WPS6383

Policy Research Working Paper 6383

Impact Evaluation Series No. 87

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March 2013

Abstract

Electricity infrastructure is one of the most important development challenges in Africa. While more resources are clearly needed to invest in new capacities, it is also important to promote energy efficiency and manage the increasing demand for power. This paper evaluates one of the recent energy-efficiency programs in Ethiopia, which distributed 350,000 compact fluorescent lamp bulbs free of charge. The impact related to this first phase is estimated at about 45 to 50 kilowatt hours per customer per month, or about 13.3 megawatts of energy savings in total. The overall impact of the compact fluorescent lamp bulb programs, thanks to which more than 5 million bulbs were distributed, could be significantly larger. The paper also finds that the majority of the program beneficiaries were low-volume customers—mostly from among the poor—although the program was not targeted. In addition, the analysis determines the distributional effect of the program: the energy savings relative to the underlying energy consumption were larger for the poor. The evidence also supports a rebound effect. About 20 percent of the initial energy savings disappeared within 18 months of the program's completion.

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IMPACT EVALUATION OF FREE-OF-CHARGE CFL BULB DISTRIBUTION IN ETHIOPIA

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Key words: Impact evaluation; energy efficiency program; fixed-effect least-squares, fixed-effect quantile regression.
JEL Classification: C33; C36; L94.

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[¶] We would like to express our special thanks to the Ethiopian Electric Power Corporation (EEPCO) and to the World Bank Country Office in Ethiopia for their close collaboration in data collection for this analysis. We also thank Luis Andres and other Bank colleagues for their insightful suggestions.

I. INTRODUCTION

1. Electricity infrastructure is one of the most important development challenges in Africa. Access to electricity is very limited across the continent. Globally, it is estimated that roughly 1.3 billion people live without access to electricity (IEA 2011). In Sub-Saharan Africa, about 585 million people, or approximately 70 percent of the total population in the region, are still living without access to power. In rural areas in particular, the electrification rate is still as low as 14 percent. In addition, many of those with nominal access to electricity face frequent, if not chronic, power outages.

2. Significant resources are required to meet the existing infrastructure deficiencies. While the region's annual spending needs are estimated at US$40.8 billion in the power sector, only US$11.6 billion is currently available (World Bank 2010). In Africa, new investment in the energy sector is generally expensive. An additional 1 MW of installed capacity would cost between US$0.3 and US$0.5 million per annum (Figure 1). Improving energy efficiency is among the important measures required to meet these gaps.

3. In theory, energy efficiency is an inexpensive win-win proposition, particularly when supply capacity is severely constrained, as it is in many African countries.[1] While end users can reduce their energy spending, power utilities can avoid costly new investment in developing their capacity. At the same time, manufacturers and vendors of energy-efficient technology can profit from the sale of energy goods or services. Moreover, energy efficiency can contribute to mitigating the effects of global warming. Africa is not a major CO^2 emitter at present; the region only accounts for some 3 percent of total CO^2 emissions, while about 15 percent of the world's total population resides there. However, among other developing regions, Africa is projected to be among the most vulnerable to climate change and possible extreme events.

4. One of the most important development efforts currently under way in Africa is the Lighting Africa Initiative, which aims to provide power access to 250 million people by 2030. The initiative seeks to promote private sector participation in the regional home appliance market to encourage the widespread distribution of energy-efficient goods and equipment, such as compact fluorescent lamp (CFL) bulbs, as well as the development of renewable energy sources, such as solar, wind and micro hydro power. Thanks to this initiative, roughly 3.8 million people have already received new access to clean, safe lighting as of 2012.[2]

5. A number of residential CFL bulb distribution programs have been implemented all over the world, including in the Philippines, Rwanda, Thailand, Uganda and Vietnam (e.g., World Bank 2006; ESMAP 2009). Recently, Ethiopia carried out a series of CFL bulb distribution programs. From an engineering point of view, these programs clearly contribute

[1] In practice, there are various institutional challenges to promoting the adoption of energy efficiency measures, e.g., long payoff periods and market failure to finance upfront large investment (see Singh et al. 2010, for example).

[2] http://www.lightingafrica.org/

to energy conservation. For instance, the CFL program in Vietnam, in which a total of 1 million CFL bulbs were distributed at favorable prices, is estimated to have reduced peak demand by 31MW (ESMAP 2009).[3] This figure is calculated based on the wattage differentials between old and new lamps. There is similar discussion in the literature on other energy-efficiency goods and equipment, such as agricultural pumps (e.g., Garg et al. 2011).

6. From an economic point of view, however, these engineering calculations may overlook at least three important aspects related to the impact of a CFL bulb program. First, the distribution of new bulbs does not automatically lead to their actual use. People may or may not use them as expected. In Vietnam, the original assumption was that a 75W incandescent lamp would be replaced with a 20W CFL. However, many households replaced old CFLs with new CFLs. As a result, the impact on the peak power demand turned out to be smaller than the engineering estimate had anticipated (ESMAP 2009).

7. Second, engineering calculations cannot capture the distributional impact that the CFL program might have. Many CFL bulb distribution programs are implemented on a voluntary participation basis. Thus, it remains open to argument who the major beneficiaries ultimately are, and exactly how they benefit from these programs. Notably, the ways of using electricity vary significantly between the rich and the poor segments of the population. In developing countries, lighting is the most basic power demand among the poor. But the potential savings from CFL bulbs may not be as significant for the rich, who use electricity for many other purposes.

