with all values for the instrumental variables. The tested sample of 10,650 observations is sufficiently large, however, to interpret the relationship.

The dummy variable for generator ownership is significant at the 0.0001 level (See Table 21). Firms with generators, when controlling for size, region, year, and sector, have exports per worker that are 0.3 percent less than firms lacking generators. A plausible explanation is that countries with frequent outages have fewer export-oriented firms than countries with more stable electrical systems.

Table 21

Test of Export/worker Shifts from Electrical Outages

	(a) Coef.	(b) Robust SE	(c) z	(d) P>z
ln of employment	0.6820	0.0498	13.7	0.000
gravity model based on GDP	-0.0004	0.0003	-1.16	0.246
ln of aggregate hours of annual outages	-0.0330	0.0221	-1.5	0.134
Square of ln of aggregate annual outages	-0.0039	0.0031	-1.24	0.215
Numeraire of ln domestic production/worker	0.2795	0.0234	11.96	0.000
Numeraire of ln labor/worker	-0.4314	0.0247	-17.49	0.000
Numeraire of ln depreciation/worker	-0.0459	0.0080	-5.71	0.000
Numeraire of ln materials/worker	0.0588	0.0181	3.25	0.001
Numeraire of ln fuel/worker	-0.0219	0.0174	-1.26	0.208
Numeraire of ln electricity/worker	-0.1045	0.0150	-6.97	0.000

Table 21 (continued).

	(a) Coef.	(b) Robust SE	(c) z	(d) P>z
Dummy variable for self-generation	-0.3093	0.0479	-6.46	0.000
Africa	-0.6583	0.1359	-4.84	0.000
East Asia & Pacific	-1.6381	0.1145	-14.31	0.000
East & Central Europe	-1.0860	0.1548	-7.01	0.000
Latin America & Caribbean	-0.8928	0.0546	-16.36	0.000
Middle East & North Africa	-1.3191	0.1825	-7.23	0.000
South Asia	-1.6244	0.2791	-5.82	0.000
High Income-Non OECD Countries	0.1621	0.1199	1.35	0.176
Surveyed in 2006	-0.9653	0.0578	-16.7	0.000
Surveyed in 2007	-0.2870	0.1207	-2.38	0.017
Surveyed in 2008	0.4156	0.2641	1.57	0.116
Surveyed in 2009	-0.1981	0.1033	-1.92	0.055
textile production	1.354	0.4246	3.19	0.001
garment production	1.075	0.4266	2.52	0.012
food production	1.097	0.4193	2.62	0.009
metals and machinery production	1.695	0.4230	4.01	0.000
electronics production	1.721	0.4316	3.99	0.000
chemicals and pharma production	1.531	0.4240	3.61	0.000
wood and furniture products	1.059	0.4311	2.46	0.014
non-metallic and plastic materials	1.455	0.4209	3.46	0.001
autos and auto parts	1.520	0.4742	3.21	0.001
other manufacturing	1.221	0.4244	2.88	0.004
Constant	4.870	0.5461	8.92	0.000

Note: Dependent variable is natural ln of exports/worker. Number of observations=9,948. Equation is significant at <.0001 level with F(32,9948) of 1840.6. Adjusted R^2=.8524. Variables ln of employment and gravity model are instrumented with a) percent firm owned by foreigners, b) output as % of capacity, c) ratio of foreign to domestic material, d) materials of domestic origin, e) average hours/week of operation, and f) percent of materials paid for before delivery. The Hansen J (Chi-square(4)) statistic of 9.39 rejects the null hypothesis of endogeneity at the 0.0519 level. Kleibergen Paap Chi-square (5) statistic of 514.3 rejects null hypothesis of underidentification at .001 level. Cragg-Donald Wald f of 103.9 rejects null hypothesis of weak instruments at <.0001 level.

Table 22

Contingency Test of Generator Ownership by Sector

	Generator		
Sector	(a) No	(b) Yes	(c) Obs
Textiles	69.6	30.4	4687
Leather	71.6	28.4	493
Garments	74.8	25.2	7040
Food	58.9	41.2	11,770
Metals and machinery	66.1	33.9	9,239
Electronics	52.8	47.2	1,668
Chemicals and pharmaceuticals	65.0	35.0	4,997
Wood and furniture	69.9	30.1	2,411
Non-metallic and plastic materials	63.1	36.9	6,539
Auto and auto components	46.6	53.4	1,007
Other manufacturing	75.0	25.0	6,316
Total	66.0	34.0	56,167

Note: Chi-square (10) of 1,100 is significant at .00001 level

Since the coefficient for generator ownership and for each of the sector dummies shifts the intercept term, the coefficients for generator ownership and sector could also offset each other if generator ownership varies by sector. Generator ownership varies from 25 percent in the garment sector to over 50 percent in autos and auto parts. A Chi-square contingency test of differences is significant at the 0.001 level, confirming the hypothesis (See Table 22). Column (a) shows the percent of sector companies lacking generators, column (b) the percent with generators, and column (c) the number of firms in the sector.

The variables for aggregate annual hours of electrical outages and for the square of annual outages are not individually significant at conventional levels but jointly significant at the 0.0001 level (Chi-square(2)=89.18, p value less than 0.00001). Because the relationship with the dependent variable is quadratic, the response depends on the level of outages (See Table 23). Column (a) shows the annual hours of outages, column (b) the statistical measure, column (c) the ln of the aggregate hours of outages, column (d) its square, and column (e) the response to the outage level in terms of the percent of exports/worker.

Table 23

Response of Exports/worker to Changes in Outages

(a) Ann hours	(b) Concept	(c) ln	(d) sq ln	(e) Ex/work(%)
0	Zero	0	0	0
270	Mean	5.598	31.342	-0.31
854	+1 SD	6.750	45.562	-0.40
1437	+2 SD	7.270	52.857	-0.45
2020	+3 SD	7.611	57.925	-0.48

Note: Electrical outages measured in annual hours

At the average level of outages in LDCs of 270 hours per year, the response is a decrease in exports/worker of 0.3 percent. The response increases continuously with the level of outages. At the upper end of the distribution, the response is 0.5 percent less exports/worker. The turning point in the quadratic function where the effects of outages increases is at 4729 hours per year, in the extreme right tail of the distribution. The response to outages, for all practical purposes, is that exports/worker continuously declines with increases in the hours of electrical outages.

Since exports per worker, unlike output per worker, is reflected directly in GDP through the net exports component, GDP from manufacturing exports declines directly with the level of electrical outages. Per capita GDP from manufacturing in LDCs is 0.3 percent less on average than is expected in the absence of electrical outages.

