The Impact of Rural Electrification

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Challenges and Ways Forward

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1 What We Know of Rural Electrification: Evidence and Challenges

According to the International Energy Agency's (IEA) World Energy Outlook (2013), more than 1.2 million people worldwide did not have access to electricity in 2011. Almost all of them live in developing countries (1,257,000 out of 1,258,000). The region most affected by the lack of electrification is Africa, specifically Sub-Saharan Africa. While the electrification rate in North Africa reached 99% in 2011, it was not higher than 32% in sub-Saharan countries. These figures are even more alarming when we consider the electrification rates in rural areas. The IEA reports that only 65.1 percent of rural areas in developing countries had access to electricity in 2011, while rural electrification rates of transition economies and OECD countries was 99.7 percent.

Electricity alone may not be able to create all the conditions for economic growth, but it is obviously essential for basic human needs and economic activity (IEA, 2013). In theory, access to electricity can improve socio-economic conditions in developing countries through its influence on key components of poverty, namely health, education, income and environment (Kanagawa and Nakata, 2008). Concerning rural areas, Khandker, Barnes, and Samad (2009) claim that lack of access to energy and more precisely to electricity is one of the major impediments to economic development. Chaurey, Ranganathan and Mohanty (2004) argue that a strong correlation exists between rural poverty and access to electricity because electricity is a pre-requisite for productive activities. In addition to improving productivity by giving access to more efficient means of production, access to an electrical grid and better electricity services could also lead to household time savings and allow them to work more hours by increasing their access to markets (Bernard and Torero, 2011). Rural electrification programs seem to be crucial to improve living conditions and promote development; however, there is also a need for evaluation of such programs' impacts to determine whether or not interventions are relevant and cost effective. Evaluations would indeed provide measurements of results and help identify the causal link between the intervention's activities and these socio-economic outcomes. Several impact estimations on various economic development measures have been conducted, reaching various conclusions.

Most of the econometric papers that one finds in the literature are actually case studies. The impact of rural electrification is often evaluated for one country or region. Many articles focus on electrification in South Africa; for example, Dinkelman (2011) that estimates the impact of rural electrification on employment and Davis (1998) who tries to identify the effects of access to electricity on rural households' choice of fuel. The impact of access to electricity in South Africa is also studied by Spalding-Fecher and Matibe (2003) and Madubansi and Shackleton (2006). The keen interest in this particular country can be explained by the historical perspective of the evolution of electricity access in remote areas of South Africa. In the early 1990s after the democratic transition, the government implemented an electrification program in the country; apartheid policies had created considerable disparities in access to infrastructure (Madubansi and Shackleton, 2006; Bekker et al., 2007). This quite recent roll-out of grid infrastructure in South Africa and the provision of electricity to households provide a very good opportunity to evaluate their impacts (Davis, 1998, Dinkelman, 2011).

The findings differ depending on the choice of datasets and econometric models. Davis (1998) and Madubansi and Shackleton (2006) focus their articles on changes in energy consumption patterns of households in rural areas following electrification. Davis (1998) uses data from a household survey and describes the evolution of energy expenditures and fuel use. The author concludes that an energy transition appeared in rural households but keeps the role of access to electricity in perspective. According to Davis, only weak evidence indeed suggests that electrification accelerated the energy transition. The more recent paper of Madubansi and Shackleton (2006) gives a detailed analysis of changes in energy consumption patterns. Using data related to five rural villages in 1991 and 2002, the authors find that "electricity is simply viewed as an additional energy, rather than an alternative." If electricity use increased for lighting and powering entertainment appliances, fuel remained the main energy source for thermal needs, with an increase in the number of fuel types used per household. Dinkelman (2011) uses panel data and two identification strategies, namely the instrumental variables strategy and fixed effects approach. Her main findings include a positive effect of electrification on female employment. She details that new infrastructure seems to increase hours of work for both men and women. If women are released from home production, their wages tend to decrease while men appear to earn more money. Again concerning South Africa, Spalding-Fecher and Matibe (2003) aim to estimate the externalities of electrification. They study air pollution impacts on human health, damages from greenhouse gas emissions, and the avoided health costs from electrification. The total external cost of electricity generation amounts to 40 percent of industrial tariffs and 20 percent of residential tariffs. These estimates lead to qualified results of electrification in South Africa. While it seems that electricity access significantly improved rural households' conditions and promoted economic activities, cleaner electricity production in the country appears to be needed.

Other countries are also studied within the literature. For instance, Khandker, Barnes and Samad (2009) and Khandker et al. (2009) analyze the welfare impacts of rural electrification and provide evidence from Bangladesh and Vietnam. Concerning Bangladesh, the authors mention the 1975 "Total Electrification Programme," a first initiative to ensure access to electricity in rural areas of the country. In 1977, the government established the Rural Electrification Board (REB), which aimed to support rural electrification. Khandker, Barnes and Samad (2009) use a survey that was conducted in 2004 by REB and various econometric models to estimate a valid counterfactual. They explain the difficulty to find a "counterfactual"; it may be hard to estimate "what would have happened to the households with electricity if they did not have electricity" (Khandker, Barnes and Samad, 2009). Noting that randomization can be difficult to implement, they use two different methods to assess the impacts of rural electrification. The first technique is the propensity score matching (PSM). The authors find that rural electrification has a significant impact on income, expenditures, and education. The second technique is the use of instrumental variables (IV) to correct for biases due to unobservables and endogeneity, which PSM does not correct for; examples include the degree of people's motivation and dynamism. Most of the findings remain unchanged but the magnitude of the impact differs. Regarding Vietnam, Khandker et al. (2009) evaluate the welfare impacts of households' rural electrification. Their analysis is based on a panel survey from 2002 and 2005. Here, the econometric framework includes difference-in-difference (DD), DD with fixed-effects regression and propensity score matching with double difference. The authors find significant positive impacts of grid electrification on households' cash income, expenditures, and educational outcome. They also stress that a saturation point is reached after prolonged exposure to electricity.

Focusing on India, Bhattacharyya (2006) claims that "rural electrification alone is unlikely to resolve the energy access problem because of low penetration of electricity in the energy mix of the poor." More recently, however, van de Walle et al. (2013) find positive effects of rural electrification on consumption and earnings, as well as on schooling for girls. They find that wage rates are not affected by the intervention and find positive externalities for electrification.. Bernard (2012) explores the impacts of rural electrification projects in Sub-Saharan Africa and gives a very interesting review of trends in electrification programs over the past 30 years in the region. While the author argues in favor of the importance of rural electrification, he also points out that its impacts on development components such as health or education are "largely undocumented." Yet, as previously mentioned here, sub-Saharan Africa remains the region most affected by the lack of electrification.