8. Finally, related to the above, people's behavior can be changed by the energy efficiency program. On one hand, the CFL bulb distribution—either free of charge or at deep discounts—could raise awareness with respect to energy efficiency and global warming, motivating people to conserve more energy on other occasions. For example, the Brazilian temporary electrification rationalization is found to have had a long-term effect. The temporarily limited electricity supply encouraged customers to purchase more energy-efficient home appliances, leading to long-term energy savings even after the supply constraint eased (Costa 2012). On the other hand, rebound or backfire effects may occur, as observed in many cases related to energy-efficient technologies. For instance, a more fuel-efficient car may motivate people to actually drive more, not less.[4]

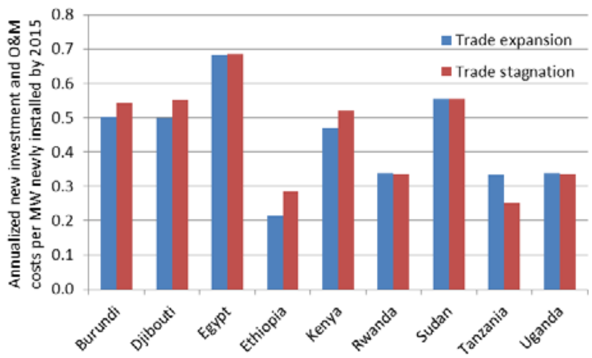
9. The current paper casts light on these issues by evaluating the energy-saving impact of a free CFL distribution program in Ethiopia. To remove possible self-selection bias, the fixed-effects model is applied for the panel data. To investigate the distributional impact, a two-step fixed-effects quantile regression (Canay 2011) is also used. The following sections are organized as follows: Section II briefly explains recent developments in the Ethiopian

[3] The average wattage of the old lamps was 58W. These were replaced with 20W CFL bulbs. With a usage factor taken into account, it is estimated that 31MW of peak demand was reduced.

[4] Evidence shows that the short- and long-term rebound effects of vehicle fuel efficiency are 4.5 percent and 22 percent, respectively (Small and van Dender 2007). The literature reports even larger rebound effects of about 50-60 percent (Frondel and Vance 2010; Frondel, Ritter, and Vance 2012). In a much broader context, the rebound effect for various GHG abatement actions is estimated at 34 percent in the UK (Druckman *et al*. 2011).

electricity sector; Section III describes the program's context; Section IV develops our empirical strategy; Section V presents main estimation results and discusses several policy implications; finally, Section VI concludes.

Figure 1. Annualized investment and O&M costs in Africa (US$ million per MW)



Source: Rosnes and Vennemo 2009.

II. Recent Power Sector Developments in Ethiopia

10. Despite rapid growth in recent years, the electricity system in Ethiopia remains largely underdeveloped. The Ethiopian Electric Power Corporation (EEPCO) currently has about 2.1 million customers (approximately 13 million people). This accounts for an electrification rate of 14 percent, with about 45 percent of the country's towns and villages connected. Power access is particularly limited in rural areas; only 2 percent of rural residents have access to power. Estimated average power consumption per capita per annum remains modest even by Sub-Saharan African standards, at 33-200 kWh. In addition, the quality of electricity service is problematic. On average, end users experience power outages 44 days per year (Foster and Morella 2010).

11. Ethiopia has great hydro potential for electricity generation. The long-term marginal cost of power generation is estimated at US$0.04 per kWh, which is much lower than that of neighboring countries. It is estimated that Ethiopia could earn significant revenue by power trading in the East Africa corridor, if all the necessary technical and institutional mechanisms were in place. It will take some time, however, for the country to develop its potential hydro capacity to serve the regional market.

12. In recent years, the Government of Ethiopia and the EEPCO, with the support of the international donor community, have been ramping up their efforts in two specific areas: the Universal Electric Access Program (UEAP) and demand-side management. EEPCO is a state-owned electricity utility, which is responsible for roughly 2,000 MW of installed capacity and 126,000 km of distribution network. Since the early 2000s, EEPCO has been investing heavily in the expansion of power access in rural and remote areas. Over the past five years, the company electrified approximately 5,000 villages (Figure 2). The total customer base of EEPCO increased from 800,000 in 2005 to 2 million in 2011. Still, there

are about 11,000 villages that remain without access to power. Further network expansion is required in order to achieve a national target of 75 percent electrification by 2015.

13. While developing its power-generation and transmission capacity, EEPCO has also been implementing a series of energy-efficiency programs at the end user level. It aims to manage the increasing demand for electricity and to simultaneously conserve energy. The first CFL bulb distribution program was carried out in June-August 2009, during which 350,000 CFL bulbs were distributed free of charge. CFL bulbs were allocated nationwide according to the number of customers that each service center covered. As a result, the vast majority of bulbs were distributed to Addis Ababa and surrounding areas. The program design was simple: each customer could obtain a maximum of four CFL bulbs in exchange for old incandescent light bulbs. More than 98 percent of beneficiaries in our sample traded in all four bulbs. Importantly, the program was not a random or targeted distribution of bulbs. Customers had to bring their old light bulbs to the nearest EEPCO service center.

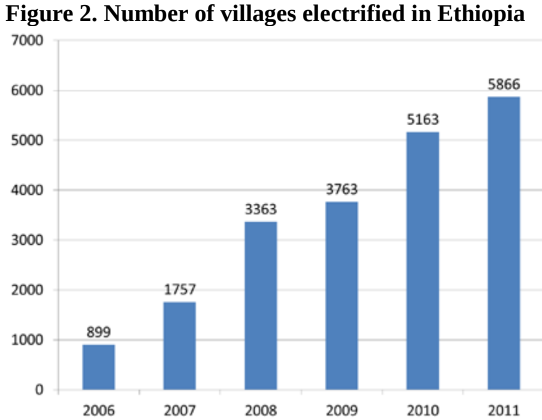
14. Following the successful implementation of the first phase, the second and third CFL bulb distribution programs were implemented in July 2011 and January 2012, respectively. In total, 9.5 million CFL bulbs were distributed. The main difference from the first phase was that, in the latter two phases, CFL bulbs were not distributed free of charge but sold at a significant discount (Table 1). For instance, customers paid EEPCO 7 Ethiopian Birr (or US$0.40) for an 11W CFL bulb, while the market price was about Br 25 (or US$1.42). The differential between the program and market prices was financed by EEPCO and international development agencies.