Research Question Three. The degree that aggregate electrical outages substitute imported intermediate materials for domestic intermediate materials

The claim in this question is that shortages of domestic intermediate goods due to aggregate power outages results in a substitution of imported intermediate goods in production. The claim is supported by production theory since imported intermediate goods are a direct substitute for domestic intermediate goods. A shift from domestic to imported intermediate goods decreases the net exports component of GDP.

Shifts from domestic to imported materials can also be the result of shifts in relative prices. Relative prices of materials are not available in the ES data set. If one assumes that relative prices do not shift in the short-term of a year, the hypothesized relationship can be tested with a pooled cross sectional regression model without noise from relative price changes.

Hypothesis HA3

Increases in aggregate electricity shortages reduce the ratio of domestically produce intermediate goods to imported intermediate goods. The tests of Hypothesis HA_3 use the natural logarithm of foreign materials per worker as the dependent variable. The model for the tests includes controls for size of company, a gravity model index to reflect trade differentials, and numeraires for the other production factors, with foreign materials as the denominator. The equations include variables for the natural logarithm of aggregate annual hours of outages and its square.

An IV regression provides consistent estimators when any of the independent variables and the error term in the equation are correlated. With instruments for the natural logarithm of size, the estimated equation is fully identified, based on the

Kleibergen-Paap LM statistic, Cragg-Donald Wald test and Hansen J Statistic (See Table 24). The column headings in Table 24 are identical to those in Table 16. The coefficients show a direct relationship between foreign materials and employment size of the firm. Bigger firms use more foreign materials than small firms. The estimated equation indicates a substitution effect with domestic materials (negative coefficient) although the coefficient is not statistically significant at conventional levels. The equation also indicates a substitution effect between foreign intermediate goods and labor, depreciation, and energy, each of which is statistically significant at the 0.0001 level.

The regional dummy variables measure the shift in regional use of foreign intermediates. The non-OECD high income countries in the sample are the base region in the model. The unrestricted model demonstrates significant regional variations in the use of foreign intermediate goods. The high-income OECD countries have the lowest consumption of foreign intermediate goods followed by the high-income non-OECD countries. South Asia firms, on average, use 72 percent more foreign intermediate goods than firms in the high-income OECD countries, followed by East Asia and the Pacific region.

The variable for natural logarithm of aggregate outages is individually insignificant but jointly significant with its square at the 0.001 level (Chi-square(2) =33.09; P value less P value less than 0.0001). Outages have a quadratic effect on the use of foreign intermediate goods, although the impact is of little practically significance at the mean level of outages in the sample (Table 25). The column headings of Table 25 are identical to those in Table 23, except that column (e) is the response in terms of percent of foreign materials/worker. The equation indicates that the effects on the GDP of less developed countries are statistically significant but practically insignificant.

Table 24

Test of Foreign Intermediate Materials

	(a) Coef.	(b) Robust SE	(c) z	(d) P>z
ln of employment	0.085	0.015	5.66	0.000
gravity model based on GDP	0.001	0.001	1.19	0.235
Numeraire of ln of output/worker	-0.555	0.009	-59.2	0.000
Numeraire of ln domestic materials/worker	-0.007	0.008	-0.86	0.387
Numeraire of ln labor/worker	-0.644	0.014	-46.84	0.000
Numeraire of ln depreciation/worker	-0.188	0.005	-34.94	0.000
Numeraire of ln energy/worker	-0.137	0.007	-20.03	0.000
ln of aggregate hours of annual outages	0.005	0.005	1.01	0.312
Square of ln of aggregate annual outages	-0.002	0.001	-2.98	0.003
Africa	-0.126	0.143	-0.88	0.379
East Asia & Pacific	-0.276	0.098	-2.82	0.005
East & Central Europe	-0.156	0.106	-1.47	0.141
Latin America & Caribbean	-0.339	0.065	-5.2	0.000
Middle East & North Africa	-0.204	0.045	-4.53	0.000
South Asia	-0.531	0.072	-7.38	0.000
High Income-Non OECD Countries	0.003	0.052	0.06	0.956
Surveyed in 2006	0.203	0.337	0.6	0.547
Surveyed in 2007	0.256	0.154	1.66	0.097
Surveyed in 2008	0.127	0.091	1.4	0.161
Surveyed in 2009	0.117	0.184	0.63	0.527
Surveyed in 2010	0.467	0.305	1.53	0.126
Surveyed in 2011	0.692	0.434	1.59	0.111
Surveyed in 2012	-0.190	0.089	-2.15	0.032
Surveyed in 2013	0.282	0.192	1.47	0.143
textile production	0.128	0.089	1.44	0.15
garment production	0.052	0.093	0.56	0.576
food production	0.104	0.115	0.91	0.365

Table 24 (continued).

	(a) Coef.	(b) Robust SE	(c) z	(d) P>z
metals and machinery production	0.127	0.088	1.45	0.148
electronics production	0.082	0.090	0.91	0.365
chemicals and pharma production	0.052	0.089	0.58	0.561
wood and furniture products	0.052	0.091	0.57	0.568
non-metallic and plastic materials	0.200	0.095	2.1	0.036
autos and auto parts	0.097	0.095	1.02	0.307
other manufacturing	0.193	0.117	1.64	0.1
Constant	-0.457	0.503	-0.91	0.364

Note: Dependent variable at natural ln of foreign intermediate materials per worker. Observations=20,718. Adjusted R^2=.9746. Equation is significant at <.0001 level with F(34,20763) of 24827.2. Variables ln of employment size and gravity index instrumented with a) ln age of business, b) ln investment by firm in prior year, and c) percent of foreign ownership in firm. The Hansen J Chi-square (4) of .071 rejects the null hypothesis of endogeneity at the .79 level. The Kleibergen-Paap Chi-square (5) of 42.91 rejects the null of underidentification at the .0001 level. The Cragg-Donald Wald F of 12.43 rejects the null hypothesis of weak instruments at the .0001 level.

Table 25

Distribution of Impact of Outages on Foreign Materials

(a) Ann hours	(b) Concept	(c) ln	(d) sq ln	(e) Foreign Mat%
0	Zero	0	0	0
270	Mean	5.598	31.342	-0.09
854	+1 SD	6.750	45.562	-0.12
1437	+2 SD	7.270	52.857	-0.14
2020	+3 SD	7.611	57.925	-0.15

Research Question Four: The degree that the electric supply industry constrains total investment levels in LDC manufacturing and reallocates investment flows from production equipment to power generation equipment

Investment in generators should in theory constrain investment in other production plants and machineries. Firms that allocate capital to generate electricity have less capital to invest in new plant and equipment. If firms operate at high utilization rates, constraints on production capacity could retard output per worker over time.

