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**Oxford Policy Management
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Energy Efficiency in the Developing World

Meredith Fowlie, and Amol Phadke *

March 5, 2017

Abstract

The literature assessing demand-side energy efficiency potential, and the policies that can be deployed to tap this potential has traditionally focused on developed and emerging economies. We review the state of knowledge on demand-side energy efficiency investments, and reframe the discussion in terms that are better suited to a low income country setting. This reframing opens up new lines of inquiry which have been under-emphasized to date. We provide a conceptual framework for exploring questions concerning the returns on investment in energy efficiency, market failures and barriers that can lead to under-investment, rebound effects, and policies designed to accelerate cost-effective investment. We highlight some institutional considerations that should inform policy prioritization and implementation in LIC settings. A case study of a large scale efficiency program in India underscores both the challenges and the potential for welfare improving energy efficiency programs in the developing world.

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1 Introduction

Energy efficiency has become a policy priority for an increasing number of countries around the world. Investments in demand-side energy efficiency improvements can mitigate a number of energy-related challenges, including the social and economic impacts of high energy costs and the environmental impacts of conventional energy production. Although the basic concept of making up-front investments to improve energy efficiency and reduce future expenditures and impacts holds broad appeal, the specific forms that this investment should take, and the policy interventions best suited to support these investments, will vary across contexts.

A growing literature on energy efficiency explores three related lines of inquiry. One assesses energy efficiency potential and the extent to which realized investments in energy efficiency fall short of (or exceed) the socially optimal level (see, for example, EPRI, 2009; McKinsey, 2009; National Academy of Science, 2009). A second investigates the market failures and barriers that can rationalize under-investment in efficiency (see, for example, Allcott and Greenstone, 2012; Gillingham and Palmer, 2014 ; Gerarden et al, 2015). The third evaluates alternative policy options used to accelerate investments in energy efficiency, both from an ex ante and ex post perspective (see for example, Davis et al., 2014; Fowlie et al. 2015).

This analysis to date has focused primarily on high income countries. Lessons learned and energy efficiency policies deployed in high income settings need not transfer to LIC settings. The two contexts differ fundamentally in terms of income levels, consumer preferences, market structures, and other factors that determine private and socially optimal levels of investment in energy efficiency. Policy objectives and priorities can also vary significantly across contexts. In high income countries, energy efficiency policies and programs are primarily motivated by a desire to reduce negative externalities (such as harmful pollution) associated with energy production, and an interest in mitigating the effects of market failures and barriers (such as asymmetric information or capital constraints) that impede cost-effective private investments in energy efficiency. In a low income country context, these arguments will also apply, but economic development priorities will also loom large. Demand-side energy efficiency investments have a potentially important role to play as a complement to economic development objectives in general, and improved energy access in particular.

Global leaders have set a goal of securing universal access to affordable, reliable, sustainable and modern energy by 2030 (UNDP, 2016). A lack of access to reliable and modern

energy services is widely viewed as a barrier to economic and human development.¹ The level of investment required to extend energy access to all has been estimated at US\$ 640 billion (USAID, 2016). A jumping off point for this paper is the idea that demand-side energy efficiency improvements have a potentially significant role to play in meeting energy access goals at least cost. Accessing this potential will require careful thinking about how to target energy efficiency investments with economic development objectives in mind, and how to implement policies given constraints on implementation capacity and other institutional factors.

Our goal in this paper is to review the state of knowledge on demand-side energy efficiency potential, and to reframe the discussion in terms that are better suited to low income country setting. This reframing opens up new or previously under-emphasized lines of inquiry concerning the extent of the efficiency ‘gap’ in low income countries; the main barriers to improving energy access and efficiency; the optimal targeting of energy efficiency policy interventions; and investments in capacity building that could enable more impactful efficiency policies. We believe these questions will become increasingly important in the coming years as countries work to extend access to modern energy services, while also improving local air quality and limiting increases in greenhouse gas emissions.

The paper is organized as follows. Section 2 provides a brief overview to motivate our focus on energy use in the buildings sector. Section 3 introduces a conceptual framework to provide a basis for characterizing optimal levels of energy efficiency investments and the market failures and barriers that can result in inefficient levels of investment. Section 4 reviews some guiding principles for energy efficiency policy implementation in a developing country context. In Section 5, an Indian case study serves to illustrate how low income country settings can present both unique challenges and tremendous potential for energy efficiency policy. Section 6 concludes.

2 Energy efficiency in a developing country context

In developing and emerging economies, future trends in energy use will be determined by a range of factors including economic development and industrial growth; the spatial organization of urban areas; transportation and related infrastructure; and the built environment. This paper will focus primarily on the building sector which embodies the biggest

¹ In contrast to high income countries, where access to energy is close to universal, more than 1.3 billion people in developing countries lack access to electricity (IEA, 2015).

unmet need for basic energy services in developing countries. (AR5). Buildings comprise the largest energy-consuming end-use sector, accounting for approximately 32% of global energy consumption (24 % for residential and 8 % for commercial) and 51% of global electricity consumption (IPCC, 2012).

Business-as-usual projections of energy use in the building sector predicts more than a two-fold increase midcentury, with most of this growth happening in urban and peri-urban areas. In the developing world, a key driver of this growth will be rising incomes and increased access to modern energy services. An estimated 1.1 billion people worldwide still live without access to electricity most of them in Africa and Asia (Pachauri et al., 2012).² A much larger number lack access to modern and reliable electricity supply. Limited access to modern, reliable energy services is broadly viewed as an important hindrance to economic development.³ Governments and multi-lateral organizations have made broad and deep commitments to increasing access to energy services, and electricity in particular (US AID, 2016). Given the long lifespans of buildings and associated end-use equipment, regions anticipating lots of new construction and increased technology adoption rates risk locking-in energy inefficiency.

