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 WP/16/85

IMF Working Paper

Western Hemisphere Department

Power It Up: Strengthening the Electricity Sector to Improve Efficiency and Support Economic Activity[1]

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April 2016

Abstract

Poor performance of the electricity sector remains a drag to economic efficiency and a bottleneck to economic activity in many low-income countries. This paper proposes a number of models that account for different equilibria (some better, some worse) of the electricity sector. They show how policy choices (affecting insolvency prospects or related to rules for electricity dispatching or tariff setting), stochastic generation costs, and initial conditions, affect investment in generation and electricity supply. They also show how credible (non-credible) promises of stronger enforcement to reduce theft result in larger (smaller) electricity supply, lower (higher) government subsidies, and lower (higher) tariffs and distribution losses, which in turn affect economic activity. To illustrate these findings, the paper reviews the experience of Haiti, a country stuck in a bad equilibrium of insufficient supply, high prices, and electricity theft; and that of Nicaragua, which is gradually transitioning to a better equilibrium of the electricity sector.

JEL Classification Numbers: Q43, Q47, Q48

Keywords: Credible and Non-Credible Promises, Economic efficiency, Economic infrastructure, Electricity Sector, Electricity Theft, Haiti, Nicaragua

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[1] We thank Christian Bogmans, Marcello Estevão, Metodij Hadzi-Vaskov, Ali Michael Mansoor, Rosalind Mowatt, Priscilla Muthoora, Sam Ouliaris, Gerardo Peraza, Delphine Prady, Johannes Wiegand, and Juan Zalduendo for reviewing the paper and providing comments, and Maria Jose Granizo for the research assistance on an earlier version of this paper.

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I. INTRODUCTION

Reliable and low-cost electricity supply is an essential input for economic activity and to attract productive investment (Alam, 2006; Payne, 2010). Conversely, high electricity costs and electricity shortages act as a disincentive to investment, hamper competitiveness, and complicate efforts aimed at poverty reduction, all in all resulting in reduced efficiency and a bottleneck to economic activity. Inadequate management of the electricity sector usually brings about electricity rationing and costly subsidies, which are often exacerbated by fraud and nonpayment, or by weak enforcement. All these elements result in price distortions as well as direct and contingent fiscal costs (IMF, 2013; Di Bella and others, 2015). Unsurprisingly, several agencies (including the World Bank and the World Economic Forum) consider the electricity sector's performance as a critical input in evaluating how easy it is to do business. Moreover, there is evidence that structural reforms, including those aimed at strengthening the electricity sector's performance and infrastructure, increase total factor productivity (IMF, 2015a).

This paper proposes a number of theoretical models for the electricity sector and illustrates some of their implications by reviewing the experience of Haiti and Nicaragua. The models allow assessing how solvency prospects, dispatching rules, generation costs resulting from alternative technologies, as well as the existing composition of the generation matrix, affect long-term investment in the sector (both level and composition), and thus supply levels and average generation costs. The models also show how a credible promise of stronger regulation and enforcement to reduce electricity theft results in larger investment and electricity supply, in lower government subsidies, and in lower tariffs and theft ratios; and, conversely, how a non-credible promise fails to attract sufficiently high investment levels, which result in a sector characterized by low electricity supply, high electricity tariffs, high distribution losses, and high government subsidies.[2]

One relevant conclusion from the models presented is that depending on policy choices, there may be different long-term equilibria for the electricity sector, some better than others. A *better equilibrium* would be generally characterized by long-term public policy choices geared at low theft-ratios and delinquency, strong enforcement, low government subsidies, appropriate tariff setting and electricity dispatching rules, all of which would result in lower generation costs and a volume of investment that is large enough to guarantee electricity supply levels commensurate with peak demand. Alternatively, a *worse equilibrium* would be characterized by high theft-ratios and government subsidies, weak enforcement, inappropriate electricity tariff setting and dispatching rules, all of which would generally result in large generation costs, as well as investment in generation and distribution that

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[2] Distribution losses consist of technical and non-technical losses. Technical losses include power dissipation in electricity system components such as those arising from transmission line losses, power transformer losses, distribution line losses, and low-voltage transformer and distribution losses. These are often accompanied by non-technical losses, which are caused by actions external to the power system and consist mainly of electricity theft, delinquency, inadequate metering and billing, and errors in accounting and record keeping (World Bank, 2009a, 2009b).

result in insufficient electricity supply levels, thereby acting as a bottleneck to economic activity.

Better and worse long-term configurations are influenced by policy choices in the short-term, which also affect the sector's performance. In this regard, the paper describes how poor management will affect the sector's cash flow and solvency prospects, and how constrained financing will result in insufficient supply or rationing, both of which act as a drag on economic activity. Similarly, it shows how cross subsidies embedded in the tariff (or implicit in high distribution losses), can act as a constraint on economic activity, either through high electricity costs, rationing, or both. In particular, the paper emphasizes that investors in electricity generation and distribution usually form their expectation about future solvency prospects based on the sector's current parameters and policies. For instance, if electricity tariffs are lower than generation costs, or if electricity theft and government subsidies are high, the cash flow generated by electricity distribution will generally be insufficient to ensure the sector's solvency and the appropriate maintenance of distribution networks (Varangu and Morgan, 2002; Morgan, 2007; and World Bank, 2009a, 2009b). This will negatively affect investors' perceptions about future solvency, and thus, their current decisions on investing in electricity generation and distribution. All this can result in a given country getting stuck with a distribution network of a size that is not commensurate with demand growth, and with an electricity generation matrix characterized by high costs.[3] Alternatively, if the management of the sector in the short term supports good solvency prospects, investment in generation and distribution will be larger, and the composition and size of the generation matrix will gradually adjust to ensure competitive costs and sufficient supply.

While financial problems of electricity sectors that rely on non-renewable generation become apparent at times of high oil prices, the recent decline in oil prices brings about new challenges. *Ceteris paribus,* lower oil prices reduce generation costs from non-renewable sources, improve the cash flow of electricity distribution, result in a decline in energy subsidies, and provide an opportunity to clean balance sheets and repay cross arrears. However, despite a history of substantial volatility and large swings in oil prices, when the latter are low the incentive for structural reforms and investment in financially less attractive renewable sources is small. Therefore, plans to rebalance electricity generation between renewable and non-renewable sources become less urgent, as hedging properties of renewable sources and environmental costs of non-renewable may get neglected.

The cases of Haiti and Nicaragua are representative of two different equilibria of the electricity sector. Haiti's experience illustrates clearly how the electricity sector can act as a bottleneck to economic activity. Inadequate management and regulation has resulted in insufficient supply, high generation costs, poor service, and has forced the private sector to self-generation, which prevents taking advantage of economies of scale. Haiti's electricity

[3] If electricity distribution is insolvent, private investment in generation may only occur provided the state offers large (and costly) guarantees, including in the form of power-purchase agreements or subsidy transfers, which in the end are likely to translate in higher electricity tariffs.

sector is a drag to the budget and an important source of macroeconomic vulnerability and strong actions have to be taken to make the sector sustainable (IMF, 2015b). In contrast, Nicaragua's experience since 2007 illustrates the transition from a worse towards a better equilibrium for the electricity sector (IMF, 2012). Strengthened regulation has gradually resulted in increased supply and a more diversified energy matrix, lower generation costs, the elimination of blackouts, decreases in theft ratios and, despite room for further improvement, in a more sustainable electricity sector. Going forward, a rule-based tariff setting in the context of a clearly specified medium-term framework should help Nicaragua consolidate the gains to date.

The paper is organized as follows. Section II presents some theoretical models that illustrate how better and worse equilibria for the electricity sector may arise. Section III discusses the experiences in Haiti and Nicaragua, and in the case of the latter, it illustrates how the ongoing transition to a fully sustainable sector may proceed through a medium-term framework. Finally, Section IV presents some concluding remarks.

II. Some Models for the Electricity Sector

This section presents a number of theoretical models for the electricity sector. It first reviews some basic concepts, and then proposes a model of optimal long-term investment in electricity generation, identifying the parameters that will influence its level and composition among different generation technologies. The section then moves to discuss issues related to the distribution network, and analyzes the role that credible government commitments to strengthen enforcement and fight theft (which are frequently associated with improvements in the regulatory framework), have on the network's size, theft ratios, electricity supply and tariffs, and economic activity. The section ends by briefly describing a number of topics relevant to the sector including the conditions upon which electricity shortages, self-generation, and cross arrears and subsidies may arise.

A. Basic Concepts

Electricity Tariffs

Electricity tariffs are periodically set by the energy regulator to cover generation, capital and operational costs, and account for distribution losses:

$$P_t^S = L_t[P_t^G + AVD_t + OF_t] \tag{1}$$

where P_t^S denotes the average electricity tariff (in, e.g., US$/MWh) charged to consumers; $P_t^G = P_t^T + P_t^E$ is the average electricity cost, which is composed by a transmission fee, P_t^T, and the electricity price charged by generators, P_t^E; AVD_t corresponds to the aggregate value of distribution and is set so to cover the operational costs of electricity distribution, capital investment and infrastructure maintenance, financial costs and taxes, and a competitive profit; and OF_t corresponds to other factors defined by the regulator, including to compensate clients or the electricity distribution company depending on circumstances.[4]

Distribution Losses

The "loss factor" $L_t \geq 1$ in equation (1) is defined as:

$$L_t \equiv \frac{1}{1-\lambda_t} \tag{2}$$

where $0 < \lambda_t < 1$ refers to the recognition of a certain level of distribution losses. Clearly, $\lambda_t > 0$ implies that the volume of electricity for which payments can be collected from consumers is a fraction $0 < 1 - \lambda_t < 1$ of the electricity purchased from generators.[5] Therefore (1) can be restated as $(1-\lambda_t)P_t^S = P_t^G + AVD_t + OF_t$, which is an expression of the cash-flow per unit of electricity sold.

Generation Costs

The price paid by the distribution company, $P_t^E = P_t^C + P_t^M$ corresponds to a weighted average of electricity purchased according to the conditions established in (usually long-term) contracts between the generation companies and the distribution company, P_t^C, and that purchased in the electricity spot market, P_t^M. In turn, the "contracts" price (or monomial price) is usually determined by:

$$P_t^C = P_t^P(M_t) + VC(M_t, Q_t) \tag{3}$$

where $P_t^P(M_t)$ is the cost for power and $VC(M_t, Q_t)$ is a pure electricity cost that tracks the variable cost of electricity generation. Both the cost for power and the variable electricity cost depend on the composition of electricity generation, M_t, but the latter also depends on the volume of electricity supplied Q_t. More specifically, $P_t^P(M_t)$ is paid to generation plants that can ensure a steady flow of electricity supply ("base load power units", e.g., generation from oil derivatives), and generally not paid to those that cannot (e.g., run-of-the-river hydroelectric, or wind-based electricity plants, among other).[6]

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[4] Tariffs are usually set as a weighted average of tariffs applied to different consumption blocks, so it involves an estimation of the composition of the client base. If, *ex post*, the composition was different than estimated, the regulator usually compensates either consumers or the distribution company, through the tariff.