Schurr and Netschurt (1960), however, indicate that capital and electricity are used as a bundle since most new equipment is driven by electricity. Shortages of electricity reduce the incentives for capital investment in manufacturing since productivity enhancement is zero when electric power is not available. The incentive to invest in new machinery and equipment is therefore inversely related to the frequency and duration of outages.

The claim of this research is that distortions in investment caused by the purchase of a generator can be measured in LDC manufacturing. The hypothesis is that overall investment levels increase when firms own generators since they have more predictable output, implying that they have higher retained earnings to invest and a higher return on that investment.

As macroeconomic theory demonstrates, capital investment is affected by the level of interest rates, at least in developed countries (Dornbusch, Fischer and Startz 2008). A number of macroeconomic variables are needed to control for economic conditions that also affect investment levels in testing this hypothesis. Investment levels are conditioned on economic growth rates, since firms do not invest in new plant and equipment if markets are static or declining. The terms of trade, as measured in relative exchange rates, can also affect output for export.

A valid test of the hypothesis must recognize that absolute investment levels rise over time as firms accumulate capital. The level of investment in a firm will therefore on average be lower in an earlier time than in a later time. The size bias is reduced by measuring investment in per worker levels but not the bias due to capital accumulation. The dependent variable that contains the effects of capital accumulation and worker size is investment per worker as a percent of book value of capital per worker. Firms with more investment/worker than depreciation/worker are accumulating capital per worker. These metrics are the best dependent variables for capturing the size and capital accumulation biases that are inherent in production functions.

Comparison of Cross Section and Panel Data Samples

The panel data sample for the enterprise surveys has fewer observations than the cross sectional sample The panel data contains 8903 observations for 5165 firms versus a cross sectional sample of 56,871 manufacturing firms. The regional distribution and sector distribution of the samples are statistically different at the 0.001 level, based on Chi-Square contingency tests (See Tables 3 and 4). The panel data is underrepresented in metals and machinery, non-metallic, and plastic materials, and autos and parts and overrepresented in leather, wood, and furniture, and other manufacturing. Panel data has an overrepresentation in high-income countries and Latin America and an underrepresentation in Africa. In terms of size, the panel sample is underrepresented for small firms and overrepresented for large firms (See Table 5). The number of countries in the panel are 55 versus 135 in the cross sectional sample. Inferences from panel data could differ from cross sectional inferences due to sample characteristics. The presence of more high-income countries could in fact skew the data for electric supply since the frequency and aggregate hours of outages are far lower in high income countries (See Appendix Table B.2). The estimated loss in output from electrical outages is 10 times as large in LDCs as in high income countries while the aggregate annual hours of electrical outages is reported as 20 times as large.

Pooled Cross Sectional Equation

If standby generators affect productivity, firms with standby generators should grow faster than firms lacking generators and therefore should invest more capital per worker than firms lacking generators. A one-tailed -test of differences in means for investment per worker of firms owning generators and those lacking them is not statistically significant at the 0.10 level (See Table 26). Column (a) of Table 26 shows the number of observations in the group column (b) the mean investment/worker for the group, column (c) is the standard error of the row mean, and column (d) the standard deviation of the group.

Table 26

Differences in Mean Investment/worker by Generator Status

Group	(a) Obs.	(b) Mean	(c) Std. Err.	(d) Std. Dev.
Generator	17237	2522.258	566.1833	74334.07
No Generator	34125	4760.368	1652.677	305298.3
combined	51362	4009.262	1114.364	252550.5
diff	-2238.11	1746.971	-5662.21	1185.989

t=--0.9484; df=51360; P=0.1715

Linear models provide a means of testing whether the investment per worker varies when controlling for company growth, capacity utilization of the firm, differences in interest rates, differences in price changes, and in electrical outages. Firms with generators should exhibit lower levels of investment than firms with generators when controlling for other variables. The OLS model of natural logarithm of investment per worker indicates that firms lacking generators, on average, invest 52 percent less per worker than firms with generators (See Table 27). The column headings are identical to those in Table 16. The signs of interest rates and electrical outages are opposite of those expected from theory. Durbin-Wu-Hausman tests (Baum 2006)

Table 27

Test of Effect of Generator Ownership

Variable	(a) Coef.	(b) Robust SE	(c) t	(d) P>t
ln of firm employment	0.1874	0.0223	8.38	0.0000
real interest rate (avg 2006-2014)	0.0464	0.0054	8.57	0.0000
avg of FDI as % of GDP (2006-14)	0.0862	0.0106	8.1	0.0000
avg of CPI index (2006-14)	0.0917	0.0104	8.77	0.0000
Firm growth in output over last 3 yrs	2.75E-12	4.18E-13	6.59	0.0000
capacity utilization	0.0085	0.0010	7.94	0.0000
Dummy variable=1 for no generator	-0.5223	0.0672	-7.76	0.0000
ln of aggregate annual hours of outages	0.2349	0.0299	7.85	0.0000
square of ln of aggregate annual outages	-0.0229	0.0041	-5.48	0.0000
Africa	-2.4375	0.1635	-14.91	0.0000
East Asia & Pacific	-2.4498	0.1828	-13.4	0.0000
East & Central Europe	-1.3286	0.1827	-7.27	0.0000
Latin America & Caribbean	-1.5314	0.1574	-9.73	0.0000
Middle East & North Africa	-3.2762	0.1882	-17.41	0.0000
South Asia	-3.5468	0.1784	-19.87	0.0000

Table 27 (continued).

Variable	(a) Coef.	(b) Robust SE	(c) t	(d) P>t
High Income-Non OECD Countries	-0.2014	0.1837	-1.1	0.2730
Surveyed in 2006	0.5792	0.1577	3.67	0.0000
Surveyed in 2007	0.5233	0.1151	4.55	0.0000
Surveyed in 2008	1.2202	0.2662	4.58	0.0000
Surveyed in 2009	1.4793	0.1603	9.22	0.0000
Surveyed in 2010	1.3723	0.1717	7.99	0.0000
Surveyed in 2011	1.3354	0.1851	7.21	0.0000
Surveyed in 2012	-0.0013	0.2064	-0.01	0.9950
Surveyed in 2013	-0.0839	0.1137	-0.74	0.4610
Textile Sector	-0.6288	0.2345	-2.68	0.0070
Garment Sector	-0.8102	0.2290	-3.54	0.0000
Metals and machinery sector	0.2631	0.2290	1.15	0.2510
Electronics sector	-0.1351	0.2651	-0.51	0.6100
Chemicals and pharma sector	0.0473	0.2354	0.2	0.8410
Wood and furniture sector	-0.5065	0.2480	-2.04	0.0410
Non-metallic and plastic mat. Sector	-0.1845	0.2338	-0.79	0.4300
Auto and auto parts sector	0.1602	0.2856	0.56	0.5750
Other manufacturing sector	-0.0641	0.2362	-0.27	0.7860
Constant term	-8.5281	1.1067	-7.71	0.0000