Research has documented how the energy efficiency attributes of electric appliances and equipment owned and operated in LICs are significantly lower as compared to both the mandated minimum energy efficiency requirement in OECD countries and the most efficient commercially available equipment (See, for example, Van Buskirk (2007)). Widespread deployment of more efficient end-use technologies and building practices could have a dramatic effect on energy consumption trajectories in developing economies. For example, Letschert and McNeil(2012) show that, by adopting best practice efficiency standards for primary appliances such as refrigerators, air conditioners, lighting, and other equipment, the West African region could save more than 60 terawatt hours (TWh) of electricity per year by 2030 (holding the level of electricity services demanded fixed).⁴ Craine et al. (2014) suggest that by increasing investment in more efficient appliances, the aforementioned cost estimates for

²<http://www.worldbank.org/en/topic/energy/overview3>

³ Studies have linked electrification with positive effects on female employment in South Africa (Dinkelman, 2011), increased employment and income in Brazil (Lipscomb et al., 2013), and increased income and expenditures in Bangladesh (Khandker, 2012). Notably, the empirical evidence on the impacts of electrification is mixed. For example, a study evaluating the effect of rural electrification in India (Burlig and Preonas, 2016) reject even modest effects on labor markets, asset ownership, housing characteristics, and village-wide outcomes.

⁴To put these findings into perspective, 60 TWh is nearly as much electricity as was consumed by the entire ECOWAS region in 2011. The largest energy savers are lighting, refrigerators and air conditioners. Energy efficiency regulations on these three end uses provide over 80% of the identified potential savings.

providing universal access to energy services could be reduced by as much as 70 percent.

In the context of ambitious energy access goals, policies that aim to improve the energy efficiency of appliances and other energy-consuming equipment can reduce the cost of delivering more reliable, modern energy services. Additional benefits could also include: improvements in the long-term viability of electricity supply; improved air quality; reductions in fuel poverty; declining role for energy subsidies; reduced exposure to energy price volatility; enhanced comfort and convenience (Tirado Herrero et al., 2012 Clinch and Healy, 2001; IPCC, 2015). The extent to which these benefits can actually be realized will greatly depend on consumer preferences, incomes, supply infrastructure, and other market features.

3 Are investments in energy efficiency efficient?

In this section, we introduce an economic framework for thinking about the costs and benefits of energy efficiency improvements. This framework, which uses social welfare maximization as an organizing principle, provides a basis for characterizing private and socially efficient levels of investment, market failures, behavioral anomalies, and institutional features that can lead to under-investment in LIC settings.

Embedded in this framework are three related efficiency concepts. The first is energy efficiency, which measures the level of energy services provided per unit of energy input. The second is private economic efficiency, which is concerned with maximizing private net benefits given income constraints, costs, and consumer preferences. The third is social economic efficiency, which is concerned with maximizing a more comprehensive measure of total social welfare.

3.1 Private investments in energy efficiency

Figure 2 illustrates three relationships that play an important role in determining an energy consumer's private investment in energy efficiency. To fix ideas, we consider the specific case of a household's choice of lighting technology. However, this basic framework can be generalized to a wide range of energy services and associated technologies.

