Does Energy-Efficiency Save Energy?
Experimental Evidence from Indian Manufacturing Plants*

Nicholas Ryan†

PRELIMINARY AND INCOMPLETE
DO NOT CITE

August 8, 2013

Abstract

Some manufacturing plants produce far more with the same inputs than other plants in the same sectors, a productivity gap that is especially wide in developing countries. Whether market differentiation and risks or market failures drive this gap is important for policy, because market failure explanations may warrant policy intervention, for example, to improve the efficiency of energy use. This paper reports on a large-scale field experiment that aimed to increase energy-efficiency, by providing energy audits and skilled energy managers, in a sample of 433 chemical and textile manufacturing plants in India. *In preliminary analysis based on incomplete endline survey data*, there are three main results. First, projected returns to energy efficiency in audited plants are high but rapidly diminishing. Second, treatment plants invest somewhat, but insignificantly, more than control plants in equipment upgrades and maintenance. Third, despite the modest scale of investment observed, treatment plants consume significantly *more* electricity than control plants at endline, suggesting a large plant increase in the use in energy services in response to greater efficiency. Ongoing data collection and analysis will revise these results and link them to the measured physical efficiency of plants.

JEL Codes: O14, Q41, D24, L65, L67

1 Introduction

In manufacturing in the United States, the difference between the productivity of efficient and inefficient plants is about two-fold (Syverson, 2011). In India and China, it is even greater (Hsieh and Klenow, 2009). Do these huge differences in productivity mean that market failures prevent less productive plants from either being driven out of the market, or from changing

*I thank Esther Duflo and Michael Greenstone for continual support and guidance and Rohini Pande for advice. I also thank R N Pandya of the Gujarat Energy Development Agency for advice and encouragement. Harsh Singh, Harsh Vijay Singh, Vipin Awatramani, Raunak Kalra and Maulik Chauhan provided exemplary research assistance and project management. I thank the MIT Energy Initiative, Veolia Environment, US AID – Development Innovation Ventures and the Sustainability Science Program at Harvard for financial support. All views and errors are my own.

†Prize Fellow, Harvard University and J-PAL. Weatherhead Center for International Affairs, K239 1737 Cambridge St., Cambridge, MA, 02138. E-mail: nickryan@fas.harvard.edu

how they produce to make up the gap? Or are they optimal responses by heterogeneous firms to market differentiation and risks? One promising way to progress on these questions is to bear down on what determines productivity in individual sectors (Syverson, 2004a).

This paper studies the efficiency with which textile and chemical plants in India use one particular input, energy. Energy is an especially important, policy-relevant input through which to view the drivers of firm productivity. From 2010 to 2040, energy use in non-OECD countries, is projected to increase 90 percent, as compared to 17 percent in the OECD (Energy Information Administration, 2013). The industrial sector accounts for the largest share of energy demand. Against this backdrop, and the likelihood that 80% of energy in 2040 will still come from fossil fuels, policy-makers have stressed the importance of efficiency for climate change mitigation. The head of the U.N. Climate Change Secretariat recently hailed energy efficiency as "the most promising means to reduce greenhouse gases in the short term."[1] The underlying logic being that energy-efficiency is cheap: if market failures make plants use energy inefficiently to begin with, fixing these failures can both reduce carbon emissions and save enough money on energy bills to be profitable even privately (See Allcott and Greenstone, 2012, for a review of the evidence on this idea).

The research design of the study is a large-scale field experiment that aimed to increase energy-efficiency in a sample of 433 manufacturing plants in India. Plants in the chemical and textile sectors can spend one-quarter of costs on electricity and primary energy, and the experimental sample exhibits wide variation in the ratio of sales to energy use, i.e. dispersion in single-factor revenue productivity. The corresponding research question is, whether sample plants are making optimal decisions about adopting energy-saving measures, given the characteristics of these measures and factor prices, or whether market failures such as informational asymmetries impede the adoption of new technologies or practices.

The experimental design provides information and skilled human capital, through two cross-randomized treatments, to address the main reasons cited for low adoption of energy-saving technologies. The first treatment, randomly assigned to 217 of 433 sample firms, is a detailed energy audit. Energy audits review the efficiency of thermal and electrical systems in the plant and recommend measures the plant could take to improve efficiency, including both practices (e.g., feeding fuel into the boiler differently) and investments (e.g., insulating steam

[1] De Boer, Yvo (August 28, 2007), available at http://www.reuters.com/article/idUSL2836333720070828 (last accessed August 8, 2013).

lines). The second treatment, randomly assigned within the energy audit treatment group to half of firms that got an audit and expressed interest in implementation, is an energy manager to follow-up on the recommendations of the audit. Energy managers visited the plant and assisted with procurement, installation, training and other aspects of the adoption of energy-saving technologies.

Data comes from three sources. First, prior to the treatments and coincident with the offer of energy consultancy to plants, energy consultants and research staff conducted a brief baseline survey covering plant characteristics and aggregate energy use and expenditure. Second, during the energy audit and energy manager treatments, energy consultants collected additional data on energy use, projected returns to energy-efficiency and the progress of implementation. Third and finally, an endline survey collected uniquely detailed information on plant efficiency and aggregate inputs and outputs. The survey design unifies the economic and technical analysis of energy efficiency. It includes not only aggregate plant outcomes such as energy bills and employment, but also detailed, equipment-level measures of, for example, the efficiency of the plant's boiler and the loading of its electric motors.