Note: Dependent variable of natural logarithm of investment per worker. Observations=35,058. R^2=.0956. F(33,35025) of .52 is insignificant at .10 level.

indicate that none of the independent variables in the equation, including the dummy variable for lack of generator, are exogenous. The estimation of the equation with seven excluded instruments failed to provide an equation with strong instruments and consistent estimators, based on the Kleinbergen-Paap rk LM statistic (Chi-square = 8.61 with p=0.1225) and the Cragg-Donald Wald F statistic (F=1.225 with IV relative bias greater than thirty percent). The consistency of the estimators is therefore suspect. The lack of orthogonal instruments does not allow the estimation of consistent estimators. The null hypothesis of no difference in investment levels per worker between firms with generators and those lacking generators cannot be tested nor rejected with cross sectional data.

Panel Data Estimation of Effects of generator ownership on investment levels

Data for examining the investment behavior of firms by generator ownership are small because of the abundance of missing data. Only 1000 of the 3555 firms in the sample include all of the variables needed to calculate investment levels per worker by generator ownership. The data for investment per worker suffers from severe skewness since companies tend to invest in lump sums rather than uniformly over time. The coefficient for firms adding a generator is not statistically different in investment/worker as a share of book value than the coefficient for firms deleting generators or the coefficient for firms that did not change generator ownership (See Table 28). An analysis of variance test of difference in means is not significant at a conventional level.

Table 28

Investment/Worker (Invw) as Proportion of Book Value/Worker

	(a) Obs	(b) Median	(c) Mean	(d) Std. Dev.
Added Generator	128	0.1713	0.6130	1.58
No Change	575	0.2000	5.7400	99.80
Deleted Generator	128	0.1449	1.0400	3.98
Total	781	0.1250	4.4300	85.69

F(2,778)=.25: P=0.776

The pattern is different when one analyzes changes in investment per worker in levels (Table 29). The mean level of investment/worker differs between firms adding generators, deleting generators, or not changing generator ownership. An analysis of variance of differences in means of the firms adding, firms deleting, and firms not changing generator status is significant at the 0.007 level. This analysis indicates that the null hypothesis of no difference in investment per worker can be rejected. A one-tailed test of difference of means indicates that investment levels of firms adding generators is greater than for firms not changing generator status at the 0.002 level (t=2.89, df=923, P=0.002). The null hypothesis of no change in investment per worker ($F_{2,873}$=.47: P=0.6222) from a change in backup power (table not shown) cannot be rejected, however.

Table 29

Investment Per Worker by Generator Status

Variable	(a) Obs	(b) Mean	(c) Std. Dev.
Added Generator	112	6163.6	27860.4
No Change	813	2739.9	7142.6
Deleted Generator	166	2466.1	5621.8
Total	1091	3049.7	27.28

F(2,1088)=5.0; P=.007

Dynamic panel models are a more robust methodology for determining the relationship between changes in generator ownership and changes in investment/worker since they allow for tests with *ceteris paribus* assumptions. The equation for testing the hypothesis Five is:

(26)

$$\Delta INVEST_{i,t1-t0} = \beta_0 + \beta_{12} INTEREST\%_{i,t1-t0} + \Delta\beta_{13} CAPTUIL_{i,t1-t0} + \beta_{14}\Delta Y_{i,t1-t0} + \beta_{15}\Delta Pcap_j + \beta_{16}\Delta FDI_j + \beta_{17}\Delta EXCHANGE_j + \beta_{18}\Delta NOGENERATOR_{i,t1-t0} + \beta_{19} GENERATOR_{it} + \beta_{20}\Delta OUTAGE + C + \varepsilon$$

Note: Δ INVEST is change in investment per worker in firm i between time periods t1 and t0, INTEREST% is the lending interest rate published by the IMF for country j, ΔCAPTUIL is change in the capital utilization rate of firm I reported in the Enterprise Surveys, ΔPcap is the the change in real per capita GDP in country j between periods, ΔFDI_j is the change in foreign direct investment in county j between periods, $\Delta EXCHANGE_j$ is the change in exchange rates relative to the U.S. dollar in country j between periods, ΔNOGENERATOR is a dummy variable indicating the addition of standby generation between periods by firm I, GENERATOR is a dummy variable for generator ownership in the current period and ΔOUTAGE is the change in aggregate annual hours of electrical outages reported by firm I in periods t and t-1. **C** is a vector of control variables, such as company size and region and sector of production.

The use of first differences and of country level variables limits the sample size of the panel to about 700 firms. First differences could not be calculated for many firms since they did not report production inputs in both panel years. The inclusion of the Lending Interest Rate and of country-level variables also limits the number of observations since the IMF does not report these figures for many LDCs in the sample. The data of generator ownership is not collected for all cases in all of the panel years. Seventy-one percent of the firms did not report generator ownership in all panel years (See Table 28).

A significant share of the firms added standby generators between the two periods (See Table 28). Nearly 17 percent of the firms with complete data added generation between the two periods. The share adding generation is largely offset, however, by the 9 percent of firms that discontinued standby generation during panels. The net change in generator ownership is 7 percent between periods.

The time dimension of the panel is restricted to two time periods for all but 116 of the firms. A LR test for panel-level heteroscedasticity (Stata 2013) is significant at the 0.0001 level (Chi2(790) =2.04 e+10). Robust-standard errors are required to test inferences in the model.

The inclusion of dummy variables for generator ownership and change in generator ownership excludes the use of fixed effects estimators in the hypothesis test, since these variables do not change between time periods. A Hausman test for comparison of the fixed and random effects (Baum 2006) model is inconclusive due to a negative chi-square value. The inconclusive Hausman test also limits the ability to test for the endogeneity of the random effect variables and the need for IV panel methods.

Variables for levels and changes in lending interest rates, FDI as percent of GDP, capacity utilization, and change in exchange rates are not statistically significant at conventional levels. The final model includes the country specific variables of percent change in GDP (DGDP), natural logarithm of company employment (lsize), change in natural logarithm of GDP/capita (lGDPcap).

The explanatory power of the model is much higher with the dependent variable of change in natural logarithm of investment per worker than the same variable measured in levels. Post-estimation tests of joint significance of regional dummy variables is significant at the 0.01 level (Chi-square(5)=16.48 with p =0.0056) while a test of joint significance of the sector variables is not significant at the 0.01 level (chi-square(10)=21.31; p=0.019). The final model includes controls for region and company size. The lack of observations eliminated the inclusion of production function variables in the equation for testing of substitution and complementarity among production inputs.