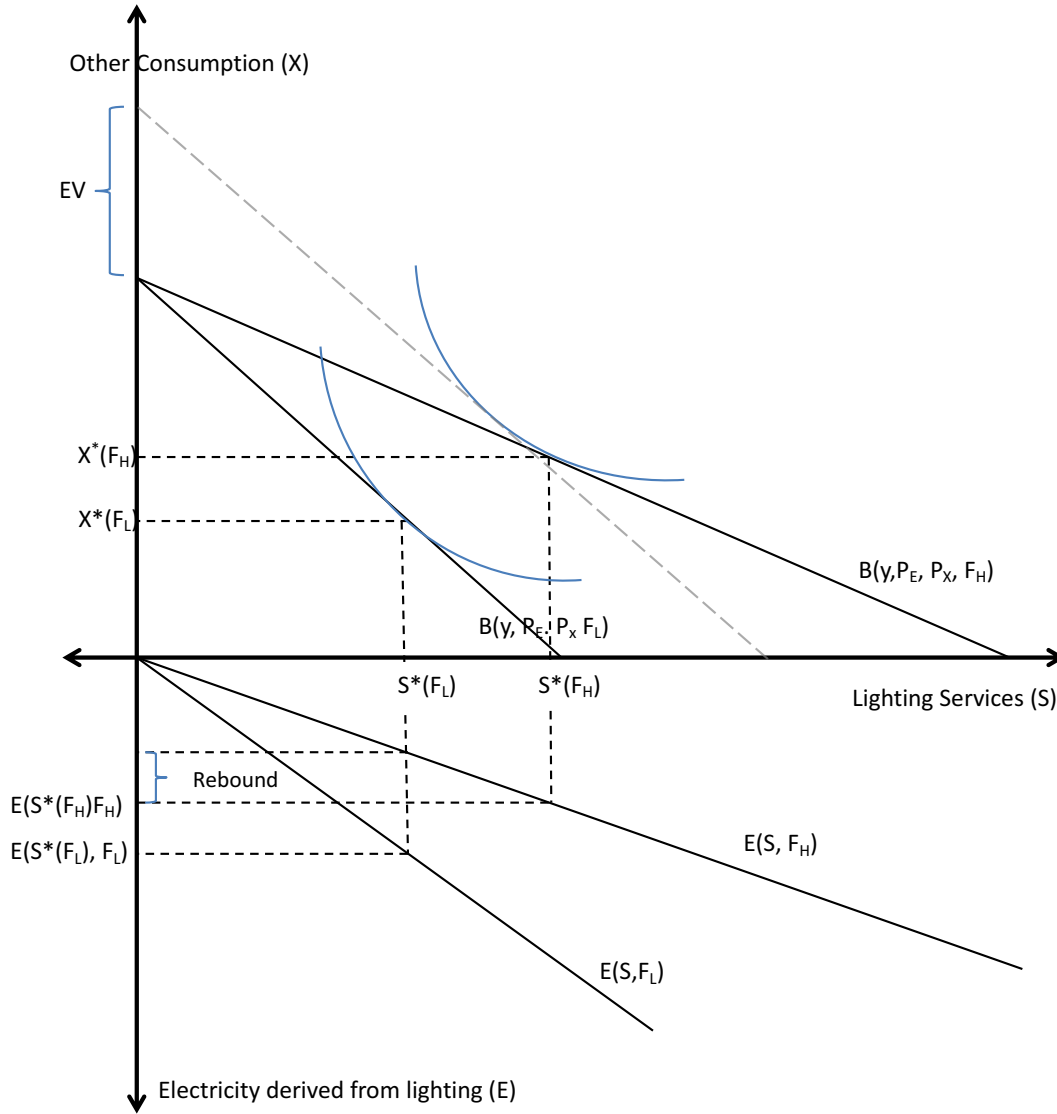


Figure 2:

Willingness to pay for an energy efficiency improvement

Notes: Budget constraints and indifference curves of a representative consumer are plotted in the top quadrant. A linear relationship between lighting services and energy consumption is plotted in the bottom quadrant. Please see text for details. This figure is a modified version of fowlie_{are}2015.

The first component of the model is the relationship between what a household consumes and the household's well-being or utility U . In this simple framework, utility depends on the consumption of lighting 'services' (S) and all other goods or services (denoted by X). The

concentric curves in the top panel are meant to represent the level of utility that households derive from different combinations of S and X . Each "indifference curve" connects consumption 'bundles' that generate the same level of utility for the household. Moving along these curves, the level of consumption of X and S change, but the level of utility stays the same.

The second component relates the level of lighting services (S) demanded to electricity consumption (E). Consider the example of a household choosing between a low efficiency lighting fixture (e.g. a compact fluorescent lamp [CFL]) or high efficiency fixture (e.g. light-emitting diode [LED]). The lower panel illustrates how the more efficient technology requires less electricity for any given level of lighting services. It follows that the implicit price per hour of lighting (i.e. the electricity price P_E times the quantity of electricity required to operate the bulb for an hour) will be lower for the more efficient appliance.

The third and final building block is the budget constraint that determines which consumption choices are accessible to this household given prices, income, and appliance holdings. In this simple model, the household allocates a fixed daily income Y across lighting expenses and other consumption. In the top quadrant of Figure 2, the downward sloping lines connect all of the 'bundles' of X and S that can be purchased with a given income Y given the prices the consumer faces. As noted above, the implicit price of S is given by $P_E \cdot F$. The unit price of 'other consumption' X is normalized to one.

In theory, the utility maximizing household will choose the combination of X and S that maximizes utility given the budget constraint. If the household is endowed with the inefficient lighting technology, the utility maximizing consumption is given by $X^*(F_L)$ and $S^*(F_L)$. If the household is endowed with the more efficient appliance (but the same income) it can achieve a higher level of utility associated with the consumption of by $X^*(F_H)$ and $S^*(F_H)$.

3.1.1 Rebound

The Figure helps to illustrate how the benefits of owning the more efficient appliance accrue in two ways. First, for a given level of lighting consumption, the household has lower energy costs and thus more income to spend on other consumption. In the figure, this benefit is captured by the increase in expenditures on other goods (i.e. $X^*(F_H) - X^*(F_L)$). Second, the energy efficiency improvement can induce an increase in the level of lighting services consumed (i.e. direct rebound).

A growing literature explores the extent to which this kind of demand rebound effects manifest in buildings and other contexts (see, for example, Druckman et al., 2011). Much

of this work focuses on OECD countries, although studies have been conducted in emerging and developing economies (see, for example, Roy, 2000)

3.1.2 Efficient levels of efficiency investment (private perspective)

This simple framework can be used to motivate an important measure of the privately captured returns on investments in energy efficiency. Figure 2 shows how the increase in household utility associated with an improvement in lighting efficiency can be measured by the ‘equivalent variation’ (denoted EV in the figure). Conceptually, EV measures the amount of money we would need to give a consumer who owns the inefficient lighting appliance to increase her welfare to the level she could achieve with the more efficient appliance. EV, represented as a transfer of income and a corresponding shift in the budget constraint, can be interpreted as the household’s willingness to pay (WTP) for the efficiency improvement.