[5] The models described later in this section will broadly assimilate distribution losses λ_t, with electricity theft and with delinquency (i.e., billed but not collected electricity). "Distribution losses" or "electricity losses" will be used interchangeably.

[6] For instance, wind-based generation depends on wind conditions (which are affected by weather, the season, the time of day, among other factors), and thus, cannot generally ensure a steady flow of supply, unless appropriate electricity storage facilities are in place, which are generally expensive. Although non-renewable generation (coal, nuclear, or oil-fired plants) is often used to satisfy base load requirements, renewable sources can also be used to this end (e.g., hydroelectric, biomass, geothermal, etc.).

Electricity Dispatching

If the regulator aims to minimize the electricity generation cost at all times, he will first dispatch electricity from those generation plants with lower costs, and as electricity demand increases, he will dispatch electricity from plants with successively higher generation costs. Optimally, base load requirements should be satisfied with reliable, low-cost generation. Shortages should generally not occur provided installed capacity is enough to cover peak electricity demand. Although peak demand will depend on economic activity and electricity tariffs, other factors also play a role (e.g., time of day or season), and thus variable electricity costs will follow. In some countries, the availability of electricity from certain generation plants may also depend on the season (e.g., run-of-the river hydroelectric plants will usually be more available during rainy seasons, which would ensure appropriate water flows per unit of time). For non-renewable generation plants (e.g., fuel oil or coal-based) electricity costs will largely depend on international oil prices.

Electricity Distribution's Cash Flow

The extent to which electricity distribution can generate enough cash flow to undertake investments, cover operational costs or pay profits, depends on how aligned are the values of the parameters in equation (1) with their actual values. In this regard, if the actual value for the cost of electricity generation P_t^{G*} is higher than that included in equation (1); or, if the ratio of distribution losses λ_t^* is higher than the ratio for actual distribution losses; or both, then:

$$AVD_t^* \equiv AVD_t + P_t^S(\lambda_t - \lambda_t^*) + (P_t^G - P_t^{G*}) < AVD_t \qquad (4)$$

where AVD_t^* denotes the actual aggregate value of distribution.[7] In case AVD_t^* is significantly lower than AVD_t, then it is possible that the cash flow from electricity sales to final consumers might be insufficient to pay for electricity generation, or capital investment might be insufficient to keep infrastructure in good shape or undertake necessary investments to reduce losses. The financial imbalance will be larger, the higher the level of electricity supplied.

B. Optimal Investment in Electricity Generation

This section proposes a streamlined model that highlights the main factors affecting optimal, long-term, investment in electricity generation.[8] The model assumes that there is an investor

[7] Expression (4) assumes that the regulator knows the exact composition of demand among different types of clients, and thus, that he does not have to compensate through OF_t, which is thus equal to zero.

[8] The models in this and next section assume that electricity generation and distribution are undertaken by private agents (or state-owned companies acting as private agents) maximizing some form of an objective function. The government is assumed to provide the regulatory framework (e.g., dispatching rules, tariff setting, among other), and its enforcement. Different approaches could be used to analyze these issues, for instance, one

(continued…)

who has some initial wealth $W > 0$, lives two periods ("present" and "future"), and wants to maximize the utility derived from consumption in period 2 (i.e., in the "future"), C_2. His utility function $U(.)$ will be continuous, twice differentiable, with $U'(.) > 0$ and $U''(.) < 0$. To maximize his utility, he can invest in period 1 (i.e., the "present") in a risk-free asset with gross return $R > 1$, or in electricity generation whose return will be uncertain. It is further assumed that there are two technologies available to produce electricity, one from renewable and the other from non-renewable sources. The return of investing in either technology will be stochastic: with probability $0 < \pi_S < 1$, the gross return of investing in electricity generation from renewable sources will be $R\mu^R$ ($R\mu^O$ for electricity generation from non-renewable sources), where $\mu^R > 1$ and $\mu^O > 1$. However, with probability $1 - \pi_S$, the return from investing in either technology will be zero.

In his decision, the investor knows that the average (expected) electricity demand in period 2 will be $Q_2^d = Y_2\alpha^{-1}$, where α is a parameter linking demand with average economic activity Y_2.[9] For each Y_2 there will be a corresponding level of peak demand, $Q_2^{d,peak} > Q_2^d$. It is assumed that there is an existing stock of electricity generation capacity composed by generation plans using both renewable and non-renewable sources. The aggregate capital stock K will be sufficient to satisfy average demand. However, it is further assumed that the existing stock of either technology $\{K^R, K^O\}$ by itself is insufficient to satisfy average (and peak) electricity demand. The model also assumes that electricity dispatching rules are such that ensure that generation costs are minimized given demand levels and the composition of the generation matrix. [10]

The cost of producing energy from non-renewable sources will depend on the price of oil, P^O, which can take two possible values: If the price of oil is high $P^O = P^{O,H}$ (an event that happens with probability $0 < \pi_H < 1$), then the cost of electricity generation from non-renewable sources will be higher than the cost from renewable sources $P^R > 0$, which is assumed to be fixed; conversely, if the price of oil is low $P^O = P^{O,L}$ (an event that happens with probability $1 - \pi_H$), then $P^R > P^{O,L}$. The assumptions above imply that the expected utilization rate of renewable generation plants when $P^O = P^{O,H}$ will be $\gamma^{R,H} = 1$, while the expected utilization rate of non-renewable generation plants will be $0 < \gamma^{O,H} < 1$. Conversely, when $P^O = P^{O,L}$, then $0 < \gamma^{R,L} < 1$, and $\gamma^{O,L} = 1$. Finally, it is assumed that investment in either generation technology requires a minimum scale $k^i > 0$, for $i = R, O$, i.e. investment in either generation technology will be either zero or $I^i \geq k^i > 0$, for $i = R, O$.

in which investment in electricity generation and distribution is completely financed by the budget. This type of approach, however, is not discussed in the paper and is left for future research.

[9] Note that this model assumes that electricity demand does not change with electricity prices. This assumption will be relaxed in the next section.

[10] By definition, average electricity demand is lower than peak demand, but higher than base load. For simplicity, it will be assumed that both renewable and non-renewable technologies in the model can be used to satisfy base load requirements.

Then, the investor will pick a pair $\{I^R, I^O\}$ to maximize his expected utility in period 2, $U(C_2)$, subject to the technological constraints and to $C_2 = (W - I^O - I^R) + I^R\eta^R + I^O\eta^O$ where η^i for $i = R, O$ is a random variable which denotes the return of investing in technology i. The investor's objective function can then be re-expressed as in (5) below:

$$\begin{aligned}\pi_S\pi_H U[(W - I^O - I^R)R + I^R R\mu^R + \gamma^{O,H} I^O R\mu^O] \\ + \pi_S(1-\pi_H)U[(W - I^O - I^R)R + I^O R\mu^O + \gamma^{R,L} I^R R\mu^R] \\ + (1-\pi_S)U[(W - I^O - I^R)R]\end{aligned} \tag{5}$$

For an interior solution (i.e., for $I^i > k^i$ for $i = R, O$), the first order conditions are:

$$\frac{U'\left(C_2^{S,H}\right)}{U'\left(C_2^{S,L}\right)} = \frac{(1-\pi_H)(\mu^R\gamma^{R,L} - \mu^O)}{\pi_H(\gamma^{O,H}\mu^O - \mu^R)} \tag{6}$$

$$\frac{\pi_H U'\left(C_2^{S,H}\right)(\mu^R - 1) + (1-\pi_S)U'\left(C_2^{S,L}\right)(\mu^R\gamma^{R,L} - 1)}{U'(C_2^I)} = \frac{(1-\pi_S)}{\pi_S} \tag{7}$$

$$\frac{\pi_H U'\left(C_2^{S,H}\right)(\gamma^{O,H}\mu^O - 1) + (1-\pi_S)U'\left(C_2^{S,L}\right)(\mu^O - 1)}{U'(C_2^I)} = \frac{(1-\pi_S)}{\pi_S} \tag{8}$$

Despite the model's simplicity, the derived investment behavior has very natural correlates with "real world" behavior. In particular, solvency considerations will impact overall investment in electricity generation. In this regard, investors likely use the observed values of $P_1^S(1-\lambda_1) - P_1^G$ at the time of investment to assess the expected solvency of the sector, i.e., the probability π_S will be a function $\pi_S = \pi_S(P_1^S - P_1^G, \lambda_1)$. In other words, in the absence of government guarantees (and at times even if these exist) drafting a mutually satisfying Power Purchase Agreement (PPA) should be more difficult if the buyer's ability to pay is perceived to be severely constrained by high distribution losses. As $P_1^S(1-\lambda_1) - P_1^G$ goes down, and even turns negative, π_S will also decrease. Given that investment in either technology requires a minimum scale, there will be a threshold level of π_S below which the optimal investment in generation will be zero. This threshold level increases if the minimum scale of investment (k^i for $i = R, O$) also increases.

Moreover, it is important to highlight the utilization rate of either technology will also be a random variable and that its value will be a function $\gamma^i = \gamma^i(P^O, P^R, K^O, K^R, \alpha, Q^d, Q^{d,peak})$, for $i = R, O$. This is the case as the utilization rate of each technology will depend on the relative electricity generation cost, which depends on a random variable, P^O. Increases in EP^O (through increases in either $\pi_H, P_2^{O,H}$, or $P_2^{O,L}$)will generally result in an increase in non-renewable generation. Clearly, the initial composition of the electricity generation matrix will play an important role in determining the value of γ^i: the more unbalanced the initial electricity generation matrix, the higher the expected utilization rate of the under-represented technology, and thus, the higher the incentive to invest in such technology. Finally, increases in average or peak electricity demand result in larger overall investment in generation, and increases in the utilization rates of both technologies.[11]

"Take-or-Pay" Contracts as a Possible Distortion

The model above assumes, crucially, that there exists a "dispatch center" in charge of programming and dispatching (on a continuous basis) the electricity supply available, with the objective of ensuring an amount of electricity that meets the country's demand at all times, with the least of interruptions, and at the minimum average variable cost.

"Take-or-pay" contracts are common in the energy sector. They provide comfort to investors in large energy projects (and their creditors), so that a reliable revenue stream will occur in every state of the world, ensuring the project's profitability and the repayment of debts incurred.[12] Concretely, these arrangements establish that the dispatch center must use a certain amount of energy from a given generation unit at a predetermined cost, no matter whether this cost is higher than in other available units, and that if electricity from such unit is not dispatched, that it should receive an equivalent payment. Proponents of these arrangements argue that they facilitate investment that would not occur otherwise, in particular in environments perceived to be risky.