Potential positive impacts of rural electrification on development seem to be accepted by consensus in scientific literature. However, methods to precisely evaluate these impacts are discussed and highlighting the issues faced by impacts estimations appears to be crucial. Evaluations are methodologically challenging but highly needed because they are used to justify projects [Bernard and Torero (2011) and Bernard and Torero (2011)].

2 What we know of Impacts and Expected Outcomes

Rural areas of poor countries are often at a disadvantage in terms of access to electricity. The high cost of providing this service in low populated, remote places with difficult terrain and low consumption result in rural electricity schemes that are usually more costly to implement than urban schemes. In addition, low rural incomes can lead to problems of affordability[1], and the long distances mean greater electricity losses and more expensive customer support and equipment maintenance. Despite this, rural electrification has been claimed to have substantial benefits, promoting production and better health and education for households. Moreover, in the report of the Independent Evaluation Group of the World Bank (IEG 2008) empirical support is found for many of these links and rates of return on rural electrification projects are sufficient to warrant the investment. Additionally, it shows that consumer willingness to pay for electricity is almost always at or above supply cost.

Despite the findings reported in the IEG report, and as Ramírez and Esfahani (1999) point out, the estimates of the impacts of infrastructure access and specifically rural electrification access have been subject to numerous criticisms, which are fundamentally associated with endogeneity problems and causality directions. Although access to infrastructure affects productivity, income, and economic growth, it also affects the supply and demand of infrastructure. By neglecting this simultaneity, there is a possibility of biasing estimated impacts.

Until very recently, the possibility of identifying causal relationships between electrification access and its impacts on productivity or rural incomes was limited to macroeconomic studies based upon time series. These studies attempted to identify whether or not these investment preceded the supposed effects that are attributed to such investments. In recent years, however, with the development of evaluation methodologies [Rosenbaum and Rubin (1983) or Heckman, Ichimura and Todd (1998)], advances have been made in establishing causal links from microeconomic evidence, comparing the trajectory of individuals subject to interventions, in relation to the trajectory of other comparable individuals that have not been subject to interventions [see for example IEG (2008), van de Walle (2003), Galiani, Gertler and Schargrodsky (2005) and Escobal and Torero (2005)].

Recent work by Bernard and Torero (2009) implemented a randomized evaluation of the impacts of rural electrification. They use discount vouchers to incentivize households to connect to the electricity grid and

[1] Although where electricity replaces other commercial fuels, such as kerosene, households' energy costs may fall rather than rise.

study how the behavior of neighbors changes with the number of voucher recipients. By focusing on social interactions effects, the authors shed light on the spillovers that are possible in this kind of design. They find that neighbors' connection behavior has large effects on a household's connection decision. While the authors cannot identify the mechanisms, the evidence suggests that social pressure to seek a higher status is the main driver of this effect. Their limited results stress the need to better understand the mechanisms through which these effects are realized. We can use this information to design policies that can change behavior on a larger scale, so that providing incentives to a small number of households can also incentivize other members of the community and improve targeting efficiency at a relatively low cost.

Another issue of concern is indoor air pollution. Approximately 2.8 billion people worldwide rely on solid fuels for cooking, lighting, and heating. These fuels are usually burned inefficiently, both as biofuels for cooking and kerosene lighting, which results in substantial emissions of air pollutants that affect human mortality and morbidity rates. As the main source of indoor air pollution, cooking with biomass has received the most attention in the literature, and significant efforts have been made to improve cooking practices. Kerosene has received less attention, despite being used to light approximately 300 million households worldwide. Kerosene emissions include fine particular matter (particles with aerodynamic diameter ≤ 2.5 µm; $PM_{2.5}$), carbon monoxide (CO), nitric oxides (NO_X), and sulfur dioxide (SO_2) (14-16). Kerosene-burning devices can impair lung function and increase cancer risks as well as incidence of infectious illness and asthma . There is extensive evidence that indoor air pollution is strongly linked to human health, especially among children, and that the presence of pollutants related to kerosene in the environment is also related to human health. In addition, kerosene lamps have important environmental consequences. It is estimated that these devices are responsible for 7 percent of annual global black carbon emissions.

The rural electrification project in El Salvador in Barron and Torero (2014) offers a unique opportunity to identify a causal relationship between access to electricity and the levels of indoor pollution driven by change in lighting sources. Barron and Torero (2014) find that household electrification is associated with large and significant reductions overnight $PM_{2.5}$ concentrations arising mainly from reductions in kerosene use, effects that are maintained at least two years after electrification. They find increases in the time allocated to non-farm work activities for males and higher overall income arguably driven by this reallocation of labor. In addition to decreases in coping cost (like kerosene expenditures and expenses to charge batteries), they find that the decreases in indoor pollution cause a decrease of acute respiratory infections in children.

2.1 Expected Outcomes

The benefits of rural electrification are theorized to be span a wide range, from increases in income due to new work opportunities to increased security and decreases in fertility [IEG (2008)]. We summarize the benefits documented in the IEG as follows:

- Income benefits from access to electricity through new opportunities of work, especially in nonfarm activities.
- Leisure and domestic benefits from lighting and TV/radio.
- Time savings from household chores which can be used for leisure and productive activities.
- Education benefits through higher earnings for children living in electrified households that have higher educational attainment.

- Increased productivity of home business through higher revenues of existing businesses and the creation of new home business.
- Increased agricultural productivity through higher revenues.
- Improved health outcomes and reduced mortality through improved indoor air quality from changes in lighting source.
- Reduced fertility at lower costs, achieved through information channels that use electricity in lieu of reproductive health programs.
- Public goods benefits, such as increased security and lower environmental contamination.

Although most of these benefits have been separately documented in the electrification studies, it would be too ambitious to purport that any study has or would be able to capture all these benefits, all the more so that it manages to separately identify the causal relationships. With that in mind, the urge is to have rural electrification programs that are informed by previous rigorously evaluations and rigorously evaluated for different subsets of these benefits. This approach would increase the available evidence that is used to argue for the need electrification by providing a systematic and objective assessment of rural electrification programs, providing accountability and learning in policymaking. Identifying the causal links and the impact pathways of rural electrification provides new opportunities that complement electrification and improve the welfare of rural households such as access to information technologies, electronic/media information campaigns, and so on, which are precluded by a lack of electricity in rural areas.

Evaluation efforts for rural electrification programs should aim to answer questions along a clear hypothesized causal link as a way to better understand the overall impact on socioeconomic development. These efforts provide and opportunity to devise innovate ways to promote adoption among the poor despite the cost of access to electricity, for example. In addition, is important to study off-grid solutions and explore what kind of sources are most effective for a given setting; as connection to the grid in remote areas might be prohibitory costly, other energy sources off the grid might be viable. These choices should take into account the uses that the households will give to electricity: in rural households in developing countries, electricity is mainly used for lighting, for example, and providing off the grid electricity options for remote areas might be a cost effective way of sharing the benefits of electrification with these remote households.