In preliminary analysis, three main findings emerge.[2] First, plants exhibit wide heterogeneity in energy-efficiency at baseline and energy audits show correspondingly high, though rapidly diminishing, projected returns on energy-efficiency investments. For an average plant, the first INR 200,000 of investment is projected to save INR 540,000 per year, and the next INR 200,000 about INR 200,000. Second, treatment plants on average spend INR 25,000 more than control firms on equipment upgrades and maintenance, which is not significantly different from control expenditures (p-value 0.16), and less than the amount recommended in audits. Given that investment is typically recalled by the plant owner or manager, rather than documented, upgrades and maintenance are noisily measured and changes may be understated.

Third, and most striking, treatment plants are estimated to have significantly *increased* energy use in response to the energy audit treatment. Metered electricity demand, the most reliable, though incomplete measure of energy consumption, rises by 18,541 kWh (standard error 7,470 kWh) per month in treatment plants on a base of 83,390 kWh in the control, for

[2] The endline survey is ongoing. The experimental sample includes 433 firms, whereas data has been collected, entered and cleaned for a sample of 220 firms as of writing. The experimental results are therefore preliminary and incomplete, pending the collection and analysis of the full endline survey data.

a rise in monthly bills of INR 133,641. Theoretically, newly more efficient plants, recognizing that efficiency lowers their cost of energy services, should expand their consumption of these services to some extent. In the energy-efficiency literature this is known as rebound (Borenstein, 2013). In studies of consumers, however, rebound is seldom viewed as great enough to offset the energy-savings from increased efficiency of new appliances (Sorrell et al., 2009). This preliminary result warrants more investigation, in the full sample and using detailed data on the efficiency of firm capital, to decompose the observed increase in energy use.

This study stems from two main branches of literature. The first is the literature on heterogeneity in manufacturing productivity. Hsieh and Klenow (2009) find that manufacturing plants in India and China exhibit much greater dispersion in productivity within sectors than plants in the United States. Bartelsman et al. (2013) find similar dispersion in the covariance between productivity and size across countries a sample of eight middle- and high-income countries. Banerjee and Duflo (2005) document wide dispersion in the marginal product of capital within countries. Bearing down on the causes of such dispersion within countries and sectors, research in the United States has attributed variation in productivity to the substitutability of products among producers within a sector (Syverson, 2004a,b).

The closest predecessor to this study is Bloom et al. (2013), which reports on an experiment that provided management consulting to 14 treatment plants in an experimental sample of 20 textile mills in the state of Maharahshtra, which borders Gujarat. The intensive consulting treatment focused on measuring output quality and spurring adoption of a set of management practices. Bloom et al. (2013) find that treatment plants adopt new management practices at higher rates and that this adoption led to reductions in quality defects and hence increases in productivity. They conclude that both limitations in the managerial span-of-control and informational barriers are likely to have impeded the prior adoption of these practices.

The second branch of literature connected to this study concerns energy-efficiency, and in particular the optimality of consumer and firm decisions about energy-saving investments. Consumers decisions about energy-efficiency investments imply using rather high discount rates, and firms value investment costs more than discounted savings (Train, 1985; Anderson and Newell, 2004). The central question in the literature is whether these decisions are privately optimal, for example owing to unobserved characteristics and risks of energy-saving investments, or reflect market failures, such as asymmetric information about energy savings or incentive problems within firms (Jaffe and Stavins, 1994). The evidence to support pervasive market failures in energy-investment decisions is thin (Allcott and Greenstone, 2012). However, as with productivity, the energy-efficiency literature is far from a positive understanding of what does drive the adoption of efficient technology and hence the wide dispersion in observed energy use.

This study contributes to these literatures by way of its setting, identification and connection of engineering and economic analyses. As a randomized-controlled trial in a large sample of Indian manufacturing plants, the study is able to cleanly identify the effects of the treatments on energy use and productivity, in a country and sector where the causes of productivity disperson are of great academic and policy interest. With unique survey data on both aggregate plant-level inputs and outputs and the efficiency of plant equipment, the study will be able to unify engineering analyses of energy-efficiency—which often stop with projected savings—and economic analysis accounting for behavioral responses. The large magnitude of increases in energy consumption observed gives a stark reminder that energy and climate policy instruments change energy use through the behavior of consumers and firms.

The rest of the paper runs as follows. Section 2 gives background on the setting for the study and the design of the experiment. Section 3 describes the data used in analysis and summary statistics on sample plants. Section 4 describes the econometric approach and results and section 5 briefly concludes.

2 Background and Experimental Design

(a) Study Context and Policy Relevance

The project studies energy-intensive manufacturing plants in the Indian state of Gujarat, which is home to 5% of Indias population but 17% of industrial investment. The sample, described below, was drawn from the chemical and textile processing sectors, in which plants may spend 10-35% of their total production costs on energy. The Gujarat Energy Development Agency (GEDA), a state government body responsible for the promotion of energy-efficient and renewable energy technologies in Gujarat, reports technically feasible "savings potentials" of around 20% of total energy bills for small plants in many energy-intensive sectors, including these two (GEDA, 2009). A recent Bureau of Energy Efficiency (BEE) study found that small chemical plants in Gujarat with less than 200 tons of production each year use 4050 kCal of energy per kilogram of product, 22% more than the 3312 kCal used by large plants (BEE, 2010).