However, if the dispatch center does not use cost as a criterion in deciding what generation units will be used and when, price signals will be distorted. Thus, the incentive to invest in generation technologies that ensure minimum costs is absent, potentially creating a barrier for new entrants and imposing a cost for the economy. Problems arising from these arrangements could be particularly severe in fragile contexts, where take-or-pay clauses may be abused either due to weak government capacity, governance issues, or both.

C. Electricity Distribution Issues

It was shown above that, in the long-term, an economic agent will invest in electricity generation only if solvency prospects are good enough. In normal circumstances, this depends on the financial health of electricity distribution, which administers the network that connects final consumers with electricity production and transmission facilities. If the cash-flow generated by electricity sales to consumers is insufficient to pay for electricity generation bills, or to ensure investment flows that are large enough to maintain the

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[11] The model does not consider explicitly the negative externalities that may arise from electricity generation from non-renewable resources (Parry and others, 2014). If the regulator's concern is that investment in renewable-based electricity supply is too low (and in oil-based too high) given the negative externalities associated with oil consumption, then the optimal policy would be to price oil efficiently through optimal Pigouvian taxes. In the absence of these taxes, it may be second-best optimal to provide a subsidy to renewable-based electricity producers by paying them a higher supply price to cover their higher supply costs and a lower supply price paid to oil-based electricity suppliers. In the model above, this could be achieved by assuming that the regulator increases sufficiently μ^R *vis-à-vis* μ^O.

[12] See Rogers and White (2013).

distribution network, investment-recovery prospects will be poor and thus, investment in generation will suffer. In such a case, a given country may get stuck with its existing generation matrix and network size, which in the long-term may result in uncompetitive electricity costs and electricity shortages as capital depreciates and electricity demand increases.[13] Moreover, if electricity prices are relatively high and the service provided by the distribution companies is poor, the utility derived by clients will be low, which may result in higher distribution losses (Strand, 2011).

Alternatively, if electricity distribution is solvent, investment-recovery prospects will be favorable. New investment will gradually contribute to optimize the electricity generation matrix, reduce electricity costs and keep up with demand which, *ceteris paribus*, will further strengthen cash-flows. In addition, lower electricity tariffs and a better service may reduce distribution losses.

Electricity distribution (whether managed by the public sector or privately) is usually regulated by the government. Regulation includes not only average electricity tariffs but also the particular tariffs applied to different types of clients; the adjustment mechanism (including frequency) of the elements in electricity tariffs; the penalties to be applied in case of delinquency or theft, and the enforcement procedures of such penalties; the organization of the spot and contract markets; and, the rules for electricity dispatching, among other.

In the long term, the cash-flow of the electricity distribution network will be given by:

$$D_t + \frac{1}{R}\left\{Q_{t+1}[P_{t+1}^S(1-\lambda) - P_{t+1}^G] - cQ_{t+1}^{\rho} - D_t R\right\} \tag{9}$$

where $D_t = K_t$ denotes debt to finance investment, electricity supply is denoted by $Q_{t+1} = \alpha K_t$ and parameters are such that $\alpha > 0$, $c > 0$, and $\rho > 1$. In broad terms, demand by the part of the population that pays for electricity $(1-\lambda)$, can be denoted by $Q_{t+1}^D = AY_{t+1} - bP_{t+1}^S$, with A and b positive parameters.[14] An economic agent seeking to optimally choose the size of the electricity network will maximize expression (9), subject to the demand of electricity, so to ensure that supply equals demand, $\frac{Q_{t+1}^D}{(1-\lambda)} = Q_{t+1}$. In order to avoid a monopolistic solution, the regulator will seek to ensure that production is largest, so a zero-profit condition (ZPC) is added as a constraint to the problem. This latter constraint by itself would be sufficient to determine the network size and the associated electricity supply. The ZPC can be reformulated to include government transfers to compensate for electricity distribution losses $\phi P_{t+1}^G \lambda Q_{t+1}$, where $0 < \phi < 1$, and a competitive profit per unit of electricity output, $\pi > 0$. Thus, the ZPC can be expressed as:

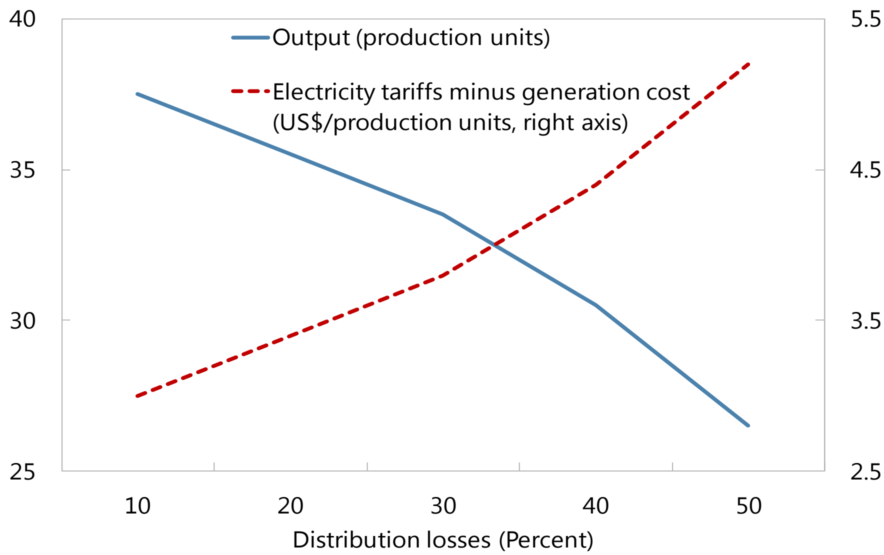
[13] If electricity distribution is insolvent, private investment in generation may only occur provided the state offers large (and costly) guarantees, which in the end would translate in higher electricity tariffs.

[14] Note that this formulation allows making electricity demand endogenous (as it depends on tariffs), but that economic activity is still exogenous.

$$a_1 Q_{t+1}^2 + a_2 Q_{t+1}^{\rho} + a_3 Q_{t+1} = 0 \tag{10}$$

where $a_1 \equiv -\frac{(1-\lambda)}{b}$, $a_2 \equiv -c$, and $a_3 \equiv \left[\frac{AY}{b}(1-\lambda) - P_{t+1}^{G}(1-\phi\lambda) - \pi - \frac{R}{\alpha}\right]$. Simple as it is, the ZPC in (10) allows deriving a number of intuitive conclusions. In particular, the larger the distribution losses λ, the lower investment will be (and thus electricity supply), and the higher electricity tariffs needed for the ZPC to hold. This is shown in Figure 1, for a given calibration of the parameters in expressions (9) and (10). Other factors also have an intuitive interpretation: higher generation costs, lower government transfers, higher required profits per unit of production, a less efficient technology (i.e., higher c or ρ) and higher interest rates will all result in lower investment (and electricity supply), and higher electricity tariffs in equilibrium.

Figure 1. Distribution Losses, Electricity Output, and Electricity Tariffs



Sources: Authors' calculations.

Credibility and Investment

If expected distribution losses are large, the optimal size of the network will be small and electricity tariffs will be high. Against this backdrop, it is possible for the regulator to try to persuade the investor to increase the size of the network with the promise that reforms will be implemented to improve the regulatory framework and strengthen enforcement, and thus reduce electricity losses. This promise may (or may not) be consistent with the government's objective function. In general terms, the problem now will be one in which the investor first picks the optimal size of the network, and after this decision has been taken, the government decides whether it will strengthen enforcement so as to reduce λ, or not. If the objective function of the government is known, the investor will take this into consideration when evaluating the regulator's promise. In other words, an equilibrium configuration for the electricity sector, including distribution losses and tariffs, will need to solve simultaneously the ZPC in (10) and the government's problem.

It is possible that a government will care about different population groups differently. This could result from the government's desire to support specific groups (e.g., for income-distribution considerations, or political purposes, among other). At a theoretical level, it would then be possible for the government to care only about the group that does not pay electricity. In such a case, after the investor picks level $Q_{t+1} = \alpha K_t$, the government will pick a $0 < \lambda < 1$ (associated with a given level of enforcement) so as to maximize the following utility function:

$$U\left(\lambda Q_{t+1}, \frac{S_{t+1} - \lambda_{t+1}\phi P_{t+1}^{G} Q_{t+1}}{P_{t+1}^{x}}\right) \tag{11}$$

The utility function in (11) is assumed to be well-behaved, and S_{t+1} to denote a given level of transfers (subsidies), and $x_{t+1} = \frac{S_{t+1} - \lambda\phi P_{t+1}^{G} Q_{t+1}}{P_{t+1}^{x}}$ to represent the consumption of other goods (different from electricity), with price P_{t+1}^{x}. A closed-form solution for $\lambda_{t+1} = \lambda(Q_{t+1})$ could be obtained, if for instance, (11) is assumed to have the following functional form:

$$w_1 \ln(\lambda_{t+1} Q_{t+1}) + w_2 \ln\left(\frac{S_{t+1} - \lambda_{t+1}\phi P_{t+1}^{G} Q_{t+1}}{P_{t+1}^{x}}\right) \tag{12}$$

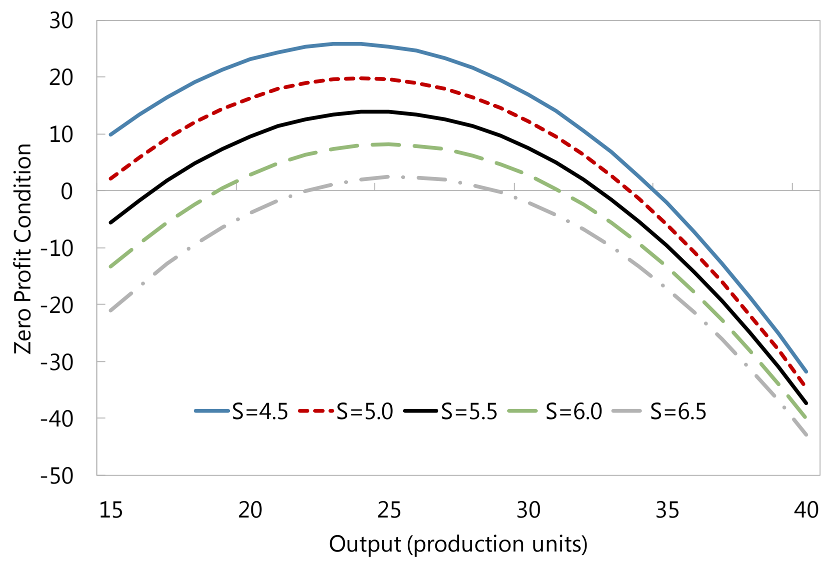
where $w_1 > 0$ and $w_2 > 0$. In this case it is possible to obtain the following closed form solution for λ_{t+1}:

$$\lambda_{t+1} = \frac{S_{t+1} w_1}{Q_{t+1}\phi P_{t+1}^{G}(w_1 + w_2)} \tag{13}$$

A backward-induction equilibrium can be obtained by replacing (13) into the ZPC in (10) and solving for $Q_{t+1} = \alpha K_t$. In particular, the investor will evaluate the credibility of the regulator's promise depending on whether it is consistent with equation (13) at his optimal level of investment.