We now present an analysis framework to guide the discussion of the main expected outcomes when designing an impact evaluation for rural electrification programs. The income of a rural household i can be expressed as the sum of incomes that the household receives for J different activities (e.g. farm and non-farm activities):

$$Y_i = \sum_j y_{ij}$$

where Y_i represents total income of the i-th household and y_{ij} represents its income from activity j. Each activity-specific income y_{ij} can be decomposed into two components: hours worked (l_{ij}) and the hourly return (y_{ij}/l_{ij}) of the i −th activity, such that:

$$Y_i = \sum_j l_{ij} \frac{y_{ij}}{l_{ij}}$$

The number of hours spent on activity j can be expressed as the product of the total hours worked (L) and the share of time allocated to activity j (Sl_j). Therefore, we can now express the total income for household i as:

$$Y_i = L\sum_j Sl_{ij}\frac{y_{ij}}{l_{ij}}$$

The hypothesis is that access to electricity in rural areas will result in a change of income for rural households through an increase in the demand for rural products and a change in prices for both farm and non-farm products. This change in income (ΔY), which is obtained by a household because of access to new businesses (both non-farm and own businesses) and or changes in purchasing prices through wages. We can then decompose the change in income in the following way:

$$\begin{aligned}\Delta Y_i \quad = \quad & \Delta L\sum_j Sl_{ij}\frac{y_{ij}}{l_{ij}} + L\sum_j\left[\Delta Sl_{ij}\frac{y_{ij}}{l_{ij}} + Sl_{ij}\Delta\left(\frac{y_{ij}}{l_{ij}}\right) + \Delta Sl_{ij}\Delta\left(\frac{y_{ij}}{l_{ij}}\right)\right] + \\ & +\Delta L\sum_j\left[\Delta Sl_{ij}\frac{y_{ij}}{l_{ij}} + Sl_{ij}\Delta\left(\frac{y_{ij}}{l_{ij}}\right) + \Delta Sl_{ij}\Delta\left(\frac{y_{ij}}{l_{ij}}\right)\right]\end{aligned}$$

Assuming that second (and higher) order interactions with changes in the return to labor are negligible, changes in income can be approximated as:

$$\Delta Y_i \approx L\sum_j\left[\Delta Sl_{ij}\frac{y_{ij}}{l_{ij}}\right] + \Delta L\left[\sum_j Sl_{ij}\frac{y_{ij}}{l_{ij}}\right] + L\sum_j\left[Sl_{ij}\Delta\left(\frac{y_{ij}}{l_{ij}}\right)\right] + \Delta L\sum_j\left[\Delta Sl_{ij}\frac{y_{ij}}{l_{ij}}\right]$$

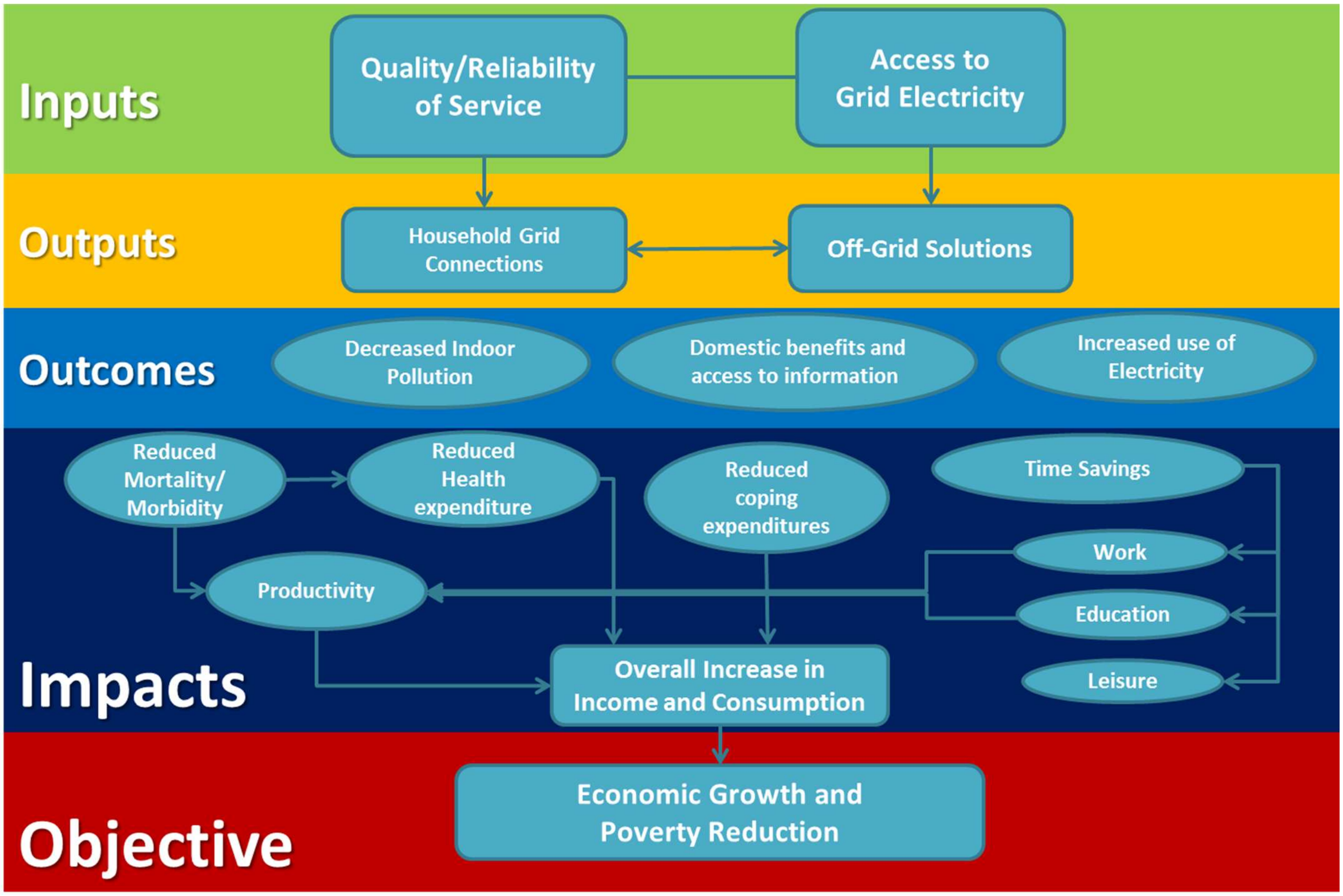
This equation represents four of the possible channels through which income may be affected by access to electricity. The first component, i.e. $L\sum_j\left[\Delta Sl_{ij}\frac{y_{ij}}{l_{ij}}\right]$, of the equation shows the impact of changes of labor allocation across activities, *keeping total hours of labor fixed*. In the rural electrification case, we are interested in analyzing shifts in labor devoted to agricultural and nonagricultural activities and whether access to electricity leads to greater opportunities for nonfarm work activities. Electricity may also create overall employment opportunities. Thus, the second component, i.e. $\Delta L\left[\sum_j Sl_{ij}\frac{y_i}{l_i}\right]$, captures the effect of changes in the household's total working hours, *keeping labor allocation constant*. Third, there is scope for increases in rural households' market efficiency through increases in their purchasing power. In this line, the third component, i.e. $L\sum_j\left[Sl_{ij}\Delta\left(\frac{y_{ij}}{l_{ij}}\right)\right]$, captures changes based on returns to labor (that is, hourly wages) allocated to agricultural and nonagricultural activities, *keeping labor allocation and total hours of labor constant*[2]. Specifically in the case of agricultural activities, this will be directly related to