Figure 2 illustrates a household’s willingness to pay for the energy efficiency improvement in a single consumption period (e.g. a representative day). However, energy-consuming appliances tend to be long lived. To construct the household’s total willingness to pay for a more efficient appliance, we take the discounted sum of benefits over the life of the appliance. In sum, the consumer should be willing to invest in the more efficient technology if the value of the stream of efficiency-induced benefits exceed the upfront costs:

$$\underbrace{I(F_h) - I(F_l)}_{\text{Additional investment cost}} < \underbrace{\sum_{t=1}^T \delta(t)EV(P_{ft}, y_t, H, L)}_{\text{Utility gain from efficiency improvement}} \quad (1)$$

The expression on the left captures the additional investment cost required to purchase the more efficient appliance. It is often (but not always) the case that more efficient appliances are priced higher in the market, presumably reflecting higher production costs. The expression on the right captures the household’s willingness to pay for the more energy efficient appliance. This WTP is increasing with household income, energy prices, and the relative efficiency attributes of the choice alternatives. Equation (1) also shows how consumer valuation of an energy efficiency improvement can also be increasing with the reliability of electricity access. The more reliable the access, the more hours the appliance will be available to provide lighting services, the more valuable an efficiency improvement.

If the costs and benefits, as perceived by energy consumers, adequately reflect the true social costs and benefits, then the private investment choice summarized by Equation (1) should deliver economically efficient levels of investment. Importantly, this efficient level

of investment will vary across contexts with different energy supply costs, energy access, incomes, and consumer preferences.

3.1.3 Limiting factors and omitted variables

Before turning to a discussion of market failures that can open up a gap between private and social values of energy efficiency, we note some important factors that are not explicitly captured by this simple framework. First, the model ignores other attributes that consumers may value (such as lighting quality in this example). If more efficient appliance choices also differ along other dimensions, this can affect consumer demand for energy efficiency. Second, we have abstracted away from supply side of the market. In the model, investment costs I and efficiency properties F are taken as given. However, the manufacturers that produce energy-consuming equipment (from light bulbs to industrial equipment) choose what products to develop and bring to the market, how to bundle energy efficiency with other attributes, how product prices vary with efficiency attributes, etc. Finally, this model does not address the choice of when to make a new investment in an energy-consuming appliance. The rate at which energy consumers adopt new energy-using technologies, and/or replace old equipment with new, will depend on investment costs, energy prices, etc. Investment timing can have a significant impact on aggregate trends in energy consumption and energy efficiency.

3.2 Market failures and other barriers to efficient investment

Real world contexts are characterized by several market failures and features that can push levels of private investment below (or above) socially optimal levels. The list of potential barriers is long. These include (but are not limited to): imperfect and/or asymmetric information, transaction costs, fragmented markets, capital constraints, a range of possible positive and negative externalities associated with energy production and consumption, pre-existing policy distortions, principal agent problems, cognitive and behavioural phenomena. Many of these factors have been discussed extensively in the economics literature (see, for example, (Gerarden et al.(2015)Gerarden, Richard G., and Robert N.); (Gillingham and Palmer(2014)); (Allcott and Greenstone(2012)); (Jaffe and Stavins(1994))). FROM AP5 (Brown et al., 2008b; Urge-Vorsatz et al., 2012a; Power, 2008; Lomas, 2009; Mlecnik, 2010; Short, 2007; Hegner, 2010; Stevenson, 2009; Pellegrini-Masini and Leishman, 2011; Greden, 2006; Collins, 2007; Houghton, 2011; Kwok, 2010; Amundsen, 2010; Monni, 2008).

Much of the work that has been done to examine the relative importance of these bar-

riers and failures in real-world settings has focused on high income countries (and emerging economies to a lesser extent). The factors and phenomena that can give rise to an efficiency gap could manifest quite differently in LIC settings. In what follows, we emphasize those factors that are likely to be most relevant to LIC contexts.

3.3 Externalities and the socially optimal level of efficiency investments

In general, the private cost-benefit calculation summarized by Equation (1) will fail to capture all of the costs and benefits associated with energy production and consumption. When energy production and consumption generates *negative* externalities, consumers will underinvest in energy efficiency improvements.

- *Environmental externalities:* In the economics literature that considers how externalities can potentially distort energy efficiency investment decisions, negative environmental externalities are emphasized (see, for example, Allcott and Greenstone, 2012). Energy production generates local, regional, and global emissions. These emissions can have significant negative health and environmental impacts (NAP, 2011). If these costs are not reflected in energy prices paid by consumers, they will not be factored into the private investment decisions summarized by Equation (1).
- *Inefficient energy prices:* Governments in many low income countries actively subsidize retail energy prices to make energy services more affordable for low income households and firms.⁵ If consumers pay a subsidized energy price, they will not internalize the full costs of energy supply.⁶
- *Network externalities* In settings where electricity access is unreliable and/or constrained, increasing household electricity consumption can compromise power quality and reliability for other consumers on the same distribution network. Private individuals are unlikely to internalize these network impacts. In these settings, energy

⁵Notably, there is lots of variation in energy prices across developing country contexts. For example, while electricity tariffs in South Africa and Zambia are among the lowest in the world, prices in Djibouti and Gabon are among the highest globally.

⁶It is not always the case that consumers face marginal prices that fall below the true social marginal cost. It can also be the case that marginal (or volumetric) energy prices are set above marginal operating costs to recover some share of the fixed costs of system operations. For example, in the United States Davis and Muehlegger (201) estimate that the mark-up over marginal operating costs is comparable to a \$50 tax on GHGs.

efficiency investments that reduce consumption at peak times can generate technological externalities. For example, Carranza and Meeks(2016) show how energy efficiency improvements, when deployed at a significant scale, can generate positive network externalities (e.g. fewer outtages and thus more reliable energy supply). Improved system reliability generates benefits for both the energy consumers who have adopted the more efficient technology, but also other energy consumers on the network.