An interesting problem arises if the investor is evaluating expanding the network in a context of high transfers (subsidies) and distribution losses. In such a case, a promise to reduce losses would imply a significant reduction in utility (11) – (12), and thus, it may be non-credible. If transfers (subsidies) and associated distribution losses are too large, the ZPC in (10) may not hold for positive levels of supply and associated investment. Figure 2 shows this for a given calibration of (10) – (13) and alternative levels of subsidies; clearly, if $S \gg 6.5$, then the ZPC does not hold for positive levels of output.

Figure 2. Optimal Output for Alternative Levels of Subsidies



Sources: Authors' calculations.

A utility function like (12) may not be very realistic in the sense that the government cares only about one group of the population. If the government cares about the whole population, it can be rewritten as:

$$w_1 \ln(\lambda_{t+1}Q_{t+1}) + w_2 \ln\left(\frac{S_{t+1} - \lambda_{t+1}\phi P^G_{t+1}Q_{t+1}}{P^x_{t+1}}\right) + w_3 \ln[(1-\lambda_{t+1})Q_{t+1}] + w_4 \ln\left[\frac{M_{t+1} - (1-\lambda_{t+1})P^S_{t+1}Q_{t+1}}{P^x_{t+1}}\right] \tag{14}$$

where M_{t+1} denotes the income of the group of the population that pays electricity, and $w_3 > 0$ and $w_4 > 0$. The maximization is subject to $0 < \lambda < 1$, and $Q_{t+1} = Q^D_{t+1} = AY_{t+1} - bP^S_{t+1}$. Expression (12) can be understood as a particular case of (14) with $w_3 = w_4 = 0$. If the government cares only about the group of the population that pays electricity, then $w_1 = w_2 = 0$. In the latter case the closed form for λ_{t+1} is:

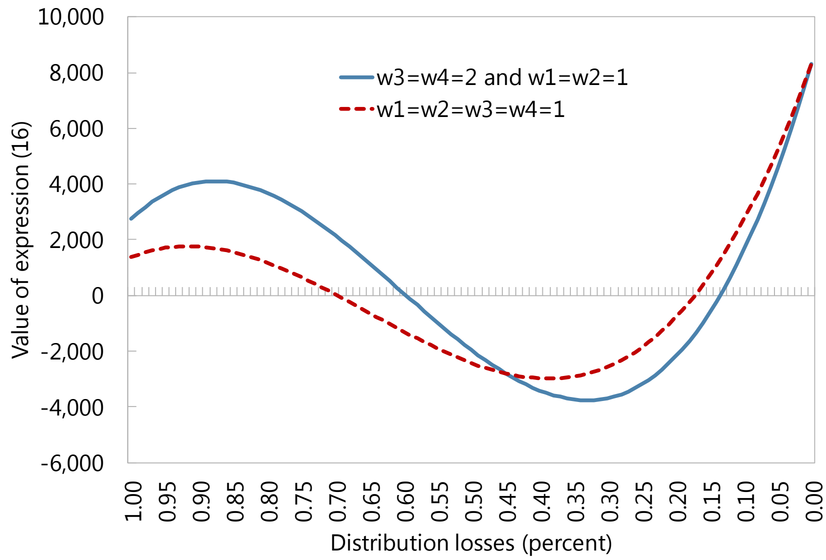
$$\lambda_{t+1} = 1 - \frac{M_{t+1}w_3}{Q_{t+1}\frac{(AY_{t+1} - Q_{t+1})}{b}(w_3 + w_4)} \tag{15}$$

If $w_i > 0$ for all i, then λ_{t+1} is:

$$\psi_1\lambda^3_{t+1} + \psi_2\lambda^2_{t+1} + \psi_3\lambda_{t+1} + \psi_4 = 0 \tag{16}$$

In equation (16) the coefficients ψ_i (for all i) are functions of the parameters in (14). As w_3 and w_4 increase relative to w_1 and w_2, the government will optimally chose a lower theft ratio (and associated enforcement level) for a given size of the distribution network. This is shown in Figure 3 for a given calibration of (10) – (14) and alternative weights for the government's objective function. The higher the weights that the government assigns on the utility of those who pay electricity (with respect who do not), the more credible will be the government's promise to reduce electricity losses. In turn, optimal (stable) λ_{t+1} obtained from (16) will be factored-in in ZPC (10) to obtain a backward-induction equilibrium. This equilibrium will involve higher electricity supply and lower electricity tariffs, as w_3 and w_4 increase relative to w_1 and w_2.

Figure 3. Distribution Losses for Alternative Government Objective Functions



Sources: Authors' calculations.

Introducing Endogenous Economic Activity

So far it was assumed that distribution losses and non-credible government promises were reflected in lower investment as well as electricity supply, and in higher electricity tariffs. However, economic activity was assumed to be exogenous, and thus electricity tariffs bore the full weight to equalize electricity supply with demand. Now, it will be assumed that $Y_{t+1} = F(Q_{t+1})$, where $F'(.) > 0$, and $F''(.) < 0$. Assuming further that the firm maximizes profits $F(Q_{t+1}) - P^S_{t+1}Q_{t+1}$ and that the ZPC applies, it is possible to derive a simple electricity demand function (for the fraction $(1-\lambda)$ of the population), that depends on P^S_{t+1}. Higher electricity tariffs (prompted, e.g., by higher distribution losses) will reduce both electricity demand and economic activity, further depressing electricity demand. In the specific case that $Y_{t+1} = AQ^{\varphi}_{t+1}$, with $0 < \varphi < 1$, electricity demand will be denoted by:

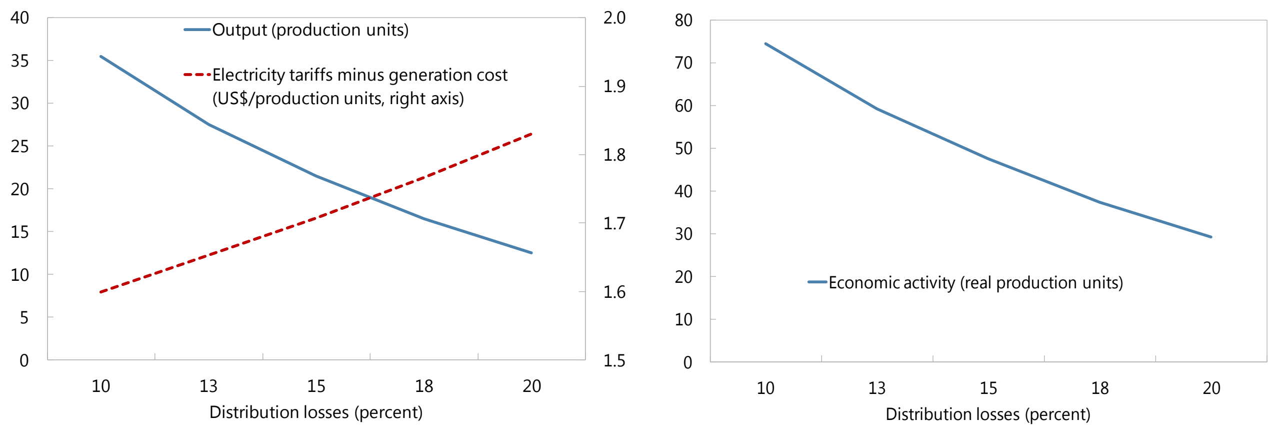
$$Q^D_{t+1} = \left(\frac{A}{P^S_{t+1}}\right)^{\frac{1}{1-\varphi}} \tag{17}$$

Solving problem (9) subject to constraint (17) and assuming zero profits for the distribution company results in a reformulated ZPC, where output is now endogenous:

$$a_1 Q_{t+1}^{\varphi} + a_2 Q_{t+1}^{\rho} + a_3 Q_{t+1} = 0 \quad (18)$$

where $a_1 \equiv A(1-\lambda)$, $a_2 \equiv -c$, and $a_3 \equiv \left[P_{t+1}^{G}(1-\phi\lambda) + \pi + \frac{R}{\alpha}\right]$.

Figure 4. Distribution losses, Supply, and Tariffs with Endogenous Economic Activity



Sources: Authors' calculations.   Sources: Authors' calculations.

Figure 4 shows how electricity supply decreases, tariffs increase, and economic activity decreases as distribution losses increase. The ZPC in (18) could be used instead of that in (10) to analyze the credibility of government promises to fight electricity theft. The results would be analogous to those already shown, but with the difference that lower electricity supply and higher tariffs would also result in lower economic activity.

Credibility and Investment Revisited

It was shown that if the government's promise to reduce theft was credible, equilibrium would be characterized by high investment and electricity supply, and low electricity theft. Alternatively, if the government's promise was not credible, low investment and electricity supply, and high theft would follow. It was also shown that if economic activity was endogenous, a larger electricity supply would support a higher level of economic activity.

This section will restate the framework to analyze a non-credible promise, but in the context of an infinitely repeated game. Figure 5 shows the simplest payoff matrix of a government that only cares for those who do not pay electricity and an investor in electricity infrastructure. There are two possible strategies for each player: the government can enforce low theft levels or let theft ratios be high; and, investment in electricity infrastructure can be high or low. The equilibrium in a non-repeated game will be one in which electricity theft is high and investment low (H, L), as allowing for high theft is a dominant strategy for the government, and thus any promise to reduce theft is non-credible. This is analogous to the result obtained before.

Note, however, that high losses and low investment (H, L) is a worse outcome for both players than low losses and high investment (L, H). The rationalization for such a payoff pair is that it is possible to imagine that at a higher level of electricity supply and economic activity, the government may be able to compensate (e.g., through transfers) for the utility loss associated with lower theft ratios.

Table 1. Simplest Stage Game for Infinitely Repeated Game

		Investment	
		Low	High
Distribution losses	High	(1, 1)	(3, 0)
	Low	(0, 1)	(2, 2)

If an infinitely repeated game is considered (with observed outcomes for all past choices), the adoption by both players of a "trigger strategy" (the government will always play L in case the investor always plays H, otherwise he will play H forever; the investor will always play H, in case the government plays L, otherwise he will play L forever) can result in a cooperative equilibrium (L, H), even if the Nash equilibrium of the stage game is (H, L), provided the common discount rate for the players is sufficiently close to one. The latter outcome would be sub-game perfect.[15] Despite its simplicity, the example above provides the intuition as what could move the economy to a better equilibrium even in the presence of a government that cares only about those who do not pay electricity. In such a world, the government's actions (beginning in the short term) should persistently go in the direction of improving the regulatory framework and its enforcement and decreasing electricity theft; the actions of the investor should persistently go in the direction of strengthening and expanding infrastructure and improving service.