[2] The size of this component will largely depend on the size of the rural electrification program; for small programs this component is likely to be negligible.

prices of their products. Finally, the fourth component, i.e. $\Delta L \sum_j \left[\Delta Sl_{ij} \frac{y_{ij}}{l_{ij}}\right]$, captures the interaction effect between changes in hours of labor and changes in labor allocation across activities.

This approach allows us to determine the extent to which each factor affects rural households' incomes: total labor supply, shares of time allocated to each activity, differential returns between agricultural and non-agricultural labor, and complementarities through the interaction effect. This framework and the findings in the IEG report provide us with a list of primary indicators to study in impact evaluations in rural electrification. These indicators provide a narrative that uses the theoretical mechanisms through which we expect electricity access to improve welfare, as presented in Figure 1. Namely, rural electrification programs increase access to grid connections and the type of off-grid options available to rural households. The change in energy uses of the households and household electricity connection take-up will depend on the type of off-grid sources available (and those that having an electricity connection might introduce, e.g. batteries) and will depend on the expected quality of services. For those that connect, we expect direct outcomes such as increase use of electricity, decreases in indoor pollution as electricity is used for lighting and increase of information in the households, as households connected to the grid have now the option of acquiring televisions, radios and mobile phones. These changes in turn will influence the number of hours of labor, health outcomes, education that increase productivity. Coupled with the decreases in health expenditures and coping cost (such as kerosene expenses, battery charging expenses, wood fetching, etc.), this will promote income and consumption growth, thus promoting the overall objective of economic growth and poverty reduction in rural areas of developing countries.

Figure 1 Impact Pathways of Rural Electrification Programs



To estimate impacts across the different pathways, we propose a series of indicators that are proxies for different impacts. We present these indicators in

Table 1, where we indicate when one would expect to observe these impacts (immediate, short term, long term), and the direction of the impact and if one could expect the effects to be different for females. Furthermore, we use this framework to illustrate the effects found in Bernard and Torero (2009) and Barron and Torero (2014) in Table 2 through Table 4. The presentation of the tables make clear the links across the two evaluations. For example, the increase in access that would expected to be realized in the immediate short term and spillovers that can increase electricity connections rates in the communities where a number of household were selected to receive a discount voucher. The tables also provides some contrasting effects. The results in Bernard and Torero (2009) are mainly in the short term mainly due to the short time period of the study; while Barron and Torero (2014) are able to provide more evidence throughout the impact pathways described above. They find the increase in access to electricity, reflecting *outputs*; decreases in indoor polluting and access to electric appliances, reflecting the changes in *outcomes*. These changes are clearly linked to specific impact in the framework, namely changes in time allocation across labor activities, improved health outcomes of vulnerable groups, etc. reflecting the expected impacts reflected in the framework. Finally, the changes in labor allocation are casually related to income changes that reflect the overall objective of the electrification intervention; economic growth and increases in overall economic wellbeing.

Table 1: Primary Indicators in Rural Electrification Impact Evaluations

Term	Theme	Indicator	Expected Impact	Gender heterogeneity
Immediate	**Coverage and Access**	• Percentage of households connected to the grid	**Positive**	No differentiated effect
		• Cost of electricity	**Negative**	No differentiated effect
		• Reliability of electric services	**Positive**	No differentiated effect
Short term	**Coping costs**	• Number of sources used	**Negative**	No differentiated effect
		• Consumption of electricity	**Positive**	No differentiated effect
		• Energy input collection time use	**Negative**	Larger effect for females
		• Coping expenses in other energy sources	**Negative**	No differentiated effect
	Health	• Indoor pollution	**Negative**	No differentiated effect
		• Incidence of acute respiratory disease among vulnerable groups	**Negative**	No differentiated effect
	Education, Leisure, and Information	• Hours in education or studying in the home	**Positive**	No differentiated effect
		• Hours spent in childcare	**No change**	No differentiated effect
		• Hours spent in entertainment and other leisure activities	**Positive**	Larger effect for females
	Productivity	• Total hours of work	**Positive**	Larger effect for females
		• Percentage of hours of agricultural	**Negative**	Larger effect for females
		• Percentage of hours of non-agricultural work	**Positive**	Larger effect for females
		• In home business productivity/revenue	**Positive**	Larger effect for females
Long term	**Economic Growth**	• Change in total income and expenditure	**Positive**	Larger effect for females
		• Percentage of poor households	**Negative**	Larger effect for females

Table 2 Immediate and Short Term Results of Electrification Impact Evaluations in Ethiopia and El Salvador, Part 1

Term	Theme	Study	Impact	Size of Effects	Heterogeneity
Immediate	**Coverage and Access**	Bernard and Torero (2009)	• Neighbors' connection behavior has large effects on a household's connection decision. • Social effect also decreases by distance, leading to sub-village clusters of high/low density of electrified households.	• **Each additional household that received a voucher within a 30 meter radius increases the probability that an individual will connect by close to 2 percentage points from a 41 percent baseline connection rate.**	No differentiated effect
		Barron and Torero (2014)	• Both the low- and high-discount vouchers increase the probability of adoption of a formal connection. • Spillover effects are large. A neighbors' connection decision explains one's own connection decision.	• **Individual discount vouchers made households 11 to 19 percentage points more likely to connect to the grid. The effect of low-discount and high discount vouchers is roughly similar.** • **A voucher allocated to a neighbor has 25% of the effect of a voucher allocated directly to a household.**	No differentiated effect No differentiated effect