Table 1. CFL bulb market and subsidized prices

	EEPCO-subsidized price	Market price
11W	Br 7 (US$0.40)	Br 25 (US$1.42)
15W	Br 8 (US$0.45)	Br 27 (US$1.54)

Sources: EEPCO and authors' own data.

Figure 2. Number of villages electrified in Ethiopia



Source: EEPCO.

III. THE PROGRAM TO BE EVALUATED AND OUR DATA

15. The current impact evaluation focuses on the first phase of the CFL bulb distribution program, implemented in 2009. In collaboration with EEPCO, the electricity consumption data were collected in Addis Ababa's Bole-Kazanchis Service Area. This service center covers 13,000 customers in total; about 3,500 customers benefited from the program and received CFL bulbs (most exchanged four, as mentioned above).

16. In our sample, 2,000 customers were randomly selected from a group of CFL beneficiaries (i.e., treatment group). Another 2,000 customers were also randomly selected from a group of customers who did not benefit from the program (i.e., control group). Each customer's monthly energy consumption and bill data were collected from January 2007 to August 2012. The sample period was intended to cover several years prior to and following implementation of the program, so that the program impact could be clearly distinguished from the trend component of the electricity demand. In our sample, 60 percent of beneficiaries received CFL bulbs in June 2009, and the rest received them in July 2009. The lengthy follow-up period allows for examination of the long-term effect of the program on people's energy use.

17. According to engineering calculations, it is estimated that about 7.2 MW of energy could be saved by the first CFL program (Table 2). The differentials between old incandescent bulbs and new, efficient CFLs are 29W to 80W. Assuming that everything else remains constant, in theory, the demand for electricity would drop by 7.2 MW immediately after implementation of the program. This represents approximately 1 percent of EEPCO's installed capacity. Recall that the first phase was implemented as a pilot and scaled up in the second and third phases. Under the same assumptions, the second phase is expected to reduce energy consumption by as much as 90 MW. This would be equivalent to nearly 10 percent of the total power generation capacity in Ethiopia in 2009.

18. It may appear that this initiative would contribute significantly to energy conservation. However, its actual impact remains to be examined further. At first glance, electricity consumption indeed dropped among beneficiaries of the program (Figure 3). But consumption by non-beneficiaries also dropped following its implementation. Thus, the program's net impact remains questionable. Moreover, statistics also suggest that, in spite of the program, demand for electricity has been increasing over time, a fact that must also be taken into account. It is likely that demand for electricity tends to increase and become diversified as the economy grows. This is because current levels of consumption are very low and the demand is for primitive purposes. This raises the question as to whether the short-term impact of this type of initiative could be different from its long-term impact.

19. Figure 3 also indicates that levels of electricity consumption among the treatment group (i.e., program beneficiaries) are systematically different from those of the control group (i.e., non-beneficiaries). Thus, the problem of self-selection must be taken into account in the program's evaluation. Ultimately, the voluntary CFL bulb distribution program benefited the

poor. Recall that the program to be evaluated involved free-of-charge CFL distribution. All of these issues will be addressed in the following analysis.

Table 2. Engineering calculations of energy savings expected from the CFL bulb program

Incandes-cent bulb	CFL bulb	Savings per bulb	Phase 1 CFLs distributed	Power savings (MW)	Phase 2 CFLs distributed	Power savings (MW)
40W	11W	29W	192,500	5.6	2,802,000	81.3
60W	15W	45W	154,000	6.9	1,672,000	75.2
100W	20W	80W	3,500	0.3	38,000	3.0
			350,000	12.8	4,512,000	159.5
			(Coincidence factor)	0.56		0.56
			Estimated total power savings	7.2		89.3

Sources: Authors' own calculation based on data provided by EEPCO.

Figure 3. Average electricity consumption of CFL beneficiaries and non-beneficiaries

Sources: Authors' own calculation based on data provided by EEPCO.

IV. Methodology

20. To evaluate the impact of the CFL bulb distribution program on energy consumption, the following demand equation is considered:

$$kwh_{it} = \alpha CFL_{it} + X_{it}'\beta + \varepsilon_{it} \quad (1)$$

where kwh_{it} is the amount of electricity consumed by household i at time t. CFL_{it} is a dummy variable taking one if household i received CFL bulbs distributed under the program, and zero otherwise. X_{it} is a set of other covariates.

21. The ordinary least squares (OLS) estimator will be biased if self-selection is not taken into account. In general, the most important empirical issue in evaluating a program or policy intervention is that there are potentially unobservable factors affecting both program

participation and outcome. This will cause self-selection bias. In the CFL bulb context, some segments of the population may be more aware of environmental issues than others. Those who are more concerned about global warming and energy efficiency are perhaps more likely to adopt new energy-efficient technologies, such as CFL bulbs, and curb their use of energy. If this is the case, CFL_{it} is correlated with people's unobservable preferences, which are included in the error term ε_{it}. As a result, the program effect captured by coefficient α would likely be negative, regardless of the program.