The final model (See Table 30) has high explanatory power for cross sectional variance (within R^2 of 0.8119) but only moderate level of variation across time (R^2 of 0.1025 between). The column headings in Table 30 are identical to those in Table 16. While changes in GDP and GDP/capita are statistically significant at the 0.01 or less level and region dummies are jointly significant at the 0.01 level, neither change in generator ownership nor presence of generator ownership are statistically significant at conventional levels. The null hypothesis of no effect on change in investment per worker from generator ownership cannot be rejected at conventional levels. While the theory that generator investment increases investment in new plant and production equipment cannot be accepted, the small sample size and limited length of time series reduce the power of the test. A likelihood ratio chi-square test of the percent of new generators by sector is marginally significant at the 0.14 level (chi-square (10) =1.56) while a likelihood ratio chi-square of the percent of new generators by region is significant at the 0.001 level (chi-square (5) =85.245). Plausible explanations are that the investment levels per worker vary regionally. The sample has too few observations to test the hypothesis by region.

The tests of this hypothesis are ambiguous. The analysis of variance of investment levels per worker indicates that firms adding generators have higher levels of investment than firms lacking generators or those not changing the status of their backup power system. The test of the same hypothesis using panel data fails to reject the null hypothesis. The small number of observations with generator ownership in the panel data provides a potentially biased sample that could explain differences in test results. The panel has significant differences in representation of sectors from the cross section, which the contingency test indicates is a bias in terms of presence or absence of generator ownership. The research question requires additional data and analysis before the theory is accepted or rejected.

Table 30

Random Effect Panel Model

Variable	(a) Coef.	(b) Robust SE.	(c) z	(d) P
Change in GDP in country	-3.387	0.817	-4.15	0.000
Ln employment size of firm	-0.125	0.019	-6.46	0.000
Change in GDP/capita in country	0.848	0.245	3.46	0.001
Dummy variable for new generator	-0.044	0.099	-0.44	0.660
Dummy variable for standby generator	0.110	0.075	1.46	0.145
Dummy variable for Africa	-0.087	0.242	-0.36	0.718
Dummy variable for East Asia & Pacific	-0.125	0.182	-0.69	0.493
East & Central Asia	-0.133	0.113	-1.17	0.240
Latin America & Caribbean	-0.035	0.117	-0.3	0.766
South Asia region	0.122	0.159	0.76	0.444
Constant term	0.658	0.148	4.44	0.000

Note: Dependent variable change in natural logarithm of investment/worker. Dependent variable in natural ln of change in investment/worker. Observations=716 with 708 groups. R^2 within of .8119, R^2 between of .1025 with overall R^2 of .1022. Wald Chi-square (10) of 73.75 significant at .0001 level.

Research Question Five: How the ownership and regulation of the transmission and distribution infrastructure affects the macroeconomic performance of manufacturing in African and Latin American LDCs

Sixty-five countries in the World Bank ES survey are also covered by Platts UDI survey of electrical systems (See Figure 2). The combination of SFA inefficiency estimates from the ES data and data on ownership of transmission and distribution assets allows the testing of Research Question number Five. The alternative hypothesis is that the output-oriented technical efficiency of manufacturing in LDCs and aggregate electricity outages are directly influenced by the ownership structure of electric transmission and distribution assets. An additional test in this research question is whether the efficiency of manufacturing varies with the previous colonizer of the country. The CEPII GeoDist dataset provides the data on previous colonial status of the countries by empire name (Mayer and Zignago 2011).

The equation using firm-level inefficiency data presented in the Methodology chapter suffered from endogeneity (Baum 2006) based on results of the Hansen J Statistic(Chi-square(2) =53.9; P=0.0000, with the null hypothesis that OLS coefficients are consistent). The equation is not estimated consistently with a series of eight excluded instrumental variables, based on the Hansen J Statistic (Chi-square(8)=387.9; P=0.0000, with the null hypothesis that OLS coefficients are consistent).

The mean level of output-oriented technical efficiency (TOE), of output-oriented technical inefficiency (TOE), and of the output-oriented technical inefficiency due to outages (OUTAGE) are calculated for each of the 65 countries from the firm level residuals in the SFA equation. Mean technical inefficiency is the dependent variable in a second-stage regression equation with categorical variables for distribution system and transmission system ownership and for each of the nine empires of colonization (See Table 31 for the list of empires). Column (a) is the number of countries by empire and column (b) is the percent of the total countries. Ninety percent of the countries in the sample had been colonized for long-periods. The final variable in the equation is the percent of gross electricity in the country lost in the transmission and distribution grid (UN 2016).

Table 31

Empire of Colonization of Countries in Sample

Empire	(a) Obs.	(b) Percent
Austria	2	2.99
Germany	3	4.48
Spain	13	19.40
France	11	16.42
Great Britain	19	28.36
Netherlands	1	1.49
None	7	10.45
Portugal	2	2.99
Russia	6	8.96
Turkey	3	4.48

The inefficiency and outage data are aggregated to a country level and retested using the second-stage regression equation below:

(27)

$$TE_j = \beta_0 + \beta_{21} OUTAGE_j + \beta_{22} OUTAGE_j^2 + \beta_{23} DISTRIBUTION_j + \beta_{24} TRANS_j + \beta_{29} \left(COLONY_j\right) + LOSS_j + C + \varepsilon$$

where OUTAGE is a measure of aggregate outages experienced in county j, **C** is a vector of control variables, DISTRIBUTION is a dummy variable for government ownership of electric distribution assets in Country j and TRANSj is a dummy variable for government ownership of transmission assets in country j, $COLONY_j$ is a series of dummy variables for colonization by various empires, $LOSS_j$ is the percentage of electricity losses in the transmission and distribution grid in country j.

The model estimated in OLS is heteroscedastic based on a Breusch-Pagan test (chi-square (1)= 30.78; p=0.0000). Categorical variables for empire of colonizer are neither individually nor jointly significant at the 0.10 level. Tests of orthogonality, using the Hansen J statistic test, indicate that the coefficients of all of the independent variables in the OLS equation are consistent without the use of instrumental variables (Chi-square (3)= 1.139; P=0.77). The variables for inefficiency due to outages and its square are jointly significant at the 0.0001 level ($F_{2, 60}$=8.40; P=0.0006). Categorical variables for transmission grid ownership by government are not individually significant at the 0.10 level and are dropped from the equation. Distribution grid ownership by government is not statistically significant at the 0.10 level (See Table 32). The null hypotheses of no difference in mean output-oriented inefficiency from government ownership of distribution and transmission grids is not rejected.