Term	Theme	Study	Impact	Size of Effects	Heterogeneity
Short term	**Coping costs**	Barron and Torero (2014)	• Decrease in the likelihood of using non-electric lighting sources. • Electrification caused large reductions in kerosene expenditures. • No evidence of changes in cooking practices; neither in the use of wood for cooking nor in the probability of cooking outdoors.	• **Most fuel changes are due to reductions in kerosene use, while other sources show economically small and statistically insignificant changes.** • **This effect would be unlikely since the use of wood for cooking was around 85% at baseline and cooking with electricity is much more expensive.**	No differentiated effect No differentiated effect No differentiated effect No differentiated effect

Table 3 Short Term Results of Electrification Impact Evaluation El Salvador, Part 2

Term	Theme	Study	Impact	Size of Effects	Heterogeneity
Short term	**Health**	Barron and Torero (2014)	• Reduction in air pollution due to substitution away from kerosene as a lighting source.	• **Overnight air pollutant concentration was 63% lower among voucher recipients. The time resilience of the effects strengthens the link between household electrification and health.**	No differentiated effect
			• Electrification leads to reduced incidence of acute respiratory infections among children under the age of six.	• **Reflected in reductions of 37-44 percent in acute respiratory infections incidence among children under 6.**	No differentiated effect
	Education, Leisure and Information	Barron and Torero (2014)	• School-age (6 to 15 year old) children increase time studying at home. No impact on the probability of enrollment.	• **Vouchers increased the probability of studying by 7 percentage points**	No differentiated effect
			• Increases in appliance ownership, such as television sets, stereos, refrigerators and blenders.	• **Increases in leisure time value. Access to refrigeration has potentially important effects on food storage, food safety, and nutrition**	No differentiated effect
			• Hours spent in entertainment and other leisure activities	• **Voucher recipients reduced leisure by an average of roughly 0.7 hours per day. This reduction is similar for low- and high-discount vouchers.**	There are no clear patterns among females. Effects are driven by males.

Table 4 Short and Long Term Results of Electrification Impact Evaluations in Ethiopia and El Salvador, Part 3

Term	Theme	Study	Impact	Size of Effects	Heterogeneity
Short Term	Productivity	**Bernard and Torero (2009)**	• No evidence of electricity's benefits in the short run of the study, in terms of either productive use or changes in time allocation		No differentiated effect
		Barron and Torero (2014)	• Beneficiaries of electrification are more likely to have engaged in self-employment, and in non-agricultural activities.	• **Non-agricultural independent work in the four weeks leading to the survey increased by 13 percentage points among voucher recipients.**	This increase seems to come from 30-40 year olds rather than younger workers. No systematic changes in time allocation among adult females, but adult males adjust their work activities, reducing time in independent farm work and increasing time in other work.

Long term	**Economic Growth**	**Barron and Torero (2014)**	• Increases in total income and expenditure	• **Annual per capita income increased by $186 among voucher recipients (34% of baseline income).**	No differentiated effect
			• Distributional effects and poverty	• **Income changes had some distributional consequences, with voucher recipients being 10 percentage points less likely to have income below the median.**	No differentiated effect

3 Methodological Challenges in Impact evaluations of Rural Electrification

We now turn to highlight the challenges in doing impact evaluations of rural electrification problems. We organize the discussion around four challenges and propose some solutions as well the caveats of these solutions.

The first challenge is selection. The link of causality between a rural electrification program and the impacts is not identified by simple before-and-after comparisons or connected and non-connected groups conditional on having access to the grid because households that connect to the grid are likely different in unobservable ways to the households that decided not to connect. This would bias estimates of the impact, which would be confounded with the unobservable variables. For example, if household that decided to connect are more dynamic, then we can observe large increases in income after connecting to the grid, but a large part of this increase is due to the innate dynamism of the household members and not necessarily because of electricity. These households would have been better of regardless of the electrification program. A solution for this selection problem is a randomized encouragement design (RED). For example, Bernard and Torero (2009) use a voucher to incentivize households in Ethiopia to connect to a new electric grid that was coming to their town and find much larger connection rates among voucher recipients. This design provides a strong instrumental variable for a household's connection status.

The limitations when implementing the RED are logistical. It is essential to give an incentive that is sufficiently large so households can connect and that the electricity providers comply with a strict protocol when distributing and cashing the incentives. This will limit any contagion effect and prevent an underground market for the incentive to develop and jeopardize the evaluation design. When implementing this design, it is important to have local partnerships that guarantee that the incentives are perceived as official by the recipients. Other characteristics of the incentives necessary to maintain the validity of the impact evaluation design are:

- the benefit of the incentive needs to be clear and understandable to all possible beneficiaries;
- the incentive needs to be non-transferable to prevent shadow/exchange markets to arise; and
- the incentive should be distributed publicly to improve credibility on the lottery nature of the allocation of the incentives.

The second challenge in rural electrification impact evaluations is endogenous infrastructure placement. Program designers would place the electric grid in areas where they are likely to get higher paying customers, in denser population areas, etc., which would bias comparison between connected and non-connected areas. A solution for this is a Pipeline Design that identifies ***intervention*** areas early in the design stage and determines ***evaluation*** areas based on the sequencing of the intervention. By using the sequencing of the program, we ensure that both treatment and control areas are comparable, as both have been selected to be connected to the grid at some point. Ideally, evaluators would also try to randomize the order of implementation. However, this is seldom times possible in infrastructure interventions. The main limitation of this design is that even when evaluators are not able to randomize the order, the order planned and proposed by the implementers can have deviations in practice. In this design is important that evaluators monitor the implementation of the program to adjust for any delays and or contamination of previously selected control areas because of circumstances unforeseen at the design stage.

Combining the pipeline design with the randomized encouragement design allows us to identify the impact of the program without the biases of program placement and selection, thus providing rigorous evidence of the causal links between rural electrification and development outcomes. With this design we can use the randomly assigned discount and an instrumental variable for a household's connection status. Furthermore, we can use the random assignment in a "reduced form" difference in difference or fixed effects estimation that uses the baseline survey (used to characterized interventions areas) and follow-up surveys (to evaluate the impact). This strategy uses the panel of households to define the impact of the program as the differential differences across time between the households that received the incentive and those that did not while allowing for fixed unobserved heterogeneity across households that might help explain the decision to connect (selection). In addition, one needs to take into account the political feasibility and budgetary constraints when distributing the incentives. The exclusion of some areas from the incentive might not be politically favorable for a policy maker, though implementing a sequencing of the voucher distribution where control households get the voucher at a later time might be a feasible option. An example of this design is from Barron and Torero (2014), where they use the sequencing of the deployment of the electric grid to select treatment and control areas and provide a discount voucher to a random selection of households in treatment areas. In their study, they address both program placement bias (by selecting control areas that are scheduled to be electrified in the near future) and households' self-selection bias (by providing the random incentive and using the voucher as an instrumental variable for connection status). The limitations of this compounded design are the same we discussed above; however, this is the strongest design to identify causal links between electrification and the welfare of households in rural areas.