22. To mitigate this problem, the fixed-effects model is used (e.g., Holl 2004; Khandker et al. 2009; Khandker and Koolwal 2011). Recall that our sample data are almost perfectly balanced for about 4,000 customers over the 67-month period (from January 2007 to July 2012). Thus, the individual- and time-specific fixed effects are included (c_i and c_t). These fixed effects will eliminate unobserved individual characteristics and time effects, mitigating the risk of self-selection bias.

$$kwh_{it} = \alpha CFL_{it} + X_{it}'\beta + c_i + c_t + \varepsilon_{it} \qquad (2)$$

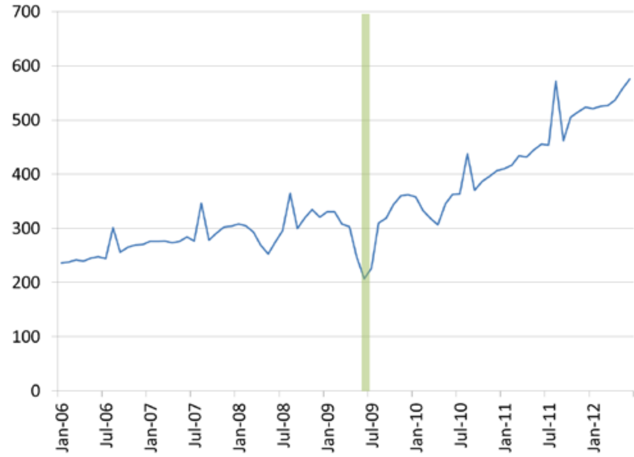
23. An alternative approach may be to assume some deterministic structure on time trend while keeping the individual fixed effects in the model. The time trend can be included in the quadratic form in time t. Given the fact that our sample data are monthly, a set of monthly dummy variables is also included (SA_t). Normally, electricity demand experiences seasonality from month to month.

24. An advantage of this specification is that it allows one to explicitly examine the effect of supply constraints. Despite the fact that the installed capacity has significantly increased over the past few years, the country recently faced a chronic power shortage. This is partly because of the rapidly growing electricity demand and partly due to Ethiopia's dependency on hydropower for electricity generation. The available capacity is highly dependent on weather conditions (e.g., Engida et al. 2011). For example, available capacity was among the lowest during the summer of 2009 (Figure 4). Thus, the total amount of electricity generated (GWh), $\overline{Q}_t$, is included in the equation. Since individual power consumption represents a tiny fraction of total power production, this supply constraint is assumed to be exogenous.[5]

$$kwh_{it} = \alpha CFL_{it} + X_{it}'\beta + c_i + \beta_Q \overline{Q}_t + T_t + T_t^2 + SA_t + \varepsilon_{it} \qquad (2')$$

[5] Our empirical results are found to be unchanged regardless of whether or not the supply constraint is included.

Figure 4. Total electricity produced in Ethiopia (GWh)



Source: EEPCO.

25. From an economic standpoint, at least two variables need to be included to estimate the electricity demand equation: marginal tariff rate (*MP*), and Nordin's (1976) difference variable (*D*). Neoclassical economic theory states that the price variable in the demand function should be a marginal price that a consumer faces, rather than the average price (computed as the total bill divided by total consumption).[6] In the electricity sector, the increasing block tariff structure is often adopted to rationalize people's power consumption.

26. Ethiopia has an increasing block tariff structure for electricity in an effort to curb the overconsumption of energy. The current tariff schedule has eight blocks, where the marginal rate increases with power consumption from Br 0.273 (or US$0.016) to Br 0.694 (or US$0.04) per kWh (Figure 5). This marginal rate should be included in the demand equation, denoted by MP_{it}. Taking the inflationary effect into account, the marginal rate is defined in real terms.[7] Thus, even if a customer consumes the same amount of electricity, the applicable marginal rate may vary across periods of time.

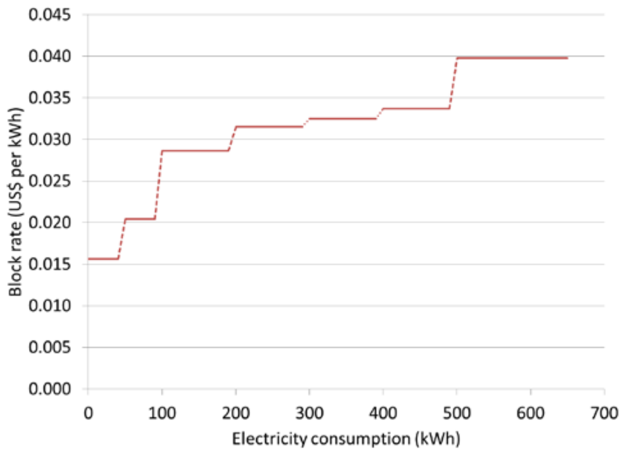
27. The increasing block tariff schedule causes positive implicit consumer surplus, which is referred to as the "Nordin's difference variable"—denoted by *D*. It is normally defined by the difference between the actual bill and what would be paid if the final block rate were applied to total consumption (Taylor 1975; Nordin 1976).[8] In the increasing block tariff case, the Nordin's *D* will be negative, except for those who consume less electricity than the first block threshold. In theory, the elasticity with respect to *D* should be the same as the income elasticity, but opposite in sign.

[6] There is a view according to which households are rarely aware of the detailed price structure or marginal prices associated with their energy consumption. But the marginal and average prices are eventually related to one another (e.g., Wilder and Willenborg 1975; Terza and Welch 1982; Nauges and van den Berg 2009).

[7] The monthly consumer price index (CPI) data come from the IMF International Financial Statistics.

[8] This is also referred to as "virtual income" by Hausman *et al.* (1979).

Figure 5. Block rates of electricity tariffs in Ethiopia



Source: EEPCO.

28. With *MP* and *D* included, the following specifications are considered:

$$kwh_{it} = \alpha CFL_{it} + \beta_{MP} MP_{it} + \beta_D D_{it} + c_i + c_t + \varepsilon_{it} \quad (3)$$

$$kwh_{it} = \alpha CFL_{it} + \beta_{MP} MP_{it} + \beta_D D_{it} + c_i + \beta_Q \overline{Q}_t + T_t + T_t^2 + SA_t + \varepsilon_{it} \quad (3')$$

Although the potential self-selection bias can be removed by the individual-specific fixed-effects c_i, Equations (3) and (3') cannot be estimated consistently by the conventional OLS. The reason is that the introduced marginal price and Nordin's *D* cause another endogeneity problem. In general, price and quantity are jointly determined in a supply-demand context. Thus, the simultaneity between price and quantity has to be addressed in order to estimate Equations (3) and (3'). Particularly under the block tariff framework, consumers may be able to choose the marginal price that would be applied by increasing or decreasing the amount of electricity that they use. In addition, the block pricing may also cause measurement errors, leading to biased results. Consumers are often uncertain about which marginal rate would be eventually applied before they receive the bills (Deller *et al*. 1986).[9] Therefore, price and quantity are endogenous and interdependent.