The model with dummy variables for each empire is not statistically significant at the 0.10 level ($F_{9,55}$ =0.633;P=0.23). The single dummy variable for lack of colonization is also tested. The null hypothesis of no difference in mean output-oriented inefficiency from prior colonization is not rejected at even the 0.10 level (Table 32). The column headings are identical to those in Table 16.

Both outages and electricity losses have significant effects on the mean output-oriented technical efficiency of manufacturing firms in LDCs. One percentage point increase in electricity losses decreases aggregate output on average by 0.07 percent. Reducing transmission and distribution grid losses from the sample average of 14.1 percent to the OECD average of 6 percent would increase manufacturing output by 0.56 percent.

Table 32

Influence of Distribution Grid Ownership on Inefficiency

Variable	(a) Coef.	(b) Robust SE	(c) t	(d) P>t
Outage inefficiency	1.0200	0.7759	1.31	0.194
Square of Outage ineff.	-1.1359	1.6420	-0.69	0.492
Losses as % production	-0.0689	0.0313	-2.20	0.032
Government ownership	0.0046	0.0031	1.48	0.144
Not colonized	0.0033	0.0044	0.76	0.450
Constant	0.0893	0.0059	15.25	0.000

Notes: Dependent variable is aggregate percent of efficiency by county using Jendrow index. Observation=64. Equation is significant at .0004 level with F(5,58) of 5.43. R^2 of .2552.

The effect of outages on technical inefficiency is quadratic. Outages reduce LDC manufacturing output by 5.8 percent at the mean level. A 1 standard deviation drop in the country outage index reduces the effect on output by 3.8 percent. An increase of 1 standard deviation in the country index decreases output by 3.8 percent. Countries that are 1 standard deviation above the mean in terms of outages, such as Bangladesh, India, Egypt, and Senegal, could increase manufacturing output by 7.6 percent if they reduced outages by two standard deviations.

Figure 2. Countries included in cross section, panel, and Platt's data.

CHAPTER V—CONCLUSIONS

This chapter summarizes the effects of electricity on manufacturing production in Less Developed Countries and subsequently derives implications of the research for existing production theory, human capital theory, and institutional economics. A discussion of the limitations of the research follows. The chapter concludes with recommendations for further research.

This research demonstrates that electricity, despite its small share of production costs, is a significant factor in manufacturing production. OLS and Stochastic Frontier Analysis models show that electricity has an output elasticity that is nearly three times larger than its share of inputs. The marginal revenue product of electricity- which is the contribution of electricity to the last unit of output- also is triple the contributions of labor and capital at the margin. The role of infrastructure, like electricity, is underestimated using production theory.

Outages of electricity increase labor costs for firms without standby power while they decrease manufacturing exports of all manufacturing firms. Outages have spillovers from distorted trade that affect global welfare as well as domestic welfare.

While standby power clearly moderates the effects of outages on lost production, the side effects include higher consumption of energy in production (which often results in higher imports of primary energy at the national level) plus higher labor content. For the sample of 25,000 firms, self-generation on average raises energy consumption per worker by 0.1 percent.

The estimates from Stochastic Frontier models indicate that electrical outages represent a substantial share of technical inefficiency (the output that could be produced under ideal operating conditions using the same level of inputs) in LDCs. In Africa, outages of electricity explain 48 percent of overall technical inefficiency. Manufacturing output in Africa could be raised by five percent simply by keeping the power uninterrupted to manufacturing companies.

These effects are not limited to Africa. Outages represent 36 percent of overall technical inefficiency in South Asia and 27 percent in the Middle East and North Africa. Electrical outages explain over 20 percent of technical inefficiency in manufacturing in other World Bank regions, except in Latin America and the Caribbean, where it accounts for 17 percent. These results confirm electric supply as the top constraint on manufacturing output in World Bank Investment Climate Surveys. These results also demonstrate that electricity supply is a more acute problem for manufacturing in LDCs than in the OECD countries. Providing electricity to industry without interruption is a strategy for raising manufacturing GDP in LDCs in the short-term, in contrast to human capital investments that require decades before realizing returns. Providing uninterrupted power to private investors is possibly a strategy for increasing the level of manufacturing investment although the hypotheses tests in this dissertation are ambiguous about that strategy.

Prior colonization does not explain differences in manufacturing inefficiency. The technical inefficiency of manufacturing does not vary by empire of colonization or by whether the country was ever colonized. Nor are differences in technical inefficiency in manufacturing explained by state ownership of transmission or distribution grids. Privatization of the electrical grid does not appear to influence the level of inefficiency in manufacturing due to electrical outages.

The data lacks variation on the categorical variables for state ownership. Ninety-seven percent of firms in the analysis are on state owned distribution grids while 86 percent are on state-owned transmission grids. Ninety-seven percent of the countries in the sample have state-owned distribution grids while 83 percent have state-owned transmission grids. The research question of whether inefficiency varies with state ownership deserves further study. The results could be different if researchers use statistical techniques that estimate corner solutions.

This study demonstrates that Stochastic Frontier methods can measure the effects of economic “bads,” such as outages, that reduce potential output as well as the effects of production technology on actual output. International Development can move beyond the study of factors that explain differences in output to the study of factors that constrain potential output.

Contributions of Research to Theory

These findings challenge the assumption in production theory of the equality of marginal revenue products of inputs at equilibrium. The equality assumption is only valid if all factors are perfect substitutes. The evidence in this study contradicts that assumption.

These results support as well as challenge prior theory. Differences in the marginal revenue product of electricity and other factor inputs support the findings of

Duggal, Saltzman, and Klein (1999) that infrastructure prices are not market determined so their marginal revenue products will not be equal to the MRP of market determined factors like capital and labor. Differences in the marginal revenue product of electricity and of other inputs support the findings of Aschauer (1989) that infrastructure investments have inordinately large effects on national productivity. Differences in the MRP of electricity over other inputs provide support for the contention of ecological economists like Stern (1993) of the limits of substitution between energy and non-energy inputs in production.

These findings support the prior research of Beenstock, Goldin, and Haitovsky (1997) and Sullivan, Vardell, and Johnson (1997) that the effects of electrical outages on production are quadratic with respect to lost production. They also support the findings of Grosfeld-Nir and Tishler (1993) that industries with low inputs of electricity have higher losses per unserved kWh than industries, such as chemicals, that have large inputs of electricity. These results do not invalidate the findings of Tishler (1993) that the cost to manufacturers of unsupplied power is 60 to 300 times the cost of supplied power.