The third problem stems from the objective function that policymakers and program designers use when deciding what projects are cost effective. The evidence suggests that the implementer solve a cost minimization problem when deciding where to extend an existing grid. There seems to be little attention paid to profit maximization; that is, taking into account that more remote (and thus more expensive) areas might have high productive potential that would be realized by electrification thus making the electrification investment ex-post profitable. The duality of cost minimization and profit maximization depends on the quasi-concavity of the production function and complete markets, situations that are not characteristic of the electricity sector-- one can easily argue that there are increasing returns to scale in some parts of the production function-- and less so in developing countries. This implies that a planner using cost functions or profit functions as objective functions would make different decisions.

To illustrate the point, suppose that we have three households, A, B and C, that we want to connect to the electric grid. As shown in Figure 2, if we connect household A at minimum cost we obtain the negative profits, and only connect household A and adjacent households. If we included the potential profits that can be obtained from connecting A to B and C we would arrive to a different conclusion. We would move southwest in the quadrant, to find the allocation that maximizes profit at a minimum cost. We arrive at point (A, B) where profits are positive and household A, B and adjacent are connected to the grid. Note that is not always profitable to connect all households, as evidenced by the point (A, B, C) being at the zero isoprofit curve.

We can further illustrate this problem in spatial terms using the rural electrification intervention in Barron and Torero (2014).

Figure 3 shows the roads available in the area of the intervention and the electricity grid that was constructed. By using only minimum cost as the objective function when implementing the grid, one will expect that most households would be near the roads. This is what we overwhelmingly observe in

Including the potential profits, as we propose, can be illustrated in Figure 4 by using the agricultural potential to proxy for potential profits (see appendix on how potential is calculated). Agricultural potential is estimated using the stochastic profit frontier. This methodology uses the production possibility frontier that describe all the possible production combinations in the area under current conditions and categorizes them depending on their efficiency in the use of resources (how near are the areas to the boundary or frontier). Rural areas in green are areas that have agricultural production potential and consequently could have higher return from being connected to the grid. Under this framework, we would prioritize the areas that have high potential (dark green) to maximize profits and also take into account the access to roads to minimize costs. In this case, while most of the new grid covers areas that have agricultural potential, there are considerable clusters that are in areas with low productive potential. While we do not assert that there are no merits to connecting households with low productive potential (in red), this framework provides us some context of what kind of outcomes we should expect to change in these areas in terms of the cost effectiveness and the sustainability of projects in these areas.

Figure 2. Optimization of electric grid using minimum cost and including potential profits