29. To deal with the simultaneity between price and quantity, we need extraneous information: i.e., instrumental variables. Following the traditional approach in the literature (e.g., Deller *et al.* 1986), *MP* and *D* are instrumented by their predicted values, based on the simple expansion of the definition of the Nordin's difference variable. To obtain the

[9] By contrast, time-of-day electricity pricing can provide the information of real-time consumption and prices to consumers with advanced meters. People may be responsive to the real-time meter readings, as experimented in Hausman *et al.* (1979).

predicted values, the actual bill payment is regressed on a constant term and the quantity of consumption:

$$Bill_{ij} = \gamma_{1j} + \gamma_{2j} kwh_{ij} + u_{ij} , \tag{4}$$

because $D_j = Bill_{ij} - MP_j * kwh_{ij}$. $Bill_{ij}$ is the amount of bill payment for customer *i*, who is faced with *j*th block marginal rate. Thus, the marginal price and Nordin's *D* can be instrumented by $\hat{\gamma}_{2j}$ and $\hat{\gamma}_{1j}$, respectively (Hewlett 1977). Note that $\hat{\gamma}_{2j}$ and $\hat{\gamma}_{1j}$ are block-specific predictions estimated from a separate regression for each *j*.

30. To estimate Equations (3) and (3'), the analysis uses the fixed-effects instrumental variable (FE IV) regression using Equation (4). This will remove the potential self-selection and simultaneity bias and provide a consistent estimate of the program impact, α. To assess the long-run impact of the CFL program, the lagged CFL impact is considered in the following specification:

$$kwh_{it} = \alpha_s CFL_{it-s} + \beta_{MP} MP_{it} + \beta_D D_{it} + c_i + c_t + \varepsilon_{it} \tag{5}$$

where CFL_{it-s} takes one if household *i* received CFL bulbs *s* months before, and zero otherwise. For instance, if $s=6$, α_s will capture the impact of using CFL bulbs at least for six months, because CFL_{it-s} is set at zero for 6 months after program implementation. By the same token, the long-term impact will be examined for $s = 1, \cdots, 24$.

31. Finally, a semi-parametric technique of quantile regression is also used to estimate the distributional impacts of the program. Quantile regression has the great advantage of capturing potential differences in the response of the dependent variable at different points. In our context, the program impacts can be different between low- and large-volume consumers. In addition, quantile regression can be more efficient than least squares estimators, if the error term is not normal (e.g., Buchinsky 1998; Koenker and Hallock 2001).

32. A two-stage fixed-effects quantile regression (2SFEQR) is applied for panel data. The 2SFEQR technique can provide an unbiased estimate as *T* increases (Canay 2011). A monte carlo simulation shows that with $T=20$, possible bias would be less than 0.04 percent. At the first stage, $\hat{c}_i$ and $\hat{c}_t$ are estimated through the standard IV fixed-effects OLS regression. By subtracting $\hat{c}_i$ and $\hat{c}_t$ from *kwh*, quantile regression is then performed on $\overline{kwh}_{it} = kwh_{it} - \hat{c}_i - \hat{c}_t$ at the second stage. Five quantiles are examined: 0.1, 0.25, 0.5, 0.75 and 0.9.

V. Main estimation results and policy implications

33. First of all, the fixed-effects OLS regression is performed. The estimated CFL bulb impact is found to be negative (Table 3). But this could be potentially biased, as discussed above. Importantly, the coefficient of the marginal price turned out to be positive when both individual and time-fixed effects are included. This contradicts economic theory. It occurred because the endogeneity between price and quantity has not yet been properly solved. Under the increasing block tariff schedule, higher block rates are applied to larger-volume consumers. The positive coefficient captured this correlation, not true price elasticity of demand.

34. To control for endogeneity, the instrumental-variable fixed-effects (IV FE) regression is used. The unbiased impact of the CFL bulb distribution is estimated at about 45-50 kWh. When both individual and time-fixed effects are included, the coefficient of *CFL* is estimated at -45. When putting a structure on the time component, the coefficient is about -50. Both are statistically significant. Therefore, it can be concluded that the program reduced electricity consumption by 45-50 kWh per customer.

35. This magnitude of impact seems to be consistent with the engineering calculations. Assuming that people use CFL bulbs 10 hours every day, the estimated coefficient can be translated to about 150 watts of energy savings. Since most program beneficiaries traded in four bulbs, the implied energy savings are 38 watts per bulb. This is broadly consistent with the wattage differentials between an old and new bulb (i.e., 40W and 11W, or 60W and 15W). In total, the program is estimated to bring 13.3 MW of energy savings to Ethiopia.[10] This investment seems to be quite cost effective, since the total cost of purchasing CFL bulbs (ignoring the bulb distribution or program administrative costs) is only about US$0.5 million.[11]

36. Apart from the CFL impact, the estimated results also suggest that the energy demand per household would increase by 3 kWh every month. This means that the demand grows by 1.4 percent per month, which is significant. At the same time, however, evidence indicates that the demand increase would likely diminish over time. The coefficient of T^2 is significant and negative. Therefore, the electricity demand would increase with time in a concave fashion, as normally expected. The supply constraint partly explains the electricity consumption as well. The coefficient of Q is positive, as expected. It means that people cannot use as much electricity as they want, when the supply capacity is low. This is simply because the limited capacity would likely lead to chronic power outages.