The Indian government places a high priority on energy-efficiency in manufacturing. The government imposes a modest coal tax of INR 50 (approximately USD 1) per ton to fund clean energy technology, but the primary policy instruments for energy efficiency are informational and capital subsidies. The Bureau of Energy Efficiency, Ministry of Power has launched a "National Mission on Enhanced Energy Efficiency" across many sectors. For industry, this mission includes both an energy-conservation credit trading system, for very large plants, and, for smaller plants, a nationwide campaign of energy audits and capital subsidies to identify energy-efficient technologies and encourage their wide adoption. Numerous international partners have assisted the BEE or run campaigns with a similar purpose themselves, including the World Bank and development agencies of the United States, Germany, Japan and Switzerland.

(b) Experimental Design

The sample of plants was drawn from industrial associations with members in the textile and chemical sectors. A target sample size of 400 industrial plants was chosen to detect an 8% drop in electricity consumption with 80% statistical power, based upon energy consumption data from a sample of energy audits carried out by the Bureau of Energy Efficiency (BEE) for chemical factories in Ahmedabad, Gujarat. To reach this sample size, randomly selected industrial association members were assigned to be solicited, by energy consultants, for their interest to receive free energy consultancy, possibly including a detailed energy audit. As shown in Table 1, a total of 925 plants were contacted, of which 53% said they were interested. Plants not interested were asked why not, and typically did not respond with reasons related to energy use: only 4% said they already had an energy consultant, 4% that energy was not a large cost for their plant, and a further 5% that they expected the scope of savings was not large. Most plants that gave a reason for declining cited concerns about data confidentiality. From the 490 plants that responded with interest, the sample was cut down to 433 based on a maximum threshold for electricity load, in order to limit the sample to smaller plants and reduce the variance of energy demand in the sample.[3]

The energy consultants participating in the study were solicited from those certified by the Gujarat Energy Development Agency (GEDA) in 2009 and 2010. GEDA certifies 30 to 40 consultants as able to conduct thermal and electrical energy audits, which allows consultants to participate in GEDA-sponsored subsidy programs for energy audits, consultancy and training activities. The consultants working in the study were deliberately selected to be high-performing: the research team vetted consultants, in person and with the recommendations of GEDA, and invited 9 of the best to conduct the project treatments on the basis of their competence and past work, including in doing energy audits.

The research design was a randomized-controlled trial with two intervention arms. These two treatments, energy audits and energy managers, are designed to test the leading hypotheses for why firms do not adopt energy-efficient technologies.

Energy audit treatment. An energy audit is a thorough, on-site review of how a plant uses energy and how it might profitably use less. Consultants employ electrical, chemical and mechanical engineers who spend approximately 6 man-days on site, depending on the size of the plant, collecting energy consumption information and measuring the efficiency of energy-using systems within the plant. For example, the efficiency of insulation on steam lines, and consequent heat loss, is calculated by comparing the temperature on insulated and uninsulated portions of the lines. At the conclusion of this measurement, the consultant prepares an audit report suggesting investments to improve the efficiency of energy use, prioritized by their projected economic return. Energy auditors were paid at a flat rate by the research team, in installments on the completion of site work and the submission of the audit report to the plant. This rate varied somewhat by consultant and plant but was typically INR 40,000 to INR 65,000.

The motivation for energy audits as an intervention is the pervasive hypothesis that informational market failures may prevent the adoption of efficient technology. These failures could take two forms. First, asymmetric information between firms and service providers may deter adoption of efficient technologies. If firms are not able to independently evaluate the returns on energy-efficiency investments, energy consultants may oversell their services and drive wary firms to shade their expectation of returns or drop out of the market (DeCanio and

[3]This restriction also has a policy motivation, in that most subsidized energy-audit programs restrict eligibility based on a maximum threshold for electricity load.

Watkins, 1998; Howarth et al., 2000). Second, information about efficiency may be undersupplied in the market because it is a public good. A plant discovering, testing or disseminating a technology in its industry can benefit competitors by providing an example. Because plants do not take this common benefit into account, there will be too little information about efficiency supplied by the market (Anderson and Newell, 2004; Rohdin et al., 2007). The energy audit intervention overcomes these obstacles by providing information about energy-efficiency, specific to each plant and free of cost.