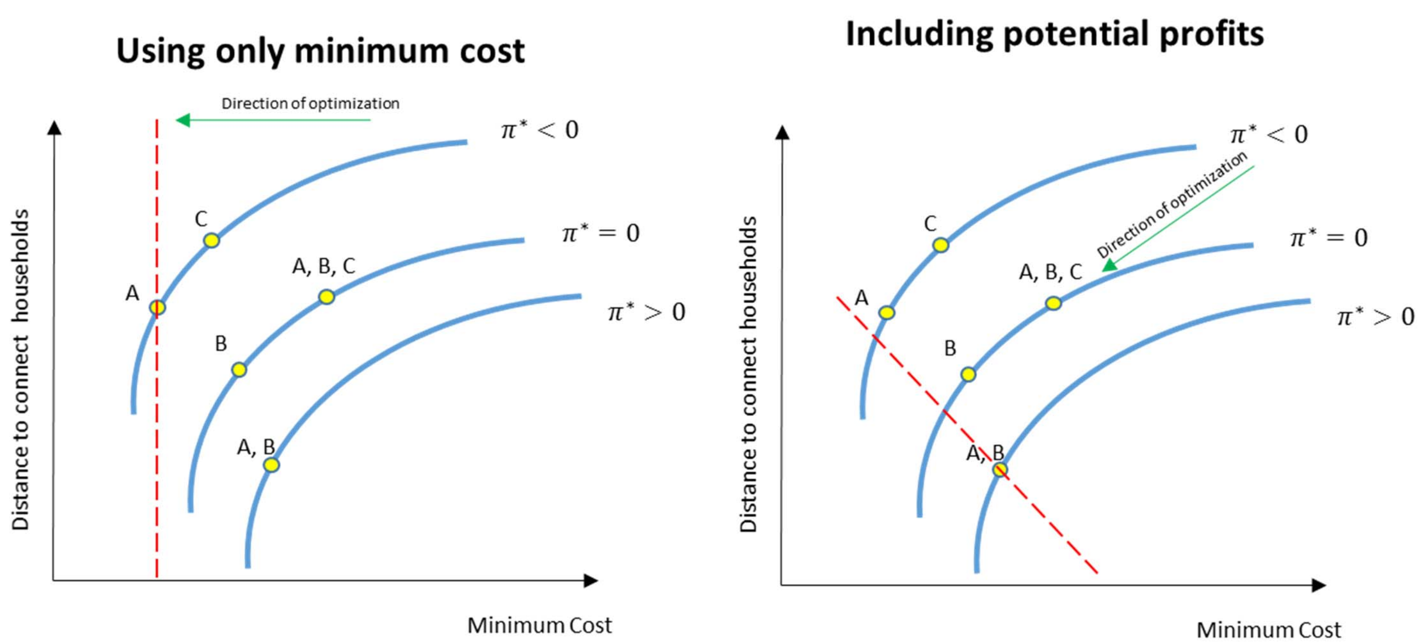


Figure 3. Roads versus electric grid: Northern Zone of El Salvador

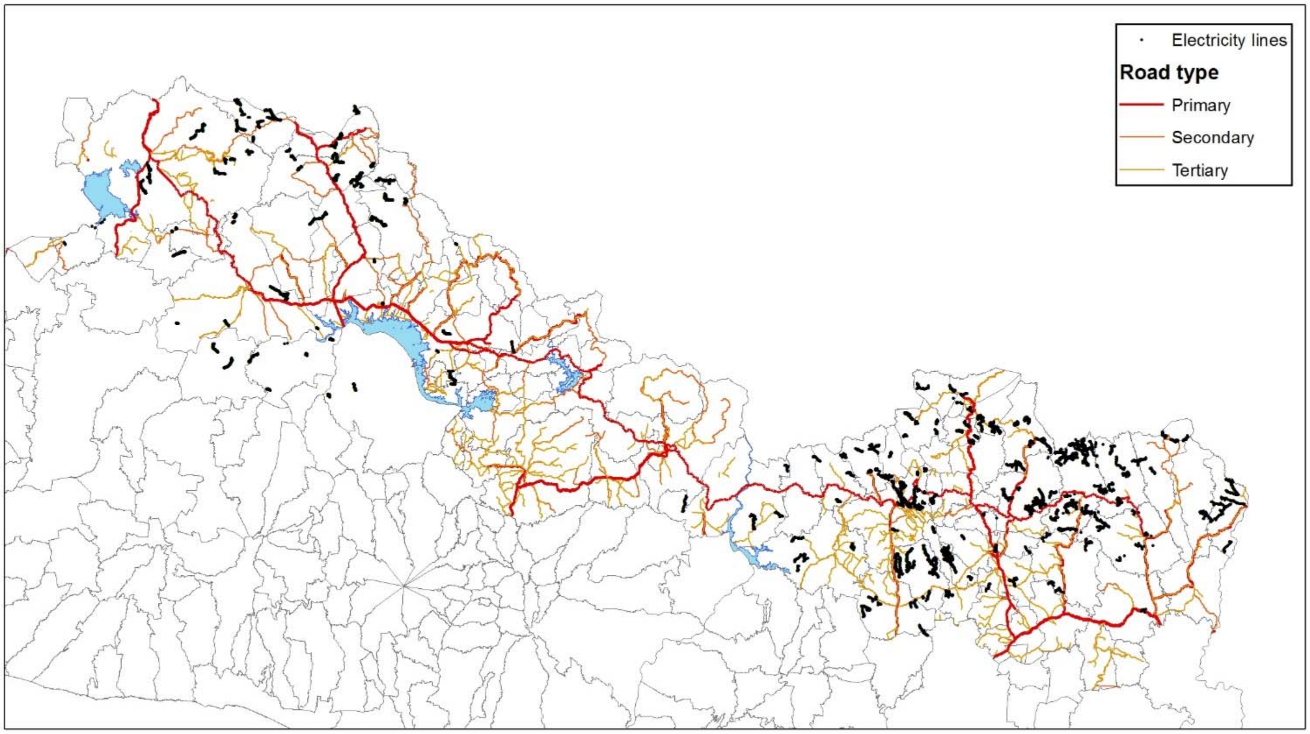
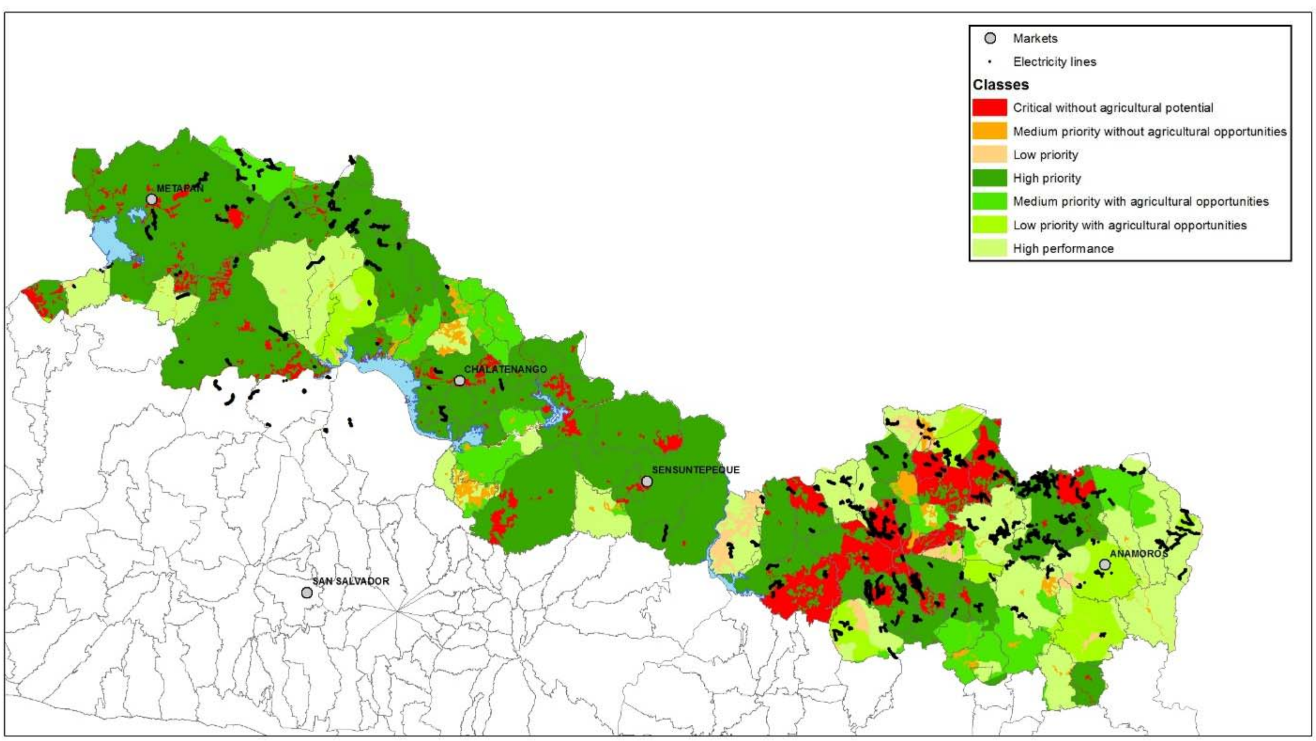


Figure 4. Agricultural typology areas versus electric grid: Northern Zone of El Salvador



The fourth problem in conducting rigorous evaluation of rural electrification resides in ignoring theoretical issues. Without a clear theoretical framework that identifies clear impact pathways and how to properly measure indicators to show the impact of the program along the different pathways, impact evaluation provides no information on where future interventions should improve if they want to have larger impacts for take-up or health, for example. In the previous section, we presented a framework based on the decomposition of household income by the labor activities that aims to solve this problem. From the framework, we proposed a concise list of primary indicators and impact pathways that would prove informative to policymakers interested in the effects of the program being evaluated and to policymakers that could implement similar programs in the future. The importance of including this issue from the planning stage cannot be understated, as this will moderate the expectations on the size of the effects we can expect from rural electrification and provide an objective measure of the success of these programs given the initial conditions in the areas of interest.