In addition to negative energy consumption externalities, there can also be positive externalities or benefits from consuming energy services. This is particularly relevant in developing country contexts. As noted above, ambitious programs that aim to provide universal access to modern energy services are predicated on the belief that energy access is crucial to human well-being and economic development. Reliable access to energy facilitates the provision of clean water, sanitation, healthcare, lighting, heating, and telecommunications. Access to these and other services can generate positive spillovers that individuals do not fully internalize when they are maximizing their private utility.

Even setting aside concerns about energy consumption externalities, there are additional factors and phenomena that can result in investment inefficiencies. Some of these factors include:

- *Asymmetric information:* Energy-consuming durables (such as lightbulbs, air conditioners, televisions, and vehicles) are, in some respects, experience goods. Manufacturers' claims about the energy efficiency attributes of their products can be difficult to validate at the time of purchase. Energy savings can only be validated by the consumer after the investment is made. This information asymmetry can lead manufacturers to over-state efficiency claims, and consumers to distrust (and thus discount) these claims. In Equation (1), this would imply that consumers discount the relative efficiency gains associated with the relatively efficient choice H . Several researchers have investigated how imperfect information can undermine investments in energy efficiency, and how interventions (such as labeling programs), can mitigate the problem (see, for example, Newell and Siikamaki(2014); (Newell and Siikamaki(2014)); Houde(2014); Giraudet and Houde(2014);; Allcot(2013),). To our knowledge, this line of inquiry has been relatively under-investigated in LIC settings.
- *Capital market failures:* Capital-constrained energy consumers may be unable to secure financing to make investments in energy efficiency even if investments deliver returns that justify the up-front cost. Capital market failures are ubiquitous in low income

country settings banerjee_{economic}2007. *Limited access to capital – or high capital costs – will drive down demand for energy efficiency improvements.*

- *Imperfect competition:* Several of the industries that produce energy-consuming durables, such as household appliances and automobiles, are dominated by large multi-product firms sell differentiated products. This creates the potential for inefficiencies associated with imperfect competition. For example, Fischer(2004) shows how strategic producers in imperfectly competitive markets may offer consumers of relatively inefficient appliances too little energy efficiency so that high-end consumers can be charged more for efficient appliances.
- *Myopia:* A growing literature investigates whether consumers are myopic when choosing among energy-consuming durables that vary in energy efficiency. Recent evidence from automobile and housing markets finds little evidence to support this hypothesis in HIC settings (see, for example, Busse et al., 2014; Sallee, 2009; Meyers, 2016 , ,). However, in settings where market conditions and infrastructure investments are changing quickly, consumer myopia could operate somewhat differently on investment decisions. For example, if electricity supply is becoming more reliable, consumers will underestimate future returns if their valuation assessment is based on existing conditions.
- *Behavioral anomalies* Empirical research has documented systematic behavioural anomalies that can lead agents to make choices that are inconsistent with their own self-interest (Shogren and Taylor, 2008; Baron, 2008) . Work by Tietenberg (2010) shows how behavioral phenomena such as help explain why information provision and monetary incentives can prove insufficient to promote even the most cost-effective investments. On the other hand, Sallee(2014) shows how, in the context of energy efficiency, some errors in judgement can be rational.
- *Transaction costs:* The model summarized in Section 3 features a well-informed consumer trading off investment costs and future benefits across more or less efficient appliances. The costs on the left side of Equation (1) are often calibrated using engineering estimates of technology costs, or costs observed in mature markets. On the consumer side, these costs do not reflect the time and resources required to make an informed decision (i.e. collecting and processing information about alternative technologies) or the non-monetary costs incurred to make the transaction (which can be large in fragmented or underserved markets). Researchers have documented how non-monetary

costs that must be incurred to implement efficiency improvements (or participate in efficiency programs) can be prohibitive (see, for example, Fowlie et al., 2015). On the producer side, the costs of bringing products to the market can be significant. Recent research finds that non-monetary transaction costs can be significant, particularly in settings where producers face high distribution costs.

The extent to which one or more of the energy use externalities and investment barriers described in this section affects energy efficiency investment choices depends on how these factors affect the arguments in equation (1). All of these factors can drive a wedge between the net benefits of an efficiency investment as perceived by private consumers, and the net benefit of the investment from a broader social perspective. If this wedge or distortion results in inefficient levels of investment in a given energy efficiency measure or improvement, this creates an opportunity for welfare improving policy intervention.

4 Policy priorities, design, implementation

The past several decades have witnessed a proliferation of policies that aim to increase the level of investment in demand-side energy efficiency improvements.⁷ Policy designs vary in terms of how they aim to influence or change private investment decisions summarized by equation (1). Some policies are designed to directly mitigate market failures or barriers that stand in the way of efficient investment (e.g. taxes that internalize emissions externalities). Other policies are designed to compensate for the effects of market failures (e.g. efficiency standards and rebate programs). Increasingly, implementing agencies are deploying a mix of policy instruments to promote energy efficiency improvements.

In principle, the choice of policy instrument and emphasis should be informed by the economic, social and environmental considerations that shape policy priorities and the institutional or contextual factors that can significantly determine the success or failure of a program. In this section, we highlight three broad considerations that should inform policy design and implementation, maintaining our emphasis on LIC contexts.

4.1 Efficiency: Where are the gaps (and why)?

Thus far, our discussion has focused on economic efficiency as a guiding principle for investments in energy efficiency. Identifying which market barriers or failures are pushing

⁷A detailed discussion of energy efficiency policies can be found in Chapter 9 of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

energy efficiency investments away from the socially optimal level is a critical first step in determining what form a policy response should take.