Energy manager treatment. A random subset of plants that complete energy audits and are interested in implementation are offered an energy manager to help in implementing audit recommendations, or otherwise helping the plant conserve energy. In this treatment consultants depute an engineer to visit the plant for approximately 12 man-days over the course of several months, as decided jointly with the plant owner. This energy manager is responsible for identifying the most promising audit recommendations, procuring equipment, overseeing installation and training plant staff on any equipment or process changes. Consultants were paid at a flat rate of INR 35,000 to 45,000 for the energy manager treatment, in two installments on the submission of progress and final reports.[4]

The motivation for energy managers as an intervention is to test the relation between skilled labor and technology adoption. A leading alternative to informational hypotheses is that efficient technology is complementary to other productive factors, especially skilled labor. Small plants relying on unskilled labor may therefore rationally choose to be less efficient—there is no use adopting sophisticated process controls that plant staff cannot operate. In this view, engineering estimates of technology savings miss the hidden costs of complementary productive inputs. A related hypothesis is that plant owners or managers, though skilled, may have a limited span-of-control over plant operations that limits the growth of productive plants or firms. The energy manager intervention overcomes this obstacle by providing skilled labor directly and monitoring that labor externally. If plants are skill-constrained, then those provided energy managers should adopt a broader set of technologies and save more energy than those provided audits alone.

[4]This rate appears lower per man-day than energy audits because (a) energy audits involve additional off-site analysis work (b) energy audits require the use of measurement instruments (c) the scheduling for energy managers is more flexible and hence the opportunity cost of time lower.

3 Data and Summary Statistics

Data on plant characteristics and outcomes was collected from three sources, a brief baseline survey, the treatments themselves and an extensive endline survey.

First, prior to the treatments and coincident with the offer of energy consultancy to plants, energy consultants and research staff conducted a brief baseline survey covering plant characteristics and aggregate energy use and expenditure. This baseline was carried out for the full sample through in-person interviews with plant owners or managers, who signed and stamped the survey form to register their interest in energy consultancy services. Second, energy consultants collected additional data during the treatments. In the energy audit treatment, consultants record aggregate energy use and record the efficiency of important plant systems. For example, consultants will measure the rate of fuel input and sources of heat loss for a boiler to calculate its thermal efficiency. Energy audit reports then project, based on such calculations, what amount of energy and money would be saved were the plant to modify its operating practices or invest in new equipment. In the energy manager treatments, consultants recorded their work and the measures that plants adopted.

The third and final source of data is an endline survey that unifies the economic and technical measurement of energy efficiency. On the economic side, surveyors with the research team interview the plant owner or manager, in the plant office, to collect plant-level characteristics, fuel consumption, electricity consumption, experience with energy consultancy or audit, inputs, outputs and production. Electricity consumption is the primary energy use outcome because it is available for all plants and is very well-measured, by recording metered demand from electricity bills. Many plants also consume a variety of fuels as a primary energy source to generate heat. The survey records fuel consumption and expenditures, which are available from bills for natural gas but from plant records or the managers estimation for most other fuels (e.g. coal, wood).

On the technical side, the survey employed experienced energy consultants, typically chemical or mechanical engineers, to measure the operating efficiency of the plant at the level of individual pieces of equipment. The survey covered both thermal and electrical energy use by all major systems in the plant. Thermal systems include the boiler, steam distribution system and process equipment, such as jet-dyeing machines or chemical reaction vessels, that employ steam. Electrical systems include the plant-wide electricity distribution system as well as individual motors, air compressors and pumps that draw most of the plants' load. Critically, when the survey did not cover all equipment of a certain type, each piece of equipment to be measured was selected using a structured process that did not reference the recommendations of plant energy audits in the treatment group, ensuring that the equipment selected for measurement would be comparable across the treatment and control groups.

Figure 1 summarizes the dispersion in energy use among sample plants using baseline data. The horizontal axis gives the annual sales of the plant and the vertical axis the annual energy bill, summing fuel and electricity bills, for both textile (Panel A) and chemical (Panel B) plants. The solid curve is a quadratic fit. Focusing on the textile plants, there are three facts of interest in the figure. First, the energy consumption of sample plants is a large fraction of sales. The best estimate is that a textile plant with USD 2m of annual sales spends about USD 400 thousand on energy, or 20% of *sales*, let alone costs. Second, energy consumption increases only gently with plant sales. Firms with greater sales either command higher prices or produce with less energy. Third, at any given level of sales, there is significant dispersion in energy use, in the range of 2-3 fold. The picture of chemical plants, in Panel B, is similar, although both the scale of plants and their energy intensity is lower. Taken together, these facts suggest wide dispersion in the efficiency of energy use among sample plants.

Table 2 compares treatment and control plants using baseline survey data. Column (1) gives mean values, standard deviations, and sample sizes for each variable for treatment plants, and column (2) the same statistics for the control. Column (3) reports differences estimated as the coefficient on energy audit treatment assignment in a regression of the baseline value of each variable on treatment assignment and strata fixed effects. While sample plants are mostly classed as small- and medium-enterprises, they are quite large operations. The average sample plant has 83 employees, sales of about USD 1.8 million and half a million dollars in capital.[5] Treatment and control firms are statistically balanced on these measures. Sample plants spend USD 84,000 on electricity and USD 112,000 on fuel in a year, or about 11% of sales. The audit treatment was stratified on these energy bills, so it is not surprising that treatment and control plants are tightly balanced on these variables at baseline. Plants

[5] The Indian government defines small- and medium-enterprises (SMEs) as having capital stock less than INR 10 million and offers various subsidies to SMEs, which together create an incentive to understate capital investment. Employment and sales are probably more reliable measures of firm size in this context.

use a variety of fuel sources, including lignite (low-grade, brown coal, 30% of the sample) to coal (21%), diesel oil (13%) and natural gas (51%). The one significant difference noted between the treatment and control groups is that treatment plants are significantly less likely (8 percentage points on a base of 55% in the control, p-value ¡ 0.10) to use natural gas. Fuel use is not mutually exclusive, as plants may switch from one fuel to another.