The divergence in the regression coefficients between firm-level and worker-level production functions in this research raises questions about the adequacy of the human capital theory of wages (Todaro and Smith 2011). If differences in wages (labor costs divided by number of employees) are fully explained by differences in human capital, the regression coefficients for firm-level equations should not differ from those in worker-level equations, since the variables are merely divided by the same constant. This research shows, however, that the returns to labor at the firm-level are statistically greater than the returns at worker-level. The returns to capital are also statistically different between firm and worker-levels. This finding suggests that factors other than human capital, such as institutional differences in work rules or mandated benefits, are also embodied in national wage rates.

The findings in this study raise questions about the validity of focusing on small business as the primary source of economic growth (Birch 1981). Both firm-level and worker-level equations in this dissertation demonstrate that larger firms in LDCs are substantially more productive and more efficient than smaller firms. Inefficiency drops by nearly 20 percent when employment moves from the mean of employment size to one standard deviation above the mean. Even if small firms on average create more jobs than large firms, they achieve the result through inefficiency and lower productivity. The tradeoff of higher employment is lower output per worker and lower productivity of resource utilization. These finding raise questions about the adoption of policies in LDCs to stimulate small business growth.

Limitations of Research

The Investment Climate Surveys used in this study are the first data for LDCs that provide firm level information on inputs of electricity and fuels. The production impacts of energy are isolated from the consumption impacts, which is a pervasive issue in studies using aggregate electricity data. These data provide evidence of the productivity effects of electricity on manufacturing output that are not estimated with aggregate electricity data.

Despite the large sample size and the range of variables in the surveys, this study could not explore Straub's (2008) hypothesis about electrical outages reducing investment levels. The survey only collects investments made in the prior fiscal year, which is too short a period, because capital investments tend to occur in bundles rather than in level annual amounts. The panel data was too short and lacked the number of observations needed for a rigorous test of the hypothesis.

A major limitation in this study is the assumption of static and uniform prices of energy and electricity across time and countries. Because many underdeveloped countries in the sample subsidize electricity and diesel fuel prices, the cross sectional analysis in this study could distort the production relationships for electricity and fuels. Unit price and unit quantity data for electricity and fuels would provide a means of examining the relationships while controlling for subsidies. Unit prices and quantities would also allow for the examination of allocative efficiency among energy inputs.

Another limitation in this research is the accuracy of the estimates of differences in exports, energy, and foreign intermediates per worker from outages. The null hypothesis of consistent estimators in these equations is rejected at the .05 level of significance but would not be rejected at the .01 or higher levels of significance. Survey data offer limited instruments for estimating the regression coefficients using instrumental variable techniques since values are firm-specific. The estimated responses from outages for these variables should be interpreted with caution.

The Investment Climate Survey does not collect data on the amount of taxes and government fees paid by LDC manufacturers. Infrastructure theory espoused by

Aschauer (1989) and Duggal, Saltzman, and Klein (1999) indicates that the contribution of electricity infrastructure in productivity is largely from its role as an unpaid factor of production. These effects cannot be accurately measured when the costs of taxes and government fees, which are factor inputs in manufacturing, are conflated with total factor productivity. A limitation in this research is that the effects of electricity as an unpaid factor of production could not be fully estimated.

Areas of Further Study and Research

This research evaluates the impacts of electrical outages on manufacturing production, which is about 20 percent of GDP in low and middle income economies (World Bank 2016). These findings, and the earlier findings of Grosfeld-Nir and Tishler (1993), are that industries with low inputs of electricity have higher losses per unserved kWh than industries with high inputs. The research in this dissertation on manufacturing should be extended to the service sector in LDCs. Since services constitute nearly triple the GDP of manufacturing in low and middle income countries (World Bank 2016) and since services likely have a lower unit input of electricity than manufacturing, aggregate technical inefficiency due to outages could be substantially higher in services than in manufacturing. The effects of outages on GDP are probably substantially larger than the effects of outages on the manufacturing share of GDP that were measured in this dissertation.

The paradox between firm-level and worker-level output elasticities of labor bears additional research by others. Institutional differences in labor law, in government mandated benefits or in government induced overhead costs could have significant impacts on labor productivity. North (1994) argues that institutional differences are the most important variables in economic productivity because countries have evolved from production-oriented to transaction-oriented economies. These data and methods could provide tests of his theory and of how institutional differences explain productivity differences.

Another area for further research is a re-examination of whether state ownership affects the levels of outages and inefficiency from outages. An unreported test using an interval-scaled interaction term demonstrates that the level of electrical system losses is statistically higher in state-owned distribution grids than in private-owned grids. This test shows that state-owned enterprises are less efficient at delivering electricity to customers than private enterprises. Use of corner solution models such as Tobit, or of interval scaled data, could provide different conclusions than this study about the research question of state ownership and inefficiency. Sample data consisting of a combination of OECD and LDC companies could also provide more variation on the categorical variables for retesting this hypothesis. The research question is an important policy issue that bears additional investigation.

The research question of outages and the level of investment is an additional issue that bears further study. Longer and larger panels with data on investment over a number of years could provide definitive tests of this important research question that remain unanswered in this study.

This above research question is related to the broader question of whether foreign direct investment increases national productivity by importing more efficient production technology to a country. The Investment Climate Survey identifies the percent of foreign investment in firms. It also has a categorical variable that identifies firms operating in export processing zones. Research questions about the effectiveness of export processing zones in removing institutional barriers to production and about whether foreign -owned firms are more efficient could also be examined using the firm-level data in this survey and stochastic frontier analysis. The combination of survey data and SFA could provide definitive answers to these disputed research questions.

APPENDIX A – Characteristics of Manufacturing Sample

Table A1.

Manufacturing Sector by Region

Region	Frequency	Percent
Africa	10,734	18.9%
East Asia & Pacific	5,237	9.2%
East & Central Asia	7,651	13.5%
Latin America & Caribbean	11,947	21.0%
Middle East & North Africa	3,486	6.1%
South Asia	11,243	19.8%
High income: OECD	2,972	5.2%
High income: nonOECD	3,601	6.3%
Total	56,871	100%

Table A2.

Manufacturing Sample by Sector

Sector	Frequency	Percent
Textiles	4,734	8.3%
Leather	494	0.9%
Garments	7,073	12.4%
Food	11,875	20.9%
Metals and Machinery	9,520	16.8%
Electronics	1,691	3.0%
Chemicals and Pharmaceuticals	5,018	8.8%
Wood and Furniture	2,457	4.3%
Non-Metallic and Plastic Materials	6,584	11.6%
Auto and Auto Components	1,014	1.8%
Other Manufacturing	6,380	11.2%
Total	56,840	100%

Table A3.