37. The electricity price elasticity is estimated at -0.29 or -0.26. This is relatively low but consistent with the existing literature. While the classical literature shows the elasticity would range from -1 to -2 (e.g., Taylor 1975; Wilder and Willenborg 1975), more recent

[10] The estimated energy savings are 37.9 watts per bulb. This is multiplied by the total number of CFL bulbs distributed, i.e., 350,000.
[11] It is assumed that a CFL bulb costs US$1.50.

literature supports a more modest range of elasticity, from -0.1 to -0.4 (e.g., Espey and Espey 2004; Bernstein and Griffin 2005; Reiss and White 2005). Our result seems reasonable because many households in Ethiopia are still using electricity for basic living needs. Therefore, the demand tends to be inelastic, even if the price is changed. Nonetheless, the price elasticity is statistically significant, indicating the importance of the price incentives to control for electricity demand.

38. The elasticity with respect to the Nordin's *D* is a mirror of income elasticity. Estimated elasticity is relatively high, at about 0.77, regardless of specifications. This must reflect the fact that the demand for electricity has been growing strongly in developing countries such as Ethiopia. As the economy grows, the electricity demand increases rapidly. This reconfirms the continuous need for electricity capacity expansion and the importance of demand-side management.

Table 3. Fixed-effects OLS and IV estimation results

	FE OLS		FE OLS		FE IV		FE IV	
CFL	-35.30	(2.70) ***	-39.90	(2.34) ***	-45.54	(0.99) ***	-49.97	(0.94) ***
MP	89.30	(28.82) ***	-123.89	(22.33) ***	-295.94	(13.17) ***	-269.83	(13.09) ***
D	-10.76	(0.23) ***	-11.46	(0.22) ***	-14.54	(0.06) ***	-14.37	(0.06) ***
Q			0.22	(0.01) ***			0.16	(0.01) ***
T			3.28	(0.20) ***			3.36	(0.11) ***
T^2			-0.02	(0.003) ***			-0.02	(0.002) ***
SA_2			-0.18	(0.99)			-0.41	(1.14)
SA_3			1.26	(1.23)			0.81	(1.15)
SA_4			-0.33	(1.12)			-1.51	(1.18)
SA_5			-5.75	(1.19) ***			-7.48	(1.20) ***
SA_6			14.65	(1.47) ***			15.10	(1.20) ***
SA_7			4.89	(1.27) ***			5.70	(1.26) ***
SA_8			-8.70	(1.12) ***			-5.06	(1.32) ***
SA_9			18.26	(1.29) ***			14.96	(1.22) ***
SA_{10}			17.49	(1.30) ***			15.35	(1.20) ***
SA_{11}			-3.46	(1.07) ***			-1.72	(1.21)
SA_{12}			-2.88	(1.05) ***			-2.29	(1.20) *
constant	-32.40	(10.37) ***	-25.05	(9.26) ***	47.99	(4.85) ***	-10.41	(6.32) *
Obs.	266836		262858		258747		254964	
No. of groups	3998		3998		3993		3993	
Fixed effects:								
Individual	Yes		Yes		Yes		Yes	
Time	Yes		No		Yes		No	
F stat	168.31		555.11					
Wald stat					1.2E+06		1.2E+06	
Implied elasticity:								
MP	0.09	(0.03) ***	-0.12	(0.02) ***	-0.29	(0.01) ***	-0.26	(0.01) ***
D	0.57	(0.01) ***	0.61	(0.01) ***	0.77	(0.003) ***	0.76	(0.003) ***

39. To assess the distributional effect, the two-stage fixed-effects quantile technique is applied for Equation (3). Note that, for computational simplicity, the two endogenous variables—*MP* and *D*—are also replaced by their predicted values using the results of the first-stage FE IV regression. The results are broadly consistent with the above FE IV estimation results. However, there are marked differences in the program impact among different quantiles in terms of energy consumption. The CFL bulb impact is estimated at -48 kWh per month for low-volume first quantile customers (Table 4). On the other hand, the estimated impact is much larger (in absolute terms) for larger-volume consumers. The coefficient is -87 for fifth quantile customers. Thus, large-volume power consumers—who are most likely the rich—have the highest energy savings impact of the CFL bulb distribution program. The estimated coefficient can translate into 73 watts of energy savings per bulb, which is consistent with the highest differential between an inefficient and a new bulb (i.e., 100W and 20W).[12]

40. In relative terms, however, the program impact is larger for low-volume power users—presumably, the poor. For first quantile customers, the estimated reduction in power use accounts for 95 percent of their total power consumption (Figure 6). By contrast, the relative impact to total power consumption is much smaller for large-volume power consumers; the savings represent only about 15 percent of their total power consumption.

41. The price and income elasticities also vary among different quantile consumers. Price elasticity is the lowest among the first quantile. As discussed, this reflects the fact that electricity demand by the poor is mostly to service basic needs. This demand must, of necessity, be price-inelastic. As household income increases, however, customers may have more flexibility in energy consumption. For instance, they could purchase more energy-efficient home appliances. Therefore, price elasticity is higher for the rich. One resulting policy implication is that price incentives in the tariff, such as increasing block rates, are particularly important to managing the electricity demand of large-volume customers.

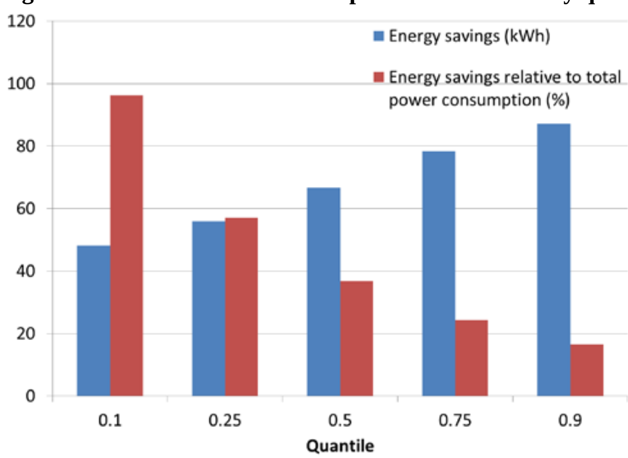
42. By contrast, income elasticity is higher for low-volume customers. This is a natural result because electricity is not a luxury good but rather a basic human need. Therefore, the power demand is not likely to increase in response to income growth. Rather, elasticity decreases from 1.8 to 1.2 when power consumption increases.