4 Results

(a) Projected Returns to Energy-Efficiency

Energy audits give recommendations to plants, based on projected energy savings and likely investment costs, on what measures they could take to profitably save energy. Many past studies of energy-efficiency have relied on such projections to argue for high returns, and it is informative to see what returns consultants project in the study sample.

Table 3 shows summary statistics on the measures recommended in energy audits. For each of nine categories of efficiency measure, column (1) gives the share of plants with some recommendation in that category, column (2) the number of recommendations conditional on any being offered, columns (3) and (4) give the mean and median investment size, in INR, and column (5) the median annual return as a fraction (1.00 = 100%) (the mean return is misleading, as some investments with small ticket sizes have very high implied returns). The most commonly recommended measures, for about 80% of plants, are motor sizing or efficiency and lighting, which are basic but prominent sources of electricity consumption. Some recommendations concern changing the connected load of the plant or controlling its power factor, in order to reduce energy bills without substantially changing energy use. On the side of conserving thermal energy, the most commonly recommended measures are insulation or heat recovery systems, whereby heat lost in transport or process is partially transferred back and to preheat boiler inputs and reduce fuel consumption.

Most investments have fairly small up-front investments and extraordinarily high up-front returns. As shown by column (3), average investments for most measures range from INR 20,000 to INR 150,000, a marginal addition to capital for sample plants. Figure 2 shows the distribution of investment sizes by measure in bins of INR 10,000 up to the 97.5th-percentile of investment. The distribution is very right-skewed–most recommended measures have small ticket sizes. Because energy savings are projected to be significant, however, returns on investment are very high. Returning to Table 3, the lowest median investment of any category of measure, air compressors, has a return of 80% per year, and most measures have median returns from 100-200% or more.

What do these audit recommendations add up to? Figure 3 gives the aggregate projected returns to energy-efficiency, scaled by dividing by the number of audited plants to reflect investments and energy bill savings for the average plant. The horizontal axis gives the required investment in energy-saving measures and the vertical axis the projected energy savings per year. Measures are ordered by decreasing returns so that the cumulative investment curve is concave. The dashed line gives, on the same scale, the slope of an investment with a 50% annual return. Two points stand out in the figure. First, returns are very high to start; the first INR 200,000 of investment yields nearly INR 600,000 of projected energy savings *per year*, dwarfing a comparison investment with a 50% annual rate of return. Second, returns rapidly diminish. The slope of the cumulative projected returns levels out and consultants offer an average of just over INR 600,000 per plant of recommended measures, which is only a modest 2% of firm capital stock. Energy-saving investments are thus projected to be limited but extremely cost-effective.

(b) Treatment Effects on Investment and Energy Use

This section considers the effects of the energy audit treatment on plant investment and energy use. The analysis is limited to the effects of the energy audit treatment, and not the energy manager treatment, as the endline survey is incomplete and the effective sample for the energy manager treatment very small. Ongoing analysis will also bring in the technical side of the endline survey to describe the physical efficiency of sample plants.

A primary outcome of interest is the extent to which sample plants adopt audit recommedations and invest in energy-efficiency, through equipment upgrades or maintenance of existing equipment. Table 4 shows the amount of investment in equipment upgrades and maintenance over the 12 months prior to the endline survey by energy audit treatment status. Column (1) gives the investment in the treatment, (2) in the control and (3) the difference between the two, estimated as the coefficient on treatment from a regression of each variable on energy audit treatment status and a set of strata fixed effects. Overall, treatment plants are estimated to invest INR 25,425 (standard error INR 17,953, p-value 0.16) more than control plants, which is modest and, given these estimates use data on only half the total sample, not significant at conventional levels. Approximately 60% of the increase in expenditure is estimated to come from maintenance investments, rather that upgrades or replacements of equipment. Maintenance includes such measures as rewinding motors, tensioning belts, repairing insulation and the like. On balance, treatment plants appear to invest modestly more than control plants.

Energy use, and in particular electricity bills, are measured more accurately than investments because electricity consumption is observed every month and recorded on formal bills. Table 5 reports the effect of the treatment on energy consumption. The regression specification is:

$$Electricity_{sim} = \beta_0 \times EnergyAuditTreatment_{si} + \alpha_s + \varepsilon_{sim},$$

where electricity consumption or bills in month m for plant i belonging to baseline strata i is regressed on a dummy for treatment assignment and strata fixed effects α_s for the energy-bill strata within which the energy audit treatment was randomly assigned. The sample is limited to energy bill observations after the audit treatment was implemented and the error term is clustered at the plant level to account for serial correlation in energy bills. The sample includes 210 plants and the average plant has 11 observations for monthly electricity consumption.