Lack of access to financing and other capital market related barriers and failures have been well documented in LIC settings. As a result, policies that aim to mitigate these barriers, such as programs that offer on bill financing for energy efficiency investments, could be relatively more important and impactful in an LIC context.⁸ As noted above, more research is needed to investigate the relative importance of various market failures and barriers in LIC settings.

4.2 Equity: Who are the winners and losers?

In addition to economic efficiency considerations, there are other important criteria that should influence policy design choices. The distribution of policy impacts - in terms of both costs and benefits- will be of particular concern in settings where poverty alleviation is the driving impetus for policy intervention. Assuring fairness in the distribution of policy impacts may require some efficiency trade offs. For example, raising electricity prices to more accurately reflect supply costs and energy-use externalities is a standard economic prescription for efficient policy. But if this policy results in an inequitable or regressive distribution of benefits, this would run counter to the larger policy goals and objectives.

Equity considerations and associated policy objectives can influence not only policy instrument choice, but also the choice of which end users and/or efficiency measures to target. In HICs, policy interventions often target those measures that appear to offer the largest net savings. In low income settings, greater emphasis could be placed on measures would predominantly impact low income consumers (for example, ceiling fans) even though the energy savings potential might be higher in appliances that are more likely to be adopted by relatively wealthy consumers (for example, air conditioners).

4.3 Institutional capacity constraints

Policy design and implementation capacities can be highly constrained by resource constraints and governance challenges.(Singh et al., 2012). In the longer run, investments in capacity building and improved governance can create an enabling environment for a broader

⁸Borgeson et al (2012) document relatively limited success of energy efficiency financing programs in an HIC context. They suggest that subsidized financing for those who already have access to capital may be a poor use of public funds. We speculate that these kinds of programs may find more success in LIC settings where capital constraints are more commonplace.

range of policies. More research is needed to identify the nature of the institutional constraints that inhibit high impact policy interventions. In the short run, energy efficiency programs and policies must be designed with these constraints in mind. Below, we identify three potential strategies for optimizing policy design subject to institutional constraints.

4.3.1 Focus on high impact end-uses

Interventions should be targeted towards end uses that can have the largest impact. For example, it is estimated that efficiency improvements in three key end uses could harness 70% of the electricity savings potential in the residential and commercial sector Sub Saharan Africa . Targeting energy efficiency programs to maximize impacts requires detailed information about electricity consumption patterns, appliance saturation, demand forecasts for energy services, energy expenditures, and current levels of end-use efficiency. Research along these lines is ongoing (see, for example, Davis and Gertler, 2015; Gertler et al., 2012 ;). More will be needed to inform the targeting of policy interventions across different country contexts.

4.3.2 Select policy designs that are easier to implement

Ease of implementation can be a pragmatic and important policy design consideration. Appliance rebates provide a case in point. Providing rebates upstream to manufacturers rather than to consumers will require significantly less implementation capacity because the number of manufacturers are typically significantly lower than the number of consumers. Research evaluating the choice to deliver policy incentives upstream versus downstream is somewhat limited (see, for example, De La Rue et al., 2014). More research is needed to help policy makers streamline and simplify policy implementation.

The ease of monitoring and enforcement is another important consideration. Policies that have been shown to be environmentally and cost-effective in some settings, such as building codes and appliance standards, will have minimal impact absent careful monitoring and strong enforcement.

5 Case study

A large scale government initiative currently underway in India, the Domestic Efficient Lighting Program(DELDP), provides an innovative example of how an energy efficiency program can significantly accelerate the adoption of more efficient appliances in an LIC setting. This

program, unlike any energy efficiency program we have seen implemented in HIC settings, could provide a useful model for other LIC governments confronting similar constraints and market barriers.

5.1 Policy overview

DELP, also known as Unnat Jyoti By Affordable LED's for All (UJALA), aims to promote and accelerate the adoption of LED bulbs in India. Incandescent bulbs have traditionally dominated the market for residential and commercial lighting. LEDs use 15% of the energy that comparable incandescent bulbs requires. As of January 1, 2017, more than 190 million bulbs had been sold to consumers through this program. Notably, LED prices have dropped by more than 80% since the start of the program.

This program makes more efficient lighting appliances more accessible to consumers in a number of ways. First, the program transfers deep reductions in LED prices achieved through bulk procurement directly to consumers. Second, the program offers on bill financing to consumers who choose not to pay the full cost of the LED bulb upfront. Finally, the program potentially reduces transaction costs, on both the supply and demand side, by leveraging government access to distribution networks to get these products to markets across India.

Remarks made by India's Prime Minister Narendra Modi when this ambitious program was launched suggest that the initiative was motivated by a recognition that demand-side energy efficiency improvements can significantly reduce the cost of delivering energy services to Indian consumers. Modi observed that "that it is much more economical to conserve power, than to produce power", but noted that it is challenging to harness this potential: "while one producing entity can produce a large quantity of power, it requires the active participation of crores (tens of millions) of people to conserve that amount of power."⁹ This large scale initiative was also framed as a challenge to manufacturers, to rise to the occasion, and produce LED bulbs without any compromise on quality.

The program is implemented by Energy Efficiency Services Limited (EESL) which was established to create and sustain markets for energy efficiency in India. EESL set detailed product testing, performance and quality requirements that manufacturers supplying the program must meet.¹⁰ EESL procures these LED bulbs in large quantities via periodic auctions. Once purchased at auction, these bulbs are branded and sold as Ujala bulbs.

⁹Source: http://www.pmindia.gov.in/en/news_updates/pm-launches-scheme-for-led-bulb-distribution-under-domestic-efficient-lighting-programme-in-delhi/.