[12] It is assumed that the average household uses CFL bulbs 10 hours per day.

Table 4. Distributional effects: IV Fixed-effects quantile regression

	Quantile				
	0.1	0.25	0.5	0.75	0.9
CFL	-48.17 ***	-55.91 ***	-66.71 ***	-78.32 ***	-87.13 ***
	(0.37)	(0.34)	(0.39)	(0.47)	(0.63)
MP	-47.65 ***	-146.19 ***	-346.92 ***	-618.14 ***	-856.85 ***
	(2.53)	(2.35)	(2.66)	(3.23)	(4.35)
D	-10.59 ***	-12.07 ***	-14.76 ***	-18.50 ***	-22.32 ***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
constant	-35.26 ***	0.56 ***	56.58 ***	122.06 ***	176.75 ***
	(0.55)	(0.51)	(0.58)	(0.71)	(0.95)
Obs.	258747	258747	258747	258747	258747
No. of groups	3998	3998	3998	3998	3998
Fixed effects:					
Individual	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes
Pseudo R2	0.49	0.54	0.59	0.65	0.69
Implied elasticity:					
MP	-0.14 ***	-0.33 ***	-0.57 ***	-0.77 ***	-0.87 ***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
D	1.76 ***	1.47 ***	1.31 ***	1.26 ***	1.23 ***
	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)

Figure 6. Absolute and relative impacts of CFL bulbs by quantile



43. Finally, the FE IV regression is run to evaluate the longer-term impact of the CFL program (see Equation (5)). The estimated parameters are broadly consistent with the result presented above. But a marked result is that the coefficient of the lagged intervention indicator, $CFL_{t\text{-}s}$, decreases in absolute terms over time, until it becomes stabilized at about -35 18 months following program implementation (Figure 7). The detailed estimation results are shown in Table 5. This fact can be interpreted to mean that part of the energy savings impact was possibly offset by the rebound effect. Still, about 80 percent of the initial effect was sustained over the long term. This by no means changes the importance of energy

efficiency programs, such as Ethiopia's CFL bulb distribution initiative. But policymakers may need to be aware of this rebound effect.

44. One of the policy implications may be that a series of energy efficiency programs is needed in an effort to promote energy efficiency over time, given that consumer demand for energy will become increasingly diversified as the economy grows. Electricity will increasingly be used for various purposes, in addition to lighting. Customers may purchase new home appliances, such as televisions, refrigerators and air conditioners. In developing countries in particular, the income elasticity of demand is often high, as described in the current paper. Therefore, the energy efficiency benefits from a one-shot program tend to be dominated by the income effect over time.

45. As the manner in which electricity is used changes, different energy efficiency programs may be needed in order to sustain the energy conservation impact over the long term. In Ethiopia, EEPCO is planning to expand its energy efficiency promotion to other products, such as cooking stoves (injera mitad) for residential customers and Power Factor Correctors for industrial customers. These are expected to further contribute to the country's energy savings.

Figure 7. Estimated energy savings by the CFL program over time (kWh per customer)

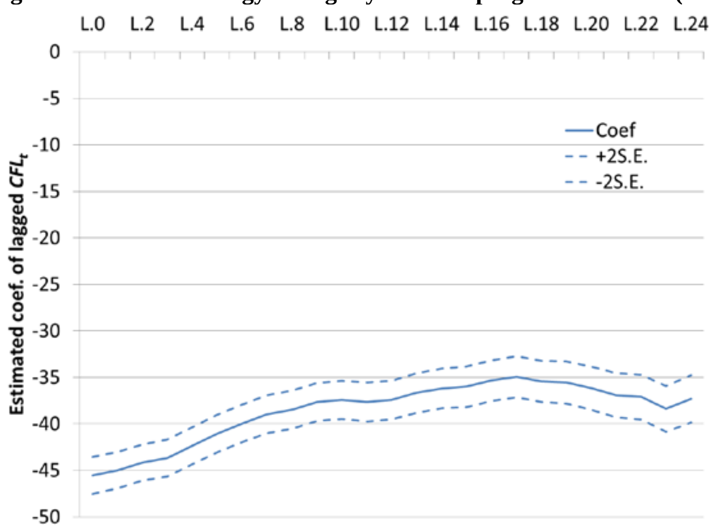


Table 5. Long-term effects of the program: IV Fixed-effects regression

	L.0	L.1	L.2	L.3	L.4	L.5	L.6	L.7	L.8	L.9	L.10	L.11	L.12
$CFL_{L.t}$	-45.54 ***	-44.98 ***	-44.15 ***	-43.66 ***	-42.33 ***	-41.05 ***	-39.95 ***	-38.96 ***	-38.46 ***	-37.64 ***	-37.42 ***	-37.64 ***	-37.44 ***
	(0.99)	(0.98)	(0.97)	(0.98)	(0.99)	(1.00)	(1.01)	(1.02)	(1.02)	(1.03)	(1.03)	(1.04)	(1.05)
MP	-295.94 ***	-284.53 ***	-277.74 ***	-270.21 ***	-265.20 ***	-267.35 ***	-260.50 ***	-257.36 ***	-261.22 ***	-279.34 ***	-303.08 ***	-301.12 ***	-294.31 ***
	(13.17)	(13.32)	(13.38)	(13.69)	(13.95)	(14.33)	(14.59)	(14.89)	(15.14)	(15.41)	(15.66)	(15.94)	(16.25)
D	-14.54 ***	-14.57 ***	-14.64 ***	-14.74 ***	-14.84 ***	-15.01 ***	-15.11 ***	-15.25 ***	-15.41 ***	-15.67 ***	-15.96 ***	-16.10 ***	-16.23 ***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Constant	47.99 ***	242.25 ***	240.38 ***	238.05 ***	235.80 ***	233.77 ***	231.32 ***	229.04 ***	227.88 ***	227.60 ***	228.12 ***	226.70 ***	224.37 ***
	(4.85)	(2.54)	(2.52)	(2.55)	(2.56)	(2.60)	(2.62)	(2.64)	(2.65)	(2.67)	(2.68)	(2.70)	(2.72)
Obs.	258747	254793	250864	246919	242983	239073	235159	231235	227328	223422	219510	215605	211707
No. of groups	3993	3989	3988	3988	3988	3988	3987	3987	3987	3987	3985	3984	3984
Fixed effects:													
Individual	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R2	1.2E+06	1.2E+06	1.3E+06	1.2E+06	1.2E+06	1.2E+06	1.2E+06	1.2E+06	1.1E+06	1.1E+06	1.1E+06	1.1E+06	1.1E+06