Table 5 presents estimates with metered electricity demand in kWh as the dependent variable. Assignment to the energy audit treatment is associated with an increase in energy demand of 18,541 kWh (standard error 7,470 kWh) on a base of 83,390 kWh in the control (or 22% of control consumption). This estimated increase is significantly different from zero at the 5% level, and the lower bound of the 95% confidence interval is a rise in energy use of about 5%. Energy bills rise a corresponding amount. Total energy bills, shown in column (2), increase INR 133,641 (standard error INR 50,567) per month, with nearly all of this due to increase variable charges for energy consumption (column 3). This higher electricity consumption is striking given the modest scale of investment that treatment plants are estimated to have undertaken, and implies a very high use-elasticity of energy services.

5 Conclusion

Given that data collection is incomplete and the analysis preliminary it would be inappropriate to conclude with regard to the early findings reported. I will instead briefly lay out the outstanding questions this analysis raises. First, to what extent did the energy audit treatment and the energy manager treatment change the operating efficiency of the plant? Even with modest investments, it is possible that, with high investment returns or changes in operating practices, treatment plants became significantly more efficient. Second, given measured changes in plant physical efficiency, what do changes in energy use imply about the use-elasticity of energy services. The second question forms a direct bridge to the productivity literature. One reason to expect that plants may have a larger energy-efficiency rebound than consumers is that firms compete in product markets and more efficient firms lower prices and gain market share. Testing this product-market channel is an important avenue for future research.

References

Allcott, H. and Greenstone, M. (2012). Is there an energy efficiency gap? *Journal of Economic Perspectives*, 26(1):3–28.

Anderson, S. and Newell, R. (2004). Information programs for technology adoption: the case of energy-efficiency audits. *Resource and Energy Economics*, 26(1):27–50.

Banerjee, A. V. and Duflo, E. (2005). Growth theory through the lens of development economics. *Handbook of economic growth*, 1:473–552.

Bartelsman, E., Haltiwanger, J., and Scarpetta, S. (2013). Cross-country differences in productivity: The role of allocation and selection. *American Economic Review*, 103(1):305–34.

Bloom, N., Eifert, B., Mahajan, A., McKenzie, D., and Roberts, J. (2013). Does management matter? evidence from india. *The Quarterly Journal of Economics*, 128(1):1–51.

Borenstein, S. (2013). A microeconomic framework for evaluating energy efficiency rebound and some implications. *National Bureau of Economic Research Working Paper*, (19044).

DeCanio, S. and Watkins, W. (1998). Investment in energy efficiency: do the characteristics of firms matter? *Review of Economics and Statistics*, 80(1):95–107.

Energy Information Administration (2013). International energy outlook 2013. *Energy Information Administration, U.S. Department of Energy.*

Howarth, B. et al. (2000). The economics of energy efficiency: insights from voluntary participation programs. *Energy Policy*, 28(6-7):477–486.

Hsieh, C.-T. and Klenow, P. J. (2009). Misallocation and manufacturing tfp in china and india. *The Quarterly Journal of Economics*, 124(4):1403–1448.

Jaffe, A. and Stavins, R. (1994). The energy-efficiency gap What does it mean? *Energy Policy*, 22(10):804–810.

Rohdin, P., Thollander, P., and Solding, P. (2007). Barriers to and drivers for energy efficiency in the Swedish foundry industry. *Energy Policy*, 35(1):672–677.

Sorrell, S., Dimitropoulos, J., and Sommerville, M. (2009). Empirical estimates of the direct rebound effect: A review. *Energy policy*, 37(4):1356–1371.

Syverson, C. (2004a). Market structure and productivity: A concrete example. *Journal of Political Economy*, 112(6).

Syverson, C. (2004b). Product substitutability and productivity dispersion. *Review of Economics and Statistics*, 86(2):534–550.

Syverson, C. (2011). What determines productivity? *Journal of Economic Literature*, 49(2):326–365.

Train, K. (1985). Discount rates in consumers' energy-related decisions: a review of the literature. *Energy*, 10(12):1243–1253.