¹⁰These include minimum requirements for more than 15 different performance characteristics including lumen output (light output), wattage, rated life, beam angle, junction temperature, and harmonics.

In addition to procuring the bulbs in large quantities, EESL works with distribution utilities to distribute the bulbs to consumers across India. State owned distribution utilities provided space to EESL in their bill payment centers for selling the LED bulbs. Further, state utilities allowed EESL to advertise the DELP program on consumer bills. In addition to supporting the distribution of the bulbs across India, EESL helped coordinate on-bill financing and quality assurance.

Over the last two years, EESL has conducted several bulk procurement auctions, and prices have continued to drop with each successive round. More than a dozen firms have participated in each of the bidding rounds. EESL started with a procurement volume of less than one million bulbs, but in the last three rounds of procurement, volumes have been in the range of 50 million bulbs.

Over the duration of the program, LED prices have been falling not only in India, but also in other major markets (such as the United States and China). Figure 3 plots average and ‘low’ retail price trajectories in selected markets because of the wide price dispersion that has been documented. A recent LBNL study based on a consumer survey in the U.S. finds that the majority (more than 80%) of respondents purchased a lamp at or below the 25th percentile price (US DOE 2016, (Gerke et al.(2014)Gerke, Ngo, Alstone, and Fisseha)).

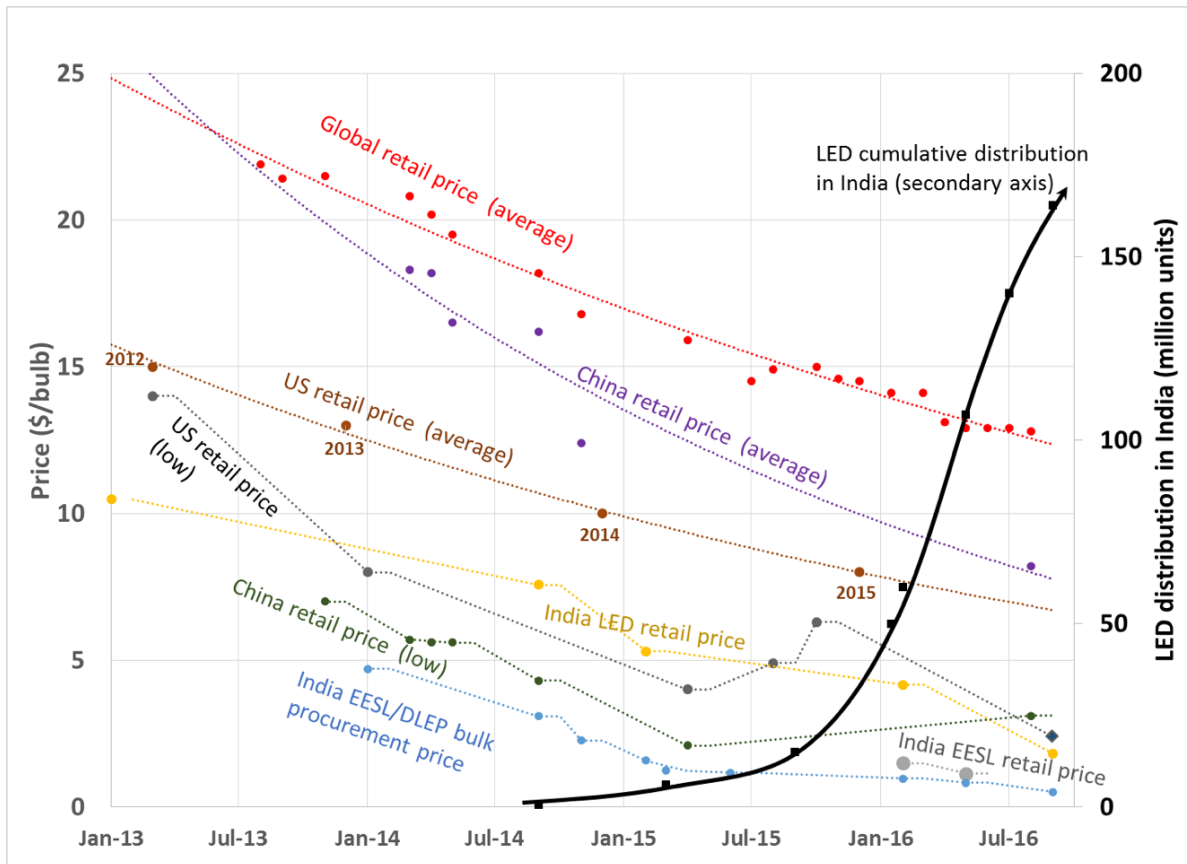


Figure 3: Price trends of 60W-bulb-equivalent LEDs and cumulative LED distribution (Mar 2013 Sep 2016). See Appendix 1 for References.

Notes: 60W-equivalent LEDs typically refer to LEDs that emit about 800 lumens and consume about 9W. Sources for US LED retail prices: US DOE Solid-State Lighting R&D Plan (2011-2016), LEDinside.com, various news articles, amazon.com. Sources for global and China LED retail prices: LEDinside.com. Sources for India LED prices and distribution: various news articles, EESL reports, the national UJALA dashboard.

It is striking that the EESL procurement price is less than half that of the retail prices of similar LED bulbs (9 Watt) in the US and in Indian retail markets outside of DELP. Figure 3 also shows a significant difference in Indian retail prices for DELP bulbs versus other comparable LED lamps for sale in the Indian market. One possible explanation for the difference is that the household-level quota on the former (4 bulbs per household) may be binding in some markets. The CFL price (not shown on this graph) averaged around \$1.50 per bulb over this time period. Around January 2016, the prices of DELP LED bulbs became comparable to the retail price of CFLs that provide the same amount of light, but

consume about 40% more electricity and do not last nearly as long.