	L.13	L.14	L.15	L.16	L.17	L.18	L.19	L.20	L.21	L.22	L.23	L.24
$CFL_{L.t}$	-36.66 ***	-36.19 ***	-36.01 ***	-35.33 ***	-34.93 ***	-35.42 ***	-35.55 ***	-36.14 ***	-36.93 ***	-37.11 ***	-38.38 ***	-37.31 ***
	(1.06)	(1.07)	(1.08)	(1.09)	(1.11)	(1.11)	(1.13)	(1.16)	(1.18)	(1.20)	(1.23)	(1.27)
MP	-287.19 ***	-288.03 ***	-277.49 ***	-267.88 ***	-259.38 ***	-249.48 ***	-245.60 ***	-247.57 ***	-256.39 ***	-265.48 ***	-264.65 ***	-272.45 ***
	(16.59)	(16.93)	(17.32)	(17.69)	(18.09)	(18.10)	(18.45)	(18.75)	(19.04)	(19.32)	(19.69)	(20.11)
D	-16.37 ***	-16.54 ***	-16.62 ***	-16.72 ***	-16.79 ***	-16.78 ***	-16.80 ***	-16.85 ***	-16.93 ***	-17.00 ***	-17.03 ***	-17.14 ***
	(0.07)	(0.07)	(0.07)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.09)
Constant	221.65 ***	219.85 ***	217.50 ***	214.85 ***	212.78 ***	211.74 ***	210.96 ***	211.11 ***	212.03 ***	212.73 ***	212.98 ***	212.53 ***
	(2.75)	(2.77)	(2.08)	(2.84)	(2.88)	(2.86)	(2.89)	(2.92)	(2.95)	(2.97)	(3.01)	(69.48)
Obs.	207804	203887	199968	196054	192132	188280	184437	180592	176770	172931	169119	165270
No. of groups	3983	3983	3981	3980	3980	3980	3980	3980	3980	3980	3980	3979
Fixed effects:												
Individual	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R2	1.1E+06	1.1E+06	1.1E+06	1.0E+06	1.0E+06	1.0E+06	1.0E+06	9.9E+05	9.6E+05	9.4E+05	9.1E+05	8.8E+05

VI. Conclusion

46. Electricity infrastructure is one of the most important development challenges in Africa, where access remains very limited. In Sub-Saharan Africa, about 585 million people, or roughly 70 percent of the total population in the region, are still living without access to power. Both significant resources and active measures are required to address the existing infrastructure gap, and promoting energy efficiency is among the most important initiatives in this respect. It is an inexpensive, win-win proposition. While end users can reduce their energy spending, power utilities can avoid costly new investments in developing their capacity. Furthermore, energy efficiency can contribute to mitigating global warming.

47. Ethiopia has been implementing a series of energy-efficiency programs at the end user level to manage the increasing demand for electricity and to conserve energy. The current paper evaluates the impact of the first CFL bulb distribution program implemented in June-August 2009. In total, 350,000 CFL bulbs were distributed free of charge nationwide in exchange for old incandescent light bulbs. The evaluation focuses on one of the service centers in Addis Ababa, Bole-Kazanchis Service Area, in which roughly 3,500 customers received CFL bulbs in the framework of this program.

48. The evidence suggests that this initiative mostly benefited the poor. Although the program was not targeted but rather distributed CFL bulbs on a voluntary basis, program participants seem to have been self-selected. The majority of beneficiaries were relatively low-volume customers, presumably from the poorer segments of society. This is because lighting is the most important electricity demand among the poor.

49. The evidence clearly shows that the CFL bulb distribution program contributed significantly to conserving energy in Ethiopia. The program is estimated to have saved 45-50 kWh per customer, bringing the country13.3 MW of energy savings in total. This investment is highly cost effective, since the total cost of purchasing CFL bulbs (ignoring other necessary costs) is about US$0.5 million.

50. It was also demonstrated that the program had a distributional effect. In absolute terms, large-volume power consumers—i.e., the rich—received the largest energy savings from the program. Relative to underlying electricity consumption, the program's impact is larger for low-volume power users. For the poorest (i.e., first quantile customers), the estimated reduction in power use accounted for 95 percent of their total power consumption.

51. Another important finding is that there seems to have been a rebound effect on the CFL bulb distribution program. Approximately 20 percent of the initial energy savings disappeared 18 months following the program's implementation. This is not surprising because estimated income elasticity is high. As the economy grows, demand for electricity is increasing. In addition, price elasticity was determined to be moderate in general but high for high-volume users. Hence, to promote energy efficiency over the long term, it is important to integrate the CFL bulb distribution program with other energy-efficiency measures and pricing incentives, such as increasing block tariffs. Depending on changing electricity

demand, other energy efficiency programs will be needed, and pricing will be an effective policy instrument to motivate the rich to rationalize their electricity use.

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