Financing Constraints, Government Transfers, Cross Arrears, and Electricity Shortages

In the short term (i.e., for an existing network and electricity supply), tariffs may be such that the cash flow of electricity distribution is negative:

$$Q_t[P_t^S(1-\lambda_t) - P_t^G - c] - I_t < 0 \qquad (19)$$

As a result, the whole sector's value added chain will be affected. In particular, the value of the parameters may be such that the ZPC in expression (10) is not satisfied for a positive value of production in the long-term. However, negative cash flows can be sustained in the short-term through transfers, recapitalization, financing, or a combination of them. Bank

[15] This results from a simple application of the "Folk Theorem" as described by Gibbons (1992).

financing and recapitalization will be options provided the negative cash flow is perceived as temporary. The government can also inject resources in the sector (in the form of capital, debt, or outright transfers). The distribution company can resort to decreases in investment (which will end up affecting the quality of service), and to arrears to suppliers, including electricity generators. In case of arrears by the distribution company, electricity generators can discontinue investment, take debt, run arrears with suppliers (including oil suppliers), receive transfers, or stop production.

Arrears in one part of the chain spilling-over to the rest of the chain are common when the electricity sector's parameters are such that (19) holds. In cases of protracted negative cash-flows, the sector will likely become dependent of government financing and transfers. If the sector is already indebted, and cross arrears are high, it is possible that a decline in government transfers will result in decreases of electricity supply in order to close the ex-ante financing gap. This would be the ultimate bottleneck for economic activity and would likely result in costly self-generation.

Cross Subsidies and Effective Electricity Generation Costs

Average electricity tariffs represent a weighted average of tariffs applied to different consumer groups. Clients are usually classified both from a commercial and regulatory perspective into residential, commercial, and industrial. Inside each of such categories, clients are further classified between large, medium, and small clients. Then, average electricity tariffs can be expressed as:

$$P_t^S = \sum_{i=1}^{N} \frac{Q_t^{i,D}}{Q_t} P_t^{i,S} \tag{20}$$

with consumer groups for which $P_t^{i,S} > P_t^S$ making a transfer to those for which $P_t^{j,S} < P_t^S$. Although it is not the purpose of the paper to discuss optimal tariff setting for different consumer groups, usually high-income households pay higher tariffs than low-income ones; and households (as a group) pay more than producers. An important consideration is related to distribution losses, which also imply a cross subsidy between those paying and not paying electricity. It was shown that if high distribution losses result in insufficient investment in generation, electricity will be in short supply and will be expensive. In turn, this will likely result in costly self-generation. In particular, depending on the type of self-generation device, it may result in increased peak demand (making electricity shortages worse), or the use of small diesel/fuel-based generation units, with generation costs significantly larger than those from larger units. Effective generation costs in such contexts are:

$$P_t^{G,effective} = \frac{Q_t^S}{Q_t^T} P_t^G + \left(1 - \frac{Q_t^S}{Q_t^T}\right) P_t^{SG} \tag{21}$$

where total electricity supplied (including through the network and self-generation) is denoted by $Q_t^T = Q_t^S + Q_t^{SG}$. The lower the proportion of supply generated through the network, the larger generation costs will be, and the more of a bottleneck electricity will be to economic activity. A sufficiently large self-generation sector may create perverse incentives, and result in persistently large distribution losses. Analogously to (20), distribution losses can be expressed as an average of losses originated from different consumer groups, weighted by their share of electricity consumption (as percentage of total electricity consumed but not paid), $\lambda_t = \sum_{i=1}^{N} \frac{Q_t^{i,T}}{\lambda_t Q_t} \lambda_t^i$.[16]

The economic interest of those supplying self-generation equipment to large consumers (and of relatively-large consumers not paying for their electricity use), could be strong enough to steer the government into having an objective function in which w_1 and w_2 are relatively large with respect w_3 and w_4 in expression (14).[17] This would result in a self-sustaining equilibrium of large losses, high electricity tariffs, and large cross subsidies between those paying and not paying electricity. With endogenous output, this would result in addition in lower levels of economic activity.

III. Case Studies: Haiti and Nicaragua

A. Haiti: Stuck in a "Bad Equilibrium"

Background (IMF, 2015b)

The situation of Haiti's electricity sector during the last decades (but in particular since the early 2000s) can be characterized by:

A weak regulatory framework. The board of *Électricité d'Haïti* (EDH) (a state-owned company in charge of distribution and transmission, and some electricity generation) is responsible for tariff determination (among other responsibilities), while the Ministry of Public Works is in charge of regulating the sector. Electricity tariffs are seldom adjusted or revised to ensure alignment of costs, recognize losses, or ensure a competitive profit; electricity dispatching rules are inefficient and do not apply the minimum marginal cost principle; and onerous PPA contracts (some of which include unwarrantedly expensive take-or-pay clauses and government guarantees), make the generation bill very costly, and introduce barriers for entry. For instance, take-or-pay clauses have resulted in a private operator appropriating a large share of the windfall generated by the lower oil prices in 2015, while generation costs remained artificially high. Lack of enforcement (due to capacity and governance problems) results in persistently high theft and delinquency. Despite significant international support (in technical assistance and financial resources), and repeated

[16] Distribution losses are generally assimilated to unbilled electricity. It is possible, however, that billed electricity remains unpaid for long periods of time. Bills could be unpaid by either private consumers or by public sector consumers (central government; state-owned enterprises, SOE; and autonomous entities). With respect to the latter, possible reasons include insufficient budget allocations; or services that cannot be discontinued, both of which will generally result in persistent distribution losses.

[17] This assumes for simplicity that purely technical losses are zero.

commitments to improve the sector, there has been very limited progress (if any) during the last decade.

Persistently high electricity distribution losses. These are the consequence of low billing rates, high delinquency on billed electricity (including by public entities like municipalities), and high theft ratios. The extremely low cash recovery index (at about 25 percent in 2014), is also due to many commercial and industrial clients resorting to self-generation.[18] Non-payment and theft occur at both ends of the income spectrum, but delinquency and theft by large clients represent the lion's share of losses. Governance problems in the state-owned EDH complicate the situation further.

Large government subsidies. The Haitian electricity sector represents a major fiscal vulnerability. The large EDH's deficit (2.5 percent of GDP in 2014), was financed with (sometimes off-budget) transfers and arrears (estimated at 3 percent of GDP at end-2014). Power generation units also run arrears on fuel purchases with an autonomous government agency that manages foreign-aid flows (2.4 percent of GDP at end-2014), further complicating the situation. Transfers to EDH crowd out priority spending in education, health, and security, and high delinquency rates by large electricity consumers result in a more regressive distribution of income.

The lack of consistent government efforts, the weak regulatory framework, capacity, and enforcement, and a fragile environment prone to unwarrantedly onerous PPAs, have all resulted in Haiti being stuck in a bad equilibrium. As suggested by the models presented above, all this imply:

Virtually inexistent investment to expand production and the grid and high generation costs. The little transparency of the electricity sector's accounts and the perception of a high risk of insolvency have acted as deterrents for investment, which is currently insufficient to boost generation capacity, maintain and expand the grid, and reduce technical and non-technical losses. Generation costs are unwarrantedly large. The share of the population connected to the grid is estimated at about 30 percent and remained stable for decades. This has complicated the provision of essential services for poverty reduction such as water and sewage, and has increased their cost. Despite the small market size, there are a number of independent grids which are not interconnected.

Frequent, long, and unplanned electricity shortages, and significant self-generation. The precarious financial condition of the electricity sector has resulted in electricity shortages. Unplanned and prolonged blackouts affect the firms' competitiveness and result in bottlenecks to economic activity. While service hours were increased with bilateral financing from Venezuela, a reduction (or a stop) of these flows will likely cause a reversion of the little improvement achieved. As a way to circumvent blackouts, the private sector resorted to expensive self-generation, foregoing economies of scale in electricity generation, which in turn further increases costs, deteriorates competitiveness, and worsens the solvency prospects

[18] The cash recovery index is calculated as the product of the billing rate times the collection rate.

of EDH. This has reinforced a vicious cycle of high cost and poor service, and prevents taking advantage of economies of scale in production.

An electricity generation matrix too biased to non-renewable resources. The composition of electricity generation is heavily tilted toward non-renewable sources, and has remained as such during the last few decades, even during the period of high prices of the commodity super cycle due to lack of investment. About 90 percent of installed generation capacity is based on oil-derivatives (diesel and fuel oil). Three independent power providers (IIP) and a tri-national enterprise (PBM, Petion-Marti-Bolivar) generate most of it.

Policy Implications and Outlook

The models described in the paper provide clear policy implications if Haiti's electricity sector is to move from a worse to a better equilibrium. In this regard, the following actions should help:

Strengthen the regulatory framework. This should result in better rules for the sector, reduce entry barriers, should ensure an efficient utilization of available units and in the composition of investment between alternative technologies, while pushing overall investment upwards. There is a large room to improve regulation, transparency, and the accountability of the sector, all of which should also result in better expectations of the sector's solvency. Revising tariffs to reflect costs (including theft), and to allow for an efficient utilization of electricity supply would prevent large industrial and commercial clients to move to off-grid self-generation. Dispatching rules should be reformed in order for generation cost to become the main driver behind the use of available generation units. Publishing all PPA contracts, auditing EDH accounts and publishing the audits, and implementing a competitive and transparent bidding process for new IPPs would serve this purpose. A revision of PPAs to reduce wide dispersion of costs across similar technologies would help to contain expenses.

Improve enforcement and reduce theft and delinquency. This should greatly improve the investors' perceptions of solvency, essential to ensure adequate investment levels. Solvency prospects depend largely on the cleaning of the cumulated arrears and stronger penalization of delinquency and theft. Penalties for nonpayment should be reviewed and enforced. EDH's own governance should be improved so as to ensure that it plays its central role in ensuring adequate billing and collections. Regular inspections on clients and evaluations on the quality of service should be led by the regulatory body and result in an improvement in collection. Regularization plans should be introduced, at least for clients with large stock of arrears. This, in turn, would help to create a culture of payment for smaller clients. Being one of the largest EDH's customers, the government should regularly pay its electricity bill and centralize the payment of electricity bills for all central government institutions. The budget should make space for the cost of public lighting, which is currently above the municipalities' finances. Implementing these measures decisively will make government promises to further tackle theft more credible and should facilitate investment.