6 Figures

Figure 1: Energy Consumption Against Sales

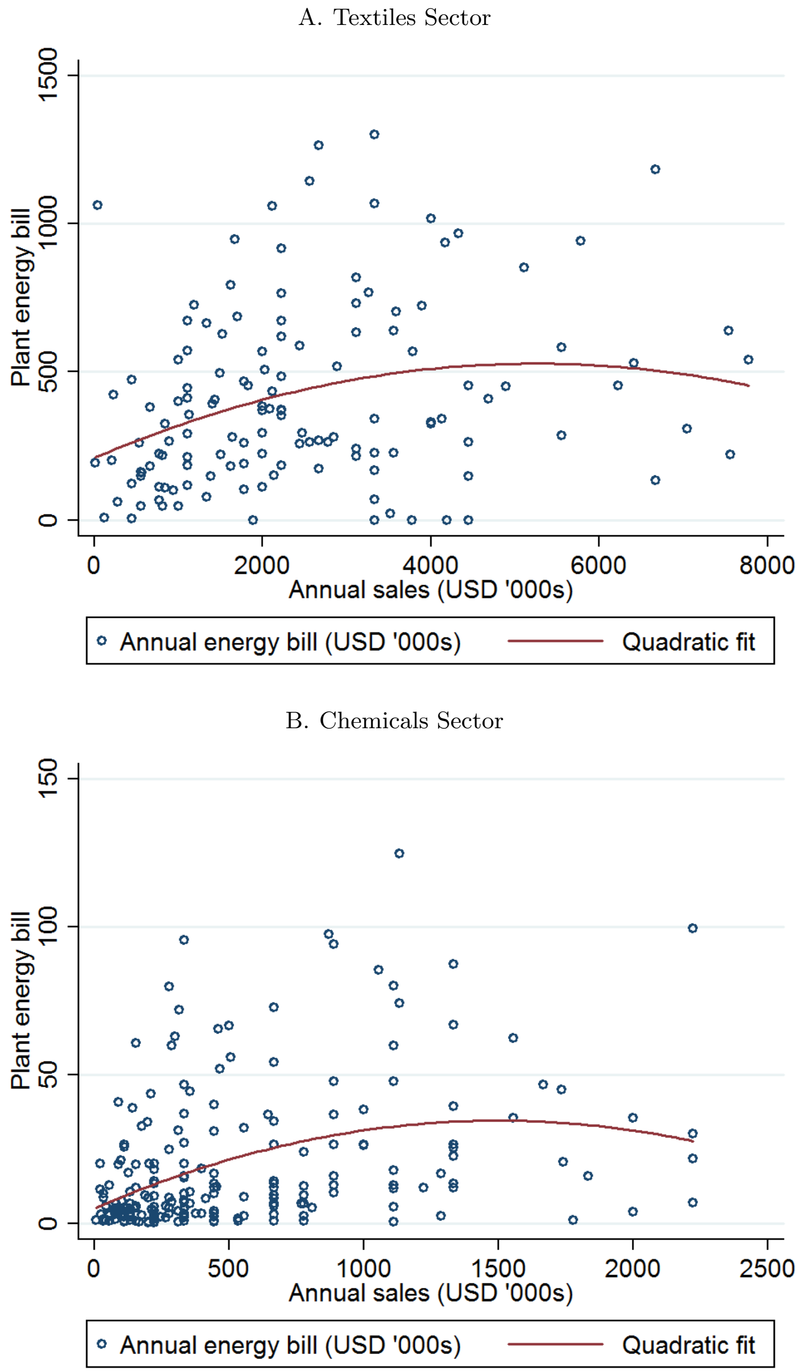
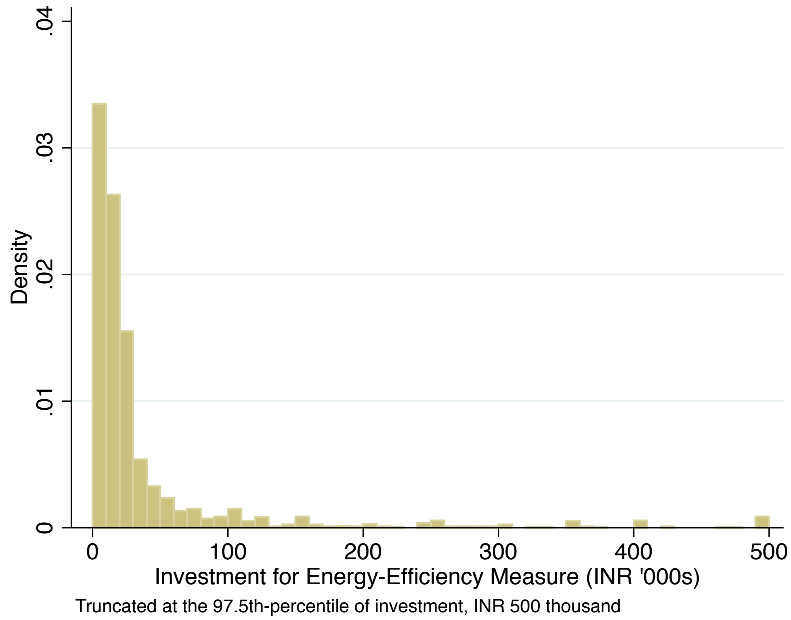
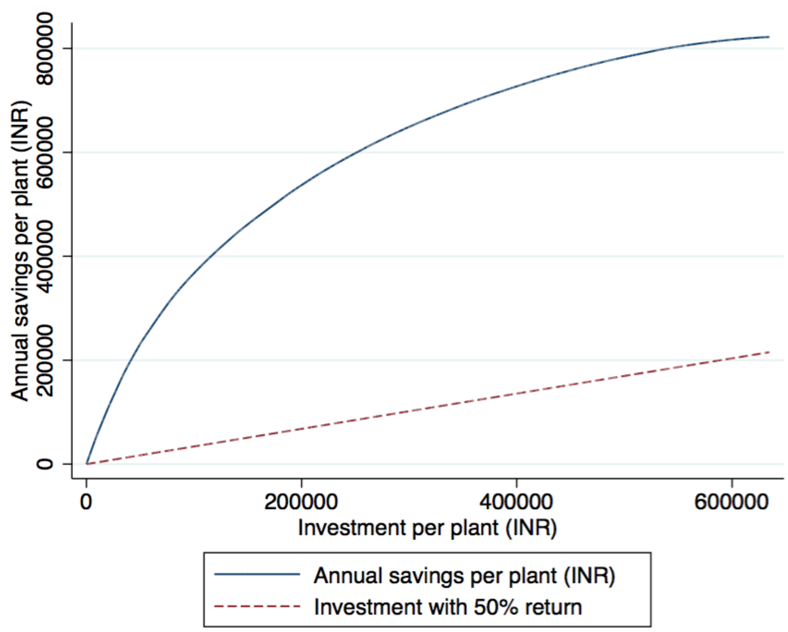


Figure 2: Energy-Efficiency Investment Sizes



The figure shows the distribution of investment costs for measures recommended in energy audits, truncated at the 97.5th percentile. The investments are for 1,959 different measures recommended to 176 treatment plants. Each bin is INR 10,000 wide.