5.2 Are these LED investments efficient?

The consumer choice model summarized in Section 3 provides a framework for thinking about consumers choices between a more efficient 9 W LED technology and a comparable (in terms of lighting intensity) 14W CFL bulb. Consider a representative Indian residential consumer paying an electricity tariff of about 8 cents/kWh and demanding 4 hours of lighting per bulb per day (Mc Neill et al., 2011) The corresponding annual cost of operating an LED is \$1.05 versus \$1.63 for the CFL (this calculation assumes no rebound). 14 Watt CFL bulbs costs about \$1.5 in the Indian market. So the consumer should compare the additional upfront investment in the LED bulb with the future stream of annual benefits which amount to at least \$0.58 per year (or higher if there is demand rebound).

LEDs are estimated to last four times as long as CFL bulbs, which complicates the calibration of Equation (1) somewhat. But over a range of time horizons and discount rates, we find that LEDs are the cost effective choice given our assumptions about electricity prices, and the lighting technology prices observed prior to the introduction of the program (i.e. \$6 per LED bulb) In other words, from a private perspective, the LED bulb appears to be the more cost effective choice *even before the DELP program was introduced*. This suggests that there were other market barriers and failures working to discourage private investments in the more efficient lighting technology. We speculate that factors such as limited access to capital, asymmetric information, fragmented retail markets, and transaction costs could partly explain the low adoption rates prior to the program. A policy intervention that aimed to increase investment in LED bulbs would ideally address these market barriers.

Thus far, our rough calculations have not accounted for any external costs of energy consumption or any external benefits generated by lighting services. Average retail prices can fall below the costs of supplying power in India (around 9 cents/ kWh) and do not reflect associated external emissions costs.¹¹. Accounting for these external costs and benefits, and any positive spillovers from electricity consumption to the extent that they exist, will only make the LED investments more attractive from a social perspective.

¹¹Source: - https://www.iea.org/publications/freepublications/publication/IndiaEnergyOutlook_WEO2015.pdf

5.3 Why did DELP accelerate investment in energy efficiency?

Figure 3 shows a striking increase in the sales of LEDs in India since the DELP program began in 2014. Although there has been no rigorous attempt to establish cause and effect, the figure suggests a causal relationship between the introduction of the DELP program and the subsequent ramp up in sales volume. This begs the question: How did the DELP program increase the adoption of this more efficient LED technology so significantly?

The policy design emphasized the mitigation of barriers to investment versus the internalization of energy-use externalities. First and foremost, the deep price reductions achieved through bulk procurement drove investment costs down to the point where purchasing the more efficient technology required no additional investment (i.e. LED prices dropped to the level of CFL prices). Economies of scale in production and reductions in transaction costs incurred by suppliers presumably played a role. The program also mitigated capital constraints through on-bill financing. EESL worked to mitigate information asymmetries by providing credible and trusted information about product quality. Because all of these changes were implemented simultaneously, it is hard to assess the relative importance of each.

In sum, this program provides a remarkable example of how a government can leverage its ability to procure and distribute more efficient technologies in large quantities. Additional research that estimates how technology adoption impacted demand for lighting services and electricity consumption (i.e. S and E in the framework outlined above) would allow for a more comprehensive evaluation of program benefits. It also points to a potential strategy for energy services companies (ESCOs) in LICs where subsidized tariffs can act as a significant barrier for financing investments in efficiency technology on the basis of future consumer bill savings. Similar to EESL, other ESCOs could reduce the cost of the efficient technology through bulk purchase and reduce the need for additional investment for efficient technology up to a point where consumer do not need financing to choose the efficient technology. It is important to study under what conditions (for example, the type of technology and the scale of bulk purchase) such a strategy would work more broadly in other LICs

There is widespread interest in expanding this policy approach to other applications and contexts. More research is needed to understand how the program impacted consumers lighting consumption, energy expenditures, the extent to which the program reduced supply-side operating costs, and the aspects of the intervention were most critical to accelerating technology adoption.

6 Conclusions

Accelerated investment in energy efficiency improvements offers a range of potential benefits and could serve as an important complement to economic development and poverty alleviation priorities. We see three lines of inquiry that should be pursued to inform targeted, impactful policy interventions in this area.

First, research that empirically investigates the fundamental relationships that determine the costs and benefits of energy efficiency improvements in low income settings is critical. On the consumer side, research that characterizes electricity consumption patterns and demand response to efficiency improvements will be important. On the supply side, limited data exists on market structure, production costs, and product design trade offs that implicate energy efficiency attributes. Information gathered on both sides will enhance targeting of efficiency investments and associated policy incentives. Field-tested baseline information on real-world performance of more efficient technologies will also be important.

Second, an empirically grounded understanding of the market failures and barriers that matter in LIC settings can usefully inform policy design and implementation. Although the literature on barriers to energy efficiency investments is large, relatively little work has been done in LIC settings. Development spillovers and network effects are examples of externalities that have been under-emphasized to date, but could be important sources of social returns on energy efficiency investments in a low-income country setting.

Finally, there is much to be learned about policy design and implementation in LIC settings. If there are cost-effective energy efficiency improvements that are not being made by private consumers, there is a potential role for policies and programs that can effectively deploy these investments. Research that explores implementation constraints and challenges, producer and consumer responses to policy incentives, and the distributional implications of alternative policy designs can usefully inform policy design and implementation going forward.

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