Reduce transfers (budgetary and non-budgetary) to the sector. This will result in an increase in the credibility of government's promises with respect to the implementation of reforms. Putting EDH onto a sustainable footing will reduce fiscal vulnerabilities, promote private investment, and be instrumental in supporting growth and poverty reduction. This virtuous cycle should be started by overhauling the financial situation of EDH, including by consolidating cross arrears, which would add clarity to the financial statements of the sector's main stakeholders. On the revenue side, initial efforts should be geared at increasing billing and collection in particular of larger clients. On the expenditure side, restraint is needed, especially with respect to the wage bill. This, together with credible plans to reflect losses and generation costs in tariffs, should contribute to a gradual improvement of the investors' perceptions about the future solvency of EDH.

Analyze the space to diversify the electricity generation matrix. Given the undiversified electricity matrix, Haiti can gain from electricity generation from renewable sources at competitive prices.[19] Going forward, interconnecting the now isolated grids will create a national market, and will allow significant electricity cost reductions in the provinces.

Establish a clearly sequenced reform program involving short- and long-term targets (and implement it). The models described above suggest that in presence of large subsidies to the electricity sector, promises of swift reform, tackle theft, and improve enforcement may lack credibility, and thus the sector may get stuck in a non-cooperative equilibrium. In this case, it would be important to carefully sequence needed actions (i.e., improve regulatory framework, reduce theft, reduce transfers to the sector, etc.) and implement them gradually. This would build credibility around the government's long-term strategy and create the conditions for higher investment, and thus for a transition from a worse to a better equilibrium for the sector.

B. Nicaragua: Gradually Lifting a Constraint on Economic Activity

Background (IMF, 2012)

Until the middle of the past decade, Nicaragua's electricity sector was performing poorly and had all the characteristics of a sector being stuck in a bad equilibrium (high theft and delinquency ratios, poor enforcement, long and unplanned blackouts, among other). Since then, the sector's situation has strengthened notably and now is transitioning towards a better equilibrium. In particular,

A strengthened regulatory framework. In order to improve the legal framework, the government and the sector's stakeholders reached an agreement in 2008 (GON 2009), establishing that the former would adjust tariffs to reflect actual generation costs, and that it would temporarily subsidize the consumption of disadvantaged neighborhoods, while non-technical losses were reduced. The government enacted legislation to strongly penalize electricity theft and further strengthened it in 2010. In addition, the government and the

[19] Haiti has potential for wind-based, hydro, and biomass electricity generation.

sector's stakeholders would eliminate their cross arrears. ENATREL (a state owned company in charge of electricity transmission, and that also operates the National Dispatch Center), would strictly program and dispatch electricity, with the objective of meeting the country's demand at all times, with the least of interruptions, and at the minimum average variable cost. As about 90 percent of the purchases by the distribution company are regulated by long-term contracts, the electricity regulator (the Nicaraguan Electricity Institute, INE) would continue to oversee them. Price signals were further strengthened through the workings of a spot market.[20]

Significantly decreased (but still high) electricity distribution losses. Before the reform program was introduced, large technical and non-technical losses of distribution (in excess of 30 percent in the early 2000s) severely affected the sector's solvency. Improvements in the regulatory framework and in enforcement resulted in significant decreases in distribution losses and delinquency. As of 2014, distribution losses stood at about 21 percent (top left panel of Figure 5).

Contained government subsidies. The improvements in the sector's performance, together with a more diversified electricity matrix, and with reductions in non-technical losses, contributed to limit budget assistance to the sector. However, non-budgetary assistance remained elevated, in particular during the period of high oil prices (2010-13). Subsidies decreased significantly together with international prices decreases since 2014 (top right panel of Figure 5).

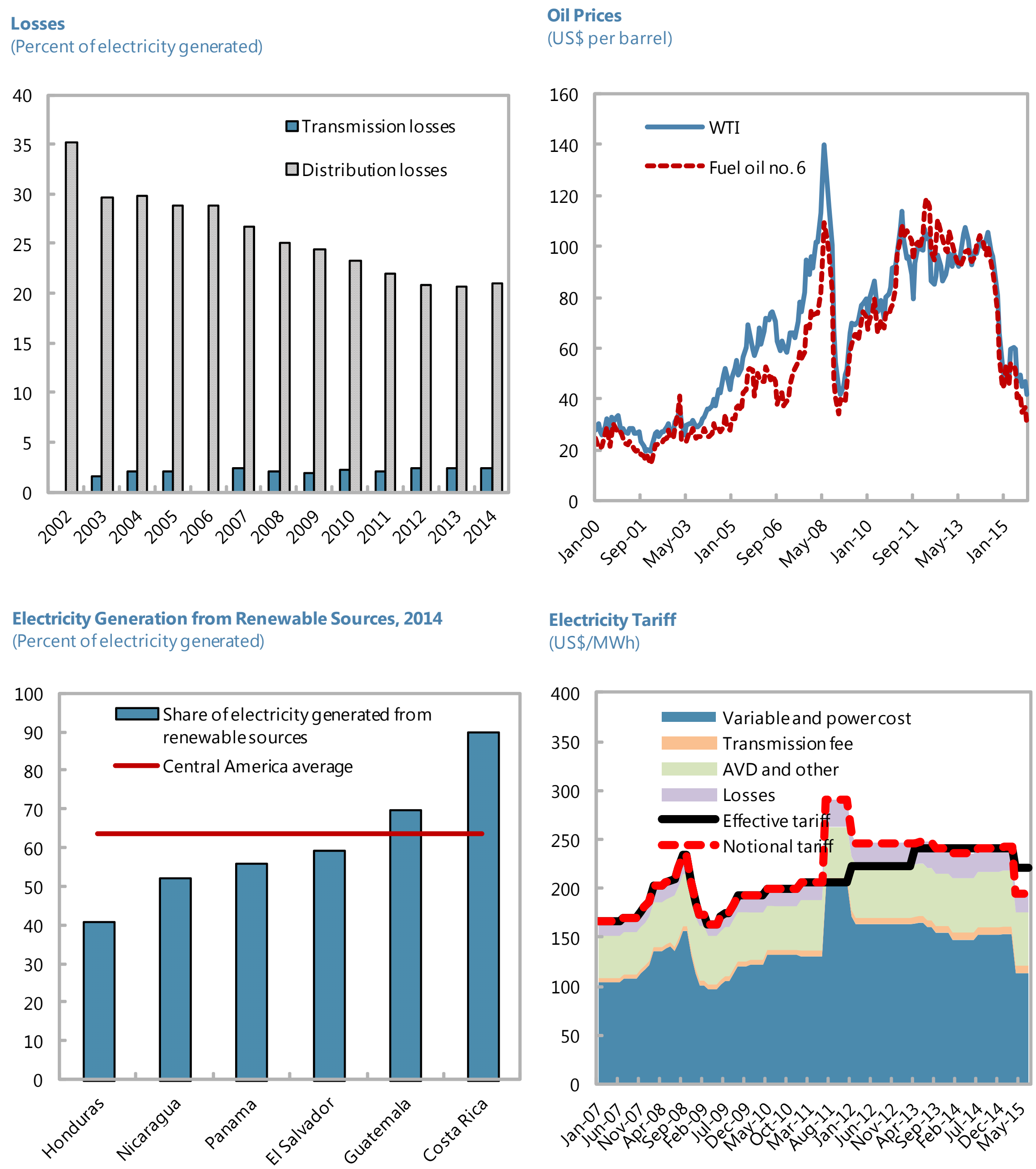
The strong policy action produced positive results relatively fast and in line with the predictions of the models presented in the paper. In particular:

Strong volumes of new investment to expand production and the grid and lower generation costs. Progress in regulatory reform, strengthened enforcement of rules, and gradual, but persistent decreases in distribution losses improved the credibility of the reform program. As prospects of solvency improved, the private sector increased investment in electricity generation and distribution. With respect to the former, effective electricity generation capacity significantly increased for the first time in a decade, from 542 MW in 2007 to 786 MW in 2014. Increased diversification of the generation matrix allowed to partially hedging the increase in oil prices during the commodity super cycle, keeping generation costs at bay.

The virtual elimination of frequent, long, and unplanned blackouts, and a reduction in self-generation. Before the reform program was implemented, the electricity sector was characterized by insufficient electricity generation capacity. Frequent and unplanned electricity shortages of electricity (which peaked in 2007) inevitably deteriorated the

[20] INE regulates and controls the energy market in Nicaragua, including electricity. In particular, INE is in charge of setting electricity tariffs (including the cost of electricity transmission), protecting consumers' rights, ensuring that the sectors' agents comply with the legal framework, and acting as arbiter for the resolution of controversies. INE is an autonomous entity, with budget autonomy.

Figure 5. Nicaragua: Electricity Sector Developments



Notes: Data on transmission losses in 2002 and 2006 are not available.
Source: Bloomberg, Nicaraguan Energy Institute, World Development Indicators, and authors' calculations.

competitiveness of firms and ultimately constrained economic activity. Energy shortages began to be gradually eliminated *pari -passu* the implementation of the reform program, and by 2010 Nicaragua was generating small seasonal electricity surpluses that were exported to the region.

A more diversified electricity generation matrix including both renewable and non-renewable resources. Clearer rules and steady implementation of the reform program resulted in increased levels of investment in generation, which allowed not only to increase generation capacity and make it commensurate with peak demand, but also, to diversify the energy matrix. While in 2007, about 75 percent of electricity was generated by non-renewable sources, this figure had decreased to 50 percent in 2014 (bottom left panel of Figure 5). Moreover, about 60 percent of total electricity was generated by the private sector.[21]

Policy Implications and Outlook

Going forward, the following actions would help Nicaragua to complete its transition towards a better equilibrium:

Continue strengthening the regulatory framework. In response to the high oil prices, policymakers opted to partially adjust electricity tariffs, as generation costs recognized in tariffs were lower than actual one. Beginning in 2011, the regulator established two different tariff schedules, one "notional" reflecting the best available annual forecast for electricity generation costs, and the other one "effective", to be applied to customers. Any difference between the two schedules would be financed with Venezuela-related resources received in the context of the oil-collaboration scheme.[22] The two schedules started to diverge in mid-2011, when the cost of electricity from non-renewable sources increased significantly (bottom right panel of Figure 5). With the end of the commodity super cycle, oil prices dropped and the notional tariff fell below the effective one, implying that the tariff formula could, in principle, generate the needed resources to repay previously received financing. The implementation of the dual tariff system constituted a step forward with respect to the previous discretion-based regime, which was raising uncertainty about the solvency prospects of the distribution company and hurting investment along all the electricity value chain. In the future, rules, rather than discretion, should be used to set tariffs. This would prevent unwarranted tariff freezes and larger than warranted tariff-cost gaps, abrupt tariffs modifications, and large subsidies.

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[21] As of end-2014, renewable sources include hydroelectric generation (10 percent of total), geothermal generation (15 percent), biomass (6 percent), and wind generation (20 percent).