Figure 3: Projected Returns to Energy-Efficiency



The figure shows aggregate projected returns to energy-efficiency, scaled by dividing by the number of audited plants to reflect investments and energy bill savings for the average plant. The horizontal axis gives the required investment in energy-saving measures and the vertical axis the projected energy savings per year. Measures are ordered by decreasing returns so that the cumulative investment curve is concave. The dashed line gives, on the same scale, the slope of an investment with a 50% annual return.

7 Tables

Table 1: Plant Interest in Energy Audit

	Plant interest	
	(1) Number	(2) Percent
Interested	490	53.0
Not interested		
Already have consultant	38	4.11
Energy not a large cost	40	4.32
Scope of savings not large	50	5.41
Other	307	33.2
Total	925	100

Table 2: Balance of Covariates by Treatment

	Treatment (1)	Control (2)	Difference (3)
Contract demand (kVA)	200.9	191.9	8.98
	[172.1]	[171.7]	(16.5)
	217	216	433
Electricity bill (Annual USD 000s)	85.7	82.6	3.08
	[109.9]	[106.3]	(10.4)
	217	216	433
Fuel bill (Annual USD 000s)	110.2	114.9	-4.63
	[428.5]	[275.0]	(34.6)
	217	216	433
Employees	83.6	82.7	0.97
	[112.7]	[117.5]	(11.2)
	215	207	422
Capital (USD 000s)	529.0	581.6	-52.6
	[750.3]	[813.1]	(81.4)
	186	183	369
Sales (USD 000s)	1677.2	1809.9	-132.7
	[2427.7]	[3725.4]	(320.2)
	195	188	383
Uses lignite (=1)	0.29	0.32	-0.029
	[0.46]	[0.47]	(0.045)
	217	216	433
Uses coal (=1)	0.23	0.19	0.036
	[0.42]	[0.39]	(0.039)
	217	216	433
Uses diesel oil (=1)	0.11	0.16	-0.051
	[0.31]	[0.37]	(0.032)
	217	216	433
Uses gas (=1)	0.47	0.55	-0.081*
	[0.50]	[0.50]	(0.048)
	217	216	433

Standard errors in parentheses, standard deviations in brackets.
Sample sizes beneath standard deviations for each column..
Regressions for difference include audit strata fixed effects.
* p lt 0.10, ** p lt 0.05, *** p lt 0.01

Table 3: Frequency of Energy-Saving Measures

	Measure Prevalence		Investment Size (INR)		Return
	Plant Share (1)	Number if Any (2)	Mean (3)	Median (4)	Median (5)
Lighting	0.82	1.57	58905	13625	0.94
Motor sizing / efficiency	0.78	10.13	46890	16250	1.02
Insulation	0.46	2.17	21442	11700	2.15
Electricity Tariff	0.42	1.40	26275	12000	4.98
Heat Recovery	0.39	1.27	268057	251168	2.99
Maintenance / Other	0.23	1.38	71135	25000	23.10
Automation	0.10	1.06	90781	30000	1.82
Compressors	0.09	1.20	157288	50000	0.80
Drives / belts / pulleys	0.07	1.91	119993	90000	0.94

Table 4: Investment in Equipment by Audit Treatment Status, Stratified

	Treatment (1)	Control (2)	Difference (3)
Equipment, total expenditure (Rs)	43589.2	35228.1	25425.2
	[114674.5]	[81809.1]	(17953.2)
	111	110	221
Cost of upgrades (Rs)	21851.4	22302.7	9509.7
	[66034.1]	[76323.6]	(12742.0)
	111	110	221
Cost of maintenance (Rs)	21737.8	12925.4	15915.5
	[80677.8]	[36161.1]	(11117.4)
	111	110	221

Standard errors in parentheses, standard deviations in brackets.
Sample sizes beneath standard deviations for each column..
Regressions for difference include audit strata fixed effects.
* p lt 0.10, ** p lt 0.05, *** p lt 0.01

Table 5: Electricity Consumption on Audit Treatment

	Electricity bill		
	Metered demand (kWh) (1)	Total (INR) (2)	Variable (INR) (3)
Audit treatment assignment (=1)	18541.4**	133640.8***	124739.4**
	(7470.1)	(50567.3)	(48533.5)
Control mean	83390.2	521678.0	503593.5
Observations	2299	2267	2267
Plants	210	207	207
Observations Per Plant	10.9	11.0	11.0

Standard errors in parentheses

Regressions include audit strata fixed effects.

Standard errors clustered at the plant level in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$