Sample by Employment Size and Ownership

Number of Employees	Firms	Percent
Small (<20)	22,373	39.3%
Medium (20-99)	20,915	36.8%
Large (100 and over)	13,583	23.9%
Total	56,871	100%
Independence	Firms	Percent
Controlled by another company	7,908	14.9%
Independent	45,077	85.1%
Type of Ownership	Firms	Percent
Publicly listed company	2,753	4.8%
Private limited liability company	24,751	43.5%
Sole Proprietorship	18,590	32.7%
Partnership	4,828	8.5%
Limited Partnership	4,317	7.6%
Other	1,080	1.9%

Table A4.

Source of Ownership by Percent

Variable	Obs	Mean	Min	Max
Private domestic entities	56,869	89.0	0	100
Private foreign entities	56,847	7.2	0	100
State ownership	56,861	0.5	0	100
Other	56,860	1.3	0	100

Table A5.

Manufacturing Sample by Market Type

Variable	Obs	Mean	Std. Dev.	Min	Max
Percent of sales in national	56,863	85.2	30.2	0	100
Percent of sales by indirect export	56,830	3.7	15.2	0	100
Percent of sales by direct export	56,632	10.1	25.4	0	100

Table A6.

Manufacturing Sample by Origin of Intermediate Materials

Variable	Obs	Mean	Std. Dev.	Min	Max
Percent domestic materials	56,777	71.3	36.7	0	100
Percent foreign materials	56,591	25.3	35.6	0	100

APPENDIX B –Outage Characteristics in Sample

Table A1.

Sample by Sector & Generator Ownership

	Generator Ownership		
Sector	No	Yes	Total
Textiles	3,262	1,425	4,687
Leather	353	140	493
Garments	5,267	1,773	7,040
Food	6,927	4,843	11,770
Metals and Machinery	6,106	3,133	9,239
Electronics	880	788	1,668
Chemicals and Pharmaceuticals	3,246	1,751	4,997
Wood and Furniture	1,686	725	2,411
Non-Metallic and Plastic Materials	4,129	2,410	6,539
Auto and Auto Components	469	538	1,007
Other Manufacturing	4,739	1,577	6,316
Total	37,064	19,103	56,167

Table A2.

Outage Experience by Region

	Outages		
Region	Yes	No	Total
Africa	8,519	2,083	10,602
East Asia and Pacific	3,032	2,193	5,225
East and Cen. Asia	3,489	4,071	7,560
Latin America and Caribbean	6,332	5,574	11,906
Middle East and North Africa	2,493	978	3,471
South Asia Region	8,256	2,952	11,208
High income: OECD	1,080	1,530	2,610
High income: nonOECD	1,219	2,346	3,565
Total	34,420	21,727	56,147

Table A3.

Percent of Firms Experiencing Outages by Region

Region	Yes	No	Total
Africa	80%	20%	10,602
East Asia and Pacific	58%	42%	5,225
East and Central Asia	46%	54%	7,560
Latin America and Caribbean	53%	47%	11,906
Middle East and North Africa	72%	28%	3,471
South Asia Region	74%	26%	11,208
High income: OECD	41%	59%	2,610
High income: nonOECD	34%	66%	3,565
Total	61%	39%	56,147

Table A4.

Descriptive Statistics of Outages by Manufacturers

Variable	Obs	Mean	Std. Dev.	Min	Max
Avg. # of Outages in last Fiscal Year	32,927	20.9	120.2	0	14,400
Avg. Length of Outage in Hours	28,675	5.1	27.1	0	2500.983
Lost Sales in % from Electrical Outages	22,156	9.1	13.2	0	100
% of Electricity Generated from Backup	17,563	24.9	29.1	0	100

Table A5.

Descriptive Statistics of Constructed Outage Values

Variable	Obs	Mean	Std. Dev.	Min	Max
Aloss (Annual # of Outages)	53,520	132.3	327.2	0	5,760
AFnDLoss (Annual aggregate hours of outages)	47,137	271.3	582.5	0	8,640
Dloss (Avg duration of outage in hrs)	50,370	2.6	7.5	0	200

APPENDIX C –Production Function Characteristics in Sample

Table A1.

Descriptive Statistics for Production Function Variables in Levels

Variable	Description	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
Yt	Annual Output in US$ last FY	50,763	3.59E+07	3.04E+09	0	5.38E+11	146.8	23,238
Et	Exports in US$ in last FY	50,362	1.59E+07	2.13E+09	0	4.57E+11	200.4	42,299
Dim	Domestic materials in US$	46,510	345,669.8	2.03E+07	0	4.32E+09	207.3	44,017
Fim	Foreign materials in US$	42,457	430,100.7	4.98E+07	0	1.01E+10	195.8	39,376
Elec	Electricity in US$	48,620	221,190.5	7,138,132	0	1.24E+09	128.5	20,064
Fuel	Non-electricity fuels in US$	43,436	193,094.4	4,808,845	0	4.95E+08	74.6	6,477
Labor	Labor in US$	49,460	1,015,337	1.50E+07	0	1.73E+09	78.5	7,577
Kdep	Depreciation in US$	35,666	9,027,304	8.45E+08	0	1.53E+11	168.1	30,003

Table A2.

Share of Descriptive Statistics for Share of Output

Variable	Description	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
shrLab	Share of labor in output	47,057	0.206	0.168	0	0.999333	1.396	5.23
shrMat	Share of materials in output	44,254	0.398	0.229	0	1	0.034	2.21
shrElec	Share of electricity in output	46,140	0.038	0.073	0	0.973904	5.78	47.43
shrFuel	Share of fuel (ex elect) in output	41,401	0.029	0.064	0	0.992064	6.28	58.81
shrDep	Share of depreciation in output	33,617	0.054	0.097	0	0.9974	4.48	29.46
	Total	28,248	0.712	0.284	0			

Table A3.

Production Function Variables in Per Worker Levels

Variable	Description	Obs	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
YtperWorker	Output per worker in US$	50,673	183,312	9,212,273	0	1.39E+09	108	13,545
FMat	Foreign materials/worker in US$	40,685	19,034	2,080,281	0	4.18E+08	199	39,957
DMat	Domestic materials/worker in US$	43,576	17,333	509,038	0	1.04E+08	198	40,633
Elecfte	Electricity/worker in US$	48,536	1,162	12,920	0	1,198,160	59.6	4,297
Fuelfte	Fuel/worker in US$	43,377	1,108	19,088	0	2,200,963	83.9	8,063
Labwk	Labor/worker in US$	49,387	6,833	103,540	0	1.51E+07	107.4	13,347
KDepworker	Depreciation/worker in US$	35,619	39,996	1,233,569	0	1.26E+08	70.9	6,003
Inputpworker	Inputs per worker in US$	29,701	95,774	3,331,370	0	5.22E+08	134	20,443

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