[22] The authorities announced that such financing would result in a "long-term" debt at zero-interest. Owing to the large fall in oil price, in April 2015 it was agreed that only one third of the difference between the effective and the notional tariff would have to be used to reduce such debt, effectively reducing the pace of the debt reduction.

Further reduce theft and delinquency through better enforcement. As suggested by the models above, further reductions in non-technical losses (through, e.g., better enforcement) will continue to signal the government's commitment with strengthening the sector. The still high non-technical losses (mostly not recognized in tariffs), continue to significantly dent the aggregate value of distribution and worsen the cash flow of the distribution company. As losses recognized in notional tariffs were far larger than those recognized in effective tariffs, the increase in generation costs during 2010 –13 aggravated the impact on the cash-flow of the electricity distribution company.

Keep fiscal subsidies to the sector low. As it is also emphasized by the models described in the paper, keeping fiscal subsidies low is essential to support the credibility of the government's promises of reform. Unrecognized distribution losses (plus, at times, arrears on the electricity bill of public sector institutions, including SOEs), have caused the distribution company to run arrears with some electricity generators. All this resulted in renewed cross arrears and in an increase in public contingent liabilities. These problems threatened to hamper the normal functioning of the sector and acted as a disincentive for private investment. Moreover, during the period in which notional tariffs were higher than effective tariffs (i.e., through the first half of 2014) the sector's debt increased, reaching about 2 percent of GDP as of end-2014.

Analyze the space to continue diversifying the electricity generation matrix. One of the positive outcomes of the successful reform of the sector has been a more diversified electricity matrix. Going forward, the authorities together with the private sector should analyze whether a further move to renewable sources is warranted as hedge against oil price fluctuations, and whether other considerations (including negative externalities of non-renewable electricity production) should be brought into the analysis.[23]

Establish a clearly defined medium-term framework for the sector. If the policy choice is to continue using a dual tariff system instead of recognizing in tariffs actual generation costs and non-technical losses at all times, decisions regarding tariffs should take into consideration the medium-term outlook for a range of variables affecting the sector, including the prospective investment in electricity generation.[24] This would greatly increase transparency and predictability and would support the credibility of government policies. The lack of a medium-term framework guiding tariff policy may result in increased uncertainty and slowdown Nicaragua's transition to a better equilibrium for the electricity sector.[25]

[23] The extent to which oil price shocks permanently affect the sector would depend on whether new investment in generation from renewable sources occurs during a reasonably short and locked-in timeframe, and is of a magnitude significant enough to increase the share of total electricity from renewable sources.

[24] These include the expected path for oil price, technical and non-technical losses, and prospective investment levels, among other.

[25] Appendix I shows an example of how such medium-term framework may look like.

IV. CONCLUDING REMARKS

It is widely acknowledged that reliable and low-cost electricity provision is critical for economic activity. Nonetheless, bad configurations of the electricity sector are relatively common in many low-income countries, and these can get them stuck in a bad equilibrium characterized by high electricity costs, electricity shortages, expensive self-generation, and large fiscal subsidies arising from unbalanced cross tariff subsidization, fraud and non-payment. Countries that managed to transition to a better equilibria for their electricity sector, are characterized by better regulatory frameworks (including adequate tariff setting, enforcement of penalties, and appropriate energy dispatching rules), lower generation costs, lower theft ratios and government subsidies, and investment levels that are large enough to guarantee an electricity supply that is commensurate with peak electricity demand.

This paper presented a series of theoretical models that formalize the existence of different equilibria for the electricity sector and highlighted a number of factors that may help the transition from one to the other. In particular, the models show that investment in the sector depends on a number of factors, including solvency prospects (which are intimately related with electricity theft and delinquency), adequate tariff setting and electricity dispatching rules, initial conditions, and minimum investment scales. In particular, the composition of investment between alternative technologies will depend on expected relative generation costs (which will affect their utilization by the dispatch center), and initial conditions regarding the composition of the generation matrix, among other; in this regard, a more diversified generation matrix will provide a better hedge to oil price fluctuations. The models presented also emphasize how the government’s credibility to address the sector’s problems (in particular that of electricity theft) can affect investment levels. If government promises to reduce theft are not credible, private investment, electricity supply and economic activity will be relatively low, and electricity tariffs, subsidies and theft relatively high. On the other hand, when promises are credible, these will spur investment in electricity generation and distribution, and may help a given country to transition from a worse towards a better equilibrium for the sector. In an infinitely repeated setting, it is possible to build credibility by continued commitment to reforms, which should be enough to move the sector to a better equilibrium.

To illustrate the existence of different equilibria, the paper presented two case studies. On the one hand, Haiti is an example of a country stuck in a bad equilibrium in which the electricity sector is a drag on economic activity: electricity supply is insufficient and shortages are frequent, generation costs are high, poor service resulted in expensive self-generation, which in turn raised even more the country’s average generation costs. As arrears are common and solvency prospects are gloomy, investment has been low, preventing the country’s transition to a better equilibrium for the sector. On the other hand, Nicaragua addressed issues with gradual but continuous efforts to strengthen regulation and tackle theft. This strengthened credibility and resulted in larger investment which boosted generation (including from non-renewable sources), lowered costs and distribution losses, and eliminated blackouts, improving efficiency and gradually lifting a constraint to economic activity.

Going forward, Haiti should adopt a program that is rooted in the short-term but has a long-term view. The adoption and implementation of a careful sequenced program would allow building credibility, and promoting investment, both elements of a cooperative equilibrium. Efforts should be geared at improving the regulatory framework (including adopting reasonable tariff setting and demand dispatching rules), review penalties for non-payment, tackle theft and strengthening enforcement (in particular from larger clients), and put the state-owned electricity company (EDH) on a sustainable footing so as to reduce fiscal transfers to the sector. This should result in a gradual change in investors' perceptions about the system solvency and would spur much needed investment, including for diversifying the energy matrix. In turn, Nicaragua should build on the actions that allowed the country to begin the transition to a better equilibrium. Efforts should be geared at continuing strengthening the regulatory framework and tackling theft. With respect to the former, if the decision is to continue with a dual tariff system, it would be essential to embed it in a medium-term framework. This would result in increased credibility and would attract the levels and composition of investment that the country needs. In addition, given that the country's growth performance remains intimately linked to oil price shocks, the importance of continued diversification should not be underestimated even in a context of low oil prices.

Appendix I. Nicaragua: A Medium-Term Framework

This Appendix proposes a medium-term framework for Nicaragua's electricity sector. Data availability allows formulating a baseline and an alternative scenario through 2021 to show how tariff setting and planned investment in generation (mostly from non-renewable sources) affect the sector's medium term sustainability. While the baseline illustrates a "no change scenario", the alternative scenario shows the implications of a change in the electricity generation matrix towards renewable sources, as described by the Electricity Generation Expansion Plan of the government (see Table A1). As a result, the baseline scenario assumes that by 2021 about half of electricity would be generated from non-renewable sources; in contrast, in the alternative scenario the coming into stream of the projects would increase the share of electricity generated from renewable sources from the current 51 percent to about 77 percent over the same period.

The baseline and alternative scenarios share a set of assumptions. In particular, electricity demand is assumed to grow by about 4 percent annually, in line with projected real GDP growth; technical and non-technical losses of distribution are assumed to remain at their average level for 2014; operational and investment spending in electricity distribution are assumed to grow in line with U.S. inflation; medium-term oil prices are assumed to be in line with the World Economic Outlook forecast at end-2015; the Bunker-WTI spread is assumed to stay at the 2014 level (8.9 US$/barrel); monomial prices of electricity generated from non-renewable (renewable) sources are assumed to be a simple average of monomial prices at the companies representing the largest share of electricity generation, and they are assumed to grow in line with bunker prices (U.S. inflation);[26] notional tariffs are assumed to reflect actual electricity generation costs and a loss factor equal to that in effect in July 2015 (i.e., L_t equal to 1.15), and effective tariffs are assumed to remain at the level observed in July 2015; and finally, the public sector is assumed to pay its electricity bill on time.

While the baseline scenario assumes an unchanged electricity generation matrix, the alternative scenario assumes that some new plants become operative. Table A1 shows that new investments are assumed to be generally consistent with those in the Electricity Generation Expansion Plan 2013-27, with a few changes. In particular, the geothermal project Casitas is assumed to be delayed by one year, and the hydroelectric projects Tumarín and Boboké are assumed to be delayed beyond 2021. Also, all projects are assumed to deliver the full generation capacity over two years. Concretely, 99 MWh of geothermal projects, 74 MWh of biomass projects, and 78 MWh of hydroelectric projects are assumed to become operational by end-2021 in the alternative scenario. Monomial prices for electricity generation from investment in renewable sources are assumed to be an average of the last three years.

The recent fall in oil prices improved the cash flow of the distribution company, but also resulted in new policy challenges. On the one hand, continuing the conversion of the generation matrix into one mainly based on renewable sources became less appealing, as

[26] A full set of detailed assumptions is available upon request.

monomial prices for electricity generation from oil derivatives are now lower than those for renewable sources. On the other hand, pursuing the planned investment program in renewable energy offers a hedge against oil price fluctuations and can secure the sector's financial solvency, with clear advantages from the environmental perspective. The baseline and alternative scenarios fall short of identifying vulnerabilities associated with fluctuations in the oil price. To analyze such vulnerabilities two stress scenarios were constructed allowing for a positive (permanent) shock in the oil prices of 50 percent in 2016. In this regard, both scenarios are subject to a permanent shock of 50 percent in the oil price in 2016, and the spread Bunker-WTI is assumed to remain constant at 8.9 US$/barrel. The rest of the assumptions are the same as above. Tables A2 and A3 present the detailed results.