4 Key Messages to Move Forward

We have presented our views on the state on the development literature on the impacts of rural electrification. Our purpose is two-fold: to identify opportunities of improvement in current evaluation designs, and to provide a unified framework that takes into account the theoretical mechanisms behind the expected benefits of electrification; more specifically, a framework that is informed by the limitations posed by the policy making environment and uses the latest methodological developments to identify causal links across the impact pathways proposed by the framework.

There are various key messages to take away from this work. Rigorous impact evaluation that includes appropriately selected control groups must be a part of rural electrification program designs. Budgeting evaluation activities and engaging with evaluators at an early stage improves to likelihood of having a high quality evaluation design; plus, if deviations occur after the design stage, the evaluators are better prepared to adjust the design so that the impact results remain informative to policy makers and future program designers. Another takeaway is to use unified framework to specify the expected outcomes and the plausible sizes of impacts. If done at the beginning of the program, this will provide context to the kind of discussion that policy makers should engage in (e.g. if they should focus on health benefits or the potential to diffuse information campaigns to rural households).

These points focus mostly on internal validity, but we also need to focus on external validity as well. Large scale rural electrification programs will provide an opportunity to test if the results from small scale impact evaluations translate to other settings. Something we have not stressed so far but that is important to keep in mind are the complementarities in the provision of different type of infrastructure. Large projects can provide an opportunity to explore complementarities with other infrastructure programs, such as mobile telephony, road access, and improved water and sanitation access. They can shed light on what are the most welfare-enhancing policy options when deciding what types of infrastructure to provide in rural areas, and especially to poor rural households.

Finally, we reiterate the need to use an objective function that casts a wider net when deciding where to place electrification programs. Focusing solely on cost minimization can result in missed opportunities. When deciding where to deploy the electric grid in rural areas it is imperative to take into account the potential profits, specifically the agricultural potential of these areas. By using the isoprofit and cost minimization framework described, rural electrification programs have the opportunity to reach more poor households and have larger impacts in the lives of the rural poor by providing new opportunities and enhancing the synergies between the agricultural and non-agricultural sector.

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Appendix

Methodology to estimate potential of micro-regions

The model

We use the basic model proposed by Aigner et al. (1977)[3] and Meeusen & van den Broeck (1977)[4] depicted in Figure 5, where the stochastic frontier production function is defined as:

$$y_i = f(x_i;\beta)\exp(v_i - u_i) \qquad (1)$$

where y_i is the possible production for farmer i,

> $f(x_i;\beta)$ is an adequate function of inputs x and parameters β,
>
> v_i is a random error with zero mean, associated with random factors that are not under the farmer's control, and
>
> u_i is a non-negative random variable associated with factors that prevent farmer i from being efficient.

Then the possible production y_i is bounded by the stochastic quantity $f(x_i;\beta)\exp(v_i)$. It is assumed that the stochastic errors v_i are i.i.d. random variables distributed $N(0,\sigma^2)$, and independent from u_i. A farmer's technical efficiency is defined as the fraction of the frontier production that is achieved by his current production. Given the frontier production of farmer i is $y_i^* = f(x_i;\beta)\exp(v_i)$ then his technical efficiency can be defined as:

$$TE_i = \frac{y_i}{y_i^*} = \frac{f(x_i;\beta)\exp(v_i - u_i)}{f(x_i;\beta)\exp(v_i)} = \exp(-u_i) \qquad (2)$$

Caudill & Ford (1993)[5] and Caudill et al. (1995)[6] showed that the presence of heteroskedasticity in u_i is particularly harmful because it introduces biases in the estimation of β and technical efficiency. This is very likely to occur if there exist sources of inefficiency related to factors specific fo the producer. In this case the distribution of u_i will not be the same for all the observations in the sample and a correction for heteroskedasticity needs to be made by modelling the variance of u_i:

$$\sigma_{u_i}^2 = \exp(z_i\delta) \qquad (3)$$

where z_i are farmer-specific factors affecting his technical efficiency.

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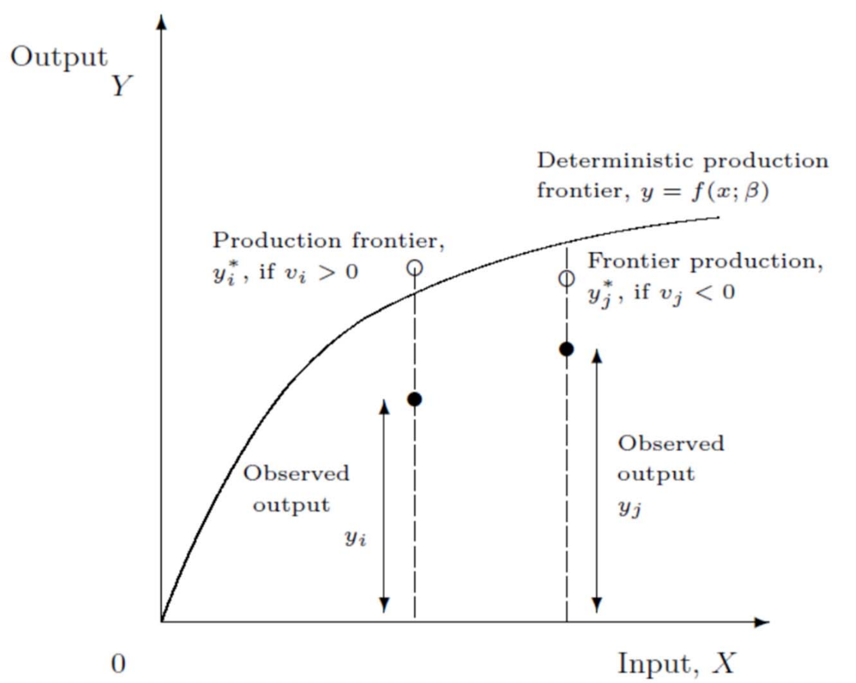
Figure 5. Graphic representation of a stochastic production frontier in the single-output, single-input case



Estimation

In order to estimate the model expressed by equations (1)-(3) we need to address the fact that farms are multi-output production units. So we need to move from a production function to a profit function approach. The stochastic frontier profit function can be expressed as (Kumbhakar & Lovell, 2000):

$$\pi_i = f(p_i, w_i; \beta)\exp(v_i - u_i) \quad (4)$$

where p_i and w_i are output and input price vectors, respectively.

To estimate equation (4) the typical data requirements are:

- Household survey data for farm profits, producer level output and input prices, and farm and household characteristics.
- GIS data for local agro-ecological characteristics such as land use, as well as for market access measures.
- Agricultural census data to extrapolate to all regions in the country.

Parameters estimates for equation (4) can then be obtained by maximum likelihood, and these can be used to predict the (stochastic) frontier profit (i.e. *potential*) and technical *efficiency* can be predicted for the *representative* farmer in a region.