Table A1. Nicaragua: Assumed Investment in Electricity Generation 2015-21

(MW)

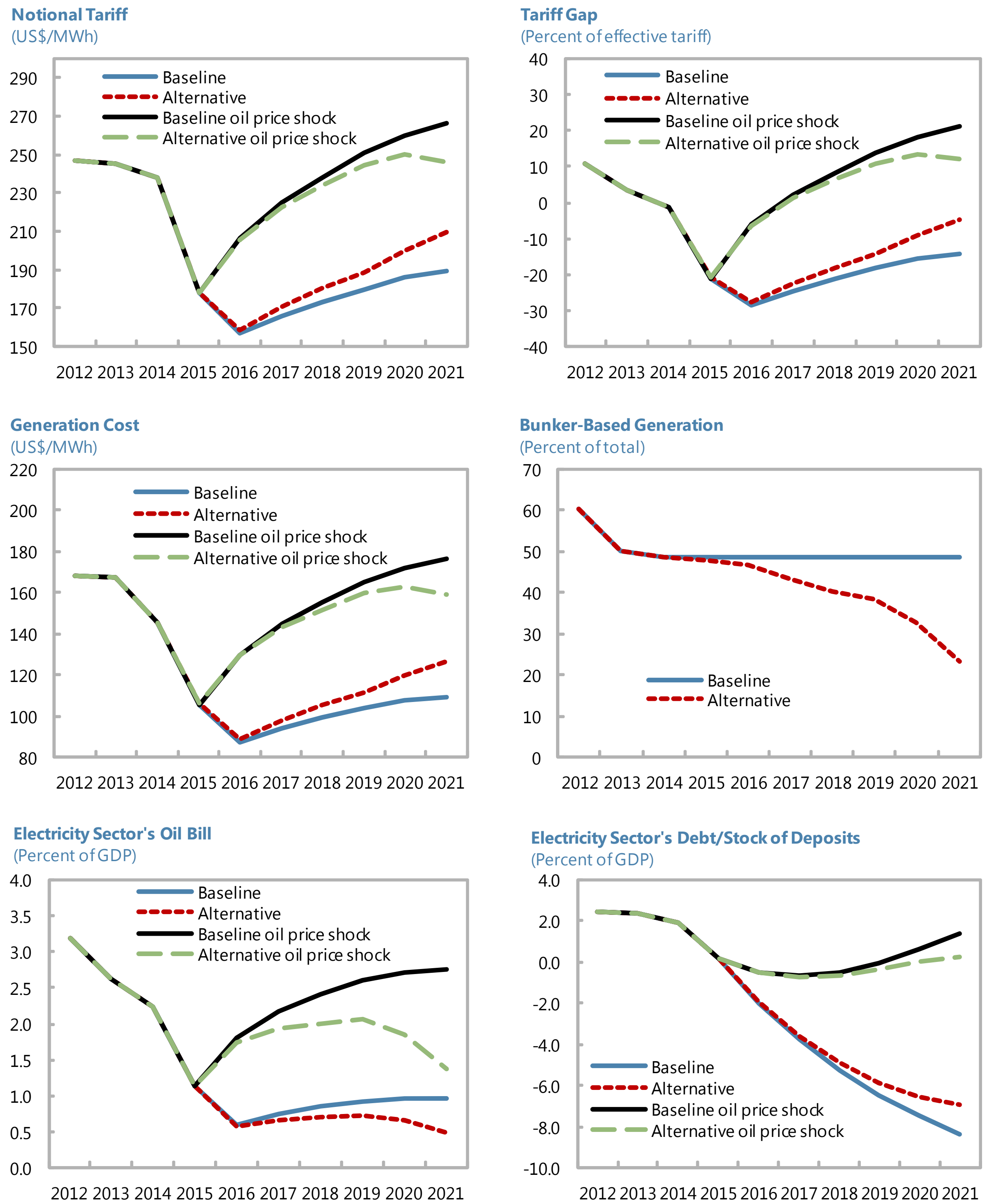
		2015	2016	2017	2018	2019	2020	2021
Geothermal	Casitas			12	12	12		
	Apoyo						12	12
	Chiltepe						12	12
	Mombacho						8	8
Hydroelectric	El Diamante		2	2	2			
	Piedra Puntuda				5	5	5	
	Copalar Bajo							50
	Salto Y-Y							8
Bagasse	Ingenio CASSUR	8	8	8				
	Montelimar		10	10	10			
	Biomasa 1						10	10

Notes: Casitas is assumed to be delayed by one year, and Tumarín and Boboké are assumed to be delayed beyond 2021. All projects are assumed to deliver the full generation capacity over three years.
Source: Ministry of Energy and Mining of Nicaragua.

Figure A1 presents the results by comparing the path for some key variables in the baseline and alternative scenarios, and showing the implications of an oil price shock on both scenarios. In the baseline scenario, the notional tariff falls 15 percent below the effective tariff in 2015 owing to fall in prices, and climbs through the medium term up to 3 percent above the effective tariff. In the alternative scenario, the generation from renewable sources comes into stream. However, owing to the low oil prices, the notional tariff climbs more rapidly in the medium term and is 10 percent above the effective tariff in 2021.[27] Moving to renewable resources still presents advantages despite higher notional tariffs due to low oil prices. While in the baseline scenario the electricity sector's oil bill reaches 1 percent of GDP in 2021, it falls to half of it in the alternative scenario; in other words, a change in the generation matrix would bring about permanent savings. Moreover, in the alternative scenario (as in the baseline), the debt related to the relief to consumers would get repaid and the distribution company would fully repay debt with generators.

[27] These scenarios are indicative, as they assume that the generation capacity of the new plants will be fully utilized and that electricity generated from non-renewable sources is a residual of the estimated demand and electricity generated from renewable sources.

Figure A1. Nicaragua: Medium-Term Sustainability of the Electricity Sector



Source: Authors' calculations.

Table A2. Nicaragua: Baseline and Alternative Scenarios

(Percent of GDP, unless otherwise specified)

				Projections						
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Baseline Scenario										
Tariffs (US$/MWh)										
Notional	247	245	238	178	157	166	173	180	186	189
Effective	223	236	241	225	220	220	220	220	220	220
Gap (percent of effective)	11	4	-1	-21	-28	-24	-21	-18	-16	-14
Generation cost (US$/MWh)	168	167	145	106	87	94	99	104	108	109
Electricity from non-renewable sources (percent of total)	60	50	49	49	49	49	49	49	49	49
Electricity sector's oil bill	3.2	2.6	2.2	1.1	0.6	0.8	0.8	0.9	1.0	1.0
Electricity sector's debt/stock of deposits	2.4	2.4	1.9	0.2	-2.0	-3.8	-5.3	-6.5	-7.5	-8.4
Relief to consumers	1.6	1.8	1.6	1.1	0.6	0.1	-0.3	-0.6	-0.8	-1.0
Net debt to generators/stock of deposits	0.8	0.6	0.3	-0.9	-2.5	-3.9	-5.0	-5.9	-6.7	-7.4
Alternative Scenario										
Tariffs (US$/MWh)										
Notional	247	245	238	178	159	171	180	189	200	209
Effective	223	236	241	225	220	220	220	220	220	220
Gap (percent of effective)	11	4	-1	-21	-28	-22	-18	-14	-9	-5
Generation cost (US$/MWh)	168	167	145	106	89	98	105	111	120	127
Electricity from non-renewable sources (percent of total)	60	50	49	48	47	43	40	38	33	23
Electricity sector's oil bill	3.2	2.6	2.2	1.1	0.6	0.7	0.7	0.7	0.7	0.5
Electricity sector's debt/stock of deposits	2.4	2.4	1.9	0.2	-1.9	-3.6	-4.9	-5.9	-6.5	-6.9
Relief to consumers	1.6	1.8	1.6	1.1	0.6	0.1	-0.2	-0.4	-0.5	-0.6
Net debt to generators/stock of deposits	0.8	0.6	0.3	-0.9	-2.5	-3.7	-4.7	-5.5	-6.0	-6.3
Memorandum Items										
Loss factor recognized in tariffs	1.13	1.15	1.16	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Subsidy for disadvantagednNeighborhoods (US$)	3	0	0	0	0	0	0	0	0	0
Technical and non-technical losses of distribution (percent)	20.9	20.7	21.1	20.8	20.8	20.8	20.8	20.8	20.8	20.8
Transmission fee (US$/MWh)	6.6	7.0	7.9	7.9	8.0	8.2	8.3	8.5	8.7	8.9
AVD in tariffs (US$/MWh)	22.1	24.1	24.4	15.9	13.1	14.1	14.9	15.6	16.1	16.4
WTI (US$/barrel)	105	104	96	51	30	36	40	43	45	45
Spread (price fuel oil no. 6 "Bunker" - WTI, US$/barrel)	-0.3	7.3	8.9	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Real GDP growth (percent)	5.1	4.5	4.7	4.0	4.2	4.0	4.0	4.0	4.0	4.0
US Inflation (percent)	2.1	1.5	1.6	0.1	1.1	1.9	2.2	2.3	2.4	2.2

Source: Bloomberg, Nicaragua Energy Institute, World Economic Outlook, and authors' calculations.

Unsurprisingly, given the different electricity generation matrices in the two scenarios, the impact of the shock is felt more strongly in the baseline than in the alternative scenario. More specifically, the notional tariff would end up 21 percent above the effective one in the baseline scenario, while it would be 12 percent higher in the alternative scenario, reflecting lower generation costs. Similarly, while the oil bill would reach 2.8 percent of GDP in 2021 in the baseline scenario, it would be half of that in the alternative scenario. Finally, the debt related to the relief to consumers would reach 4 percent of GDP in the baseline scenario and would be less than 3 percent of GDP in the alternative scenario; the distribution company would be able to repay its debt with generators in both scenarios.

Table A3. Nicaragua: Oil Price Shock

(Percent of GDP, unless otherwise specified)

				Projections						
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Baseline Scenario										
Tariffs (US$/MWh)										
Notional	247	245	238	178	206	225	238	251	260	266
Effective	223	236	241	225	220	220	220	220	220	220
Gap (percent of effective)	11	4	-1	-21	-6	2	8	14	18	21
Generation cost (US$/MWh)	168	167	145	106	130	145	156	165	172	176
Electricity from non-renewable sources (percent of total)	60	50	49	49	49	49	49	49	49	49
Electricity sector's oil bill	3.2	2.6	2.2	1.1	1.8	2.2	2.4	2.6	2.7	2.8
Electricity sector's debt/stock of deposits	2.4	2.4	1.9	0.2	-0.5	-0.7	-0.5	0.0	0.6	1.4
Relief to consumers	1.6	1.8	1.6	1.1	0.9	1.0	1.4	2.1	3.0	4.0
Net debt to generators/stock of deposits	0.8	0.6	0.3	-0.9	-1.5	-1.7	-1.9	-2.2	-2.4	-2.6
Alternative Scenario										
Tariffs (US$/MWh)										
Notional	247	245	238	178	206	223	234	244	250	246
Effective	223	236	241	225	220	220	220	220	220	220
Gap (percent of effective)	11	4	-1	-21	-6	1	6	11	14	12
Generation cost (US$/MWh)	168	167	145	106	129	143	152	159	163	159
Electricity from non-renewable sources (percent of total)	60	50	49	48	47	43	40	38	33	23
Electricity sector's oil bill	3.2	2.6	2.2	1.1	1.7	1.9	2.0	2.1	1.9	1.4
Electricity sector's debt/stock of deposits	2.4	2.4	1.9	0.2	-0.5	-0.8	-0.7	-0.4	0.0	0.2
Relief to consumers	1.6	1.8	1.6	1.1	0.9	1.0	1.3	1.8	2.4	3.0
Net debt to generators/stock of deposits	0.8	0.6	0.3	-0.9	-1.5	-1.7	-2.0	-2.2	-2.4	-2.7
Memorandum Items										
Loss factor recognized in tariffs	1.13	1.15	1.16	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Subsidy for disadvantagednNeighborhoods (US$)	3	0	0	0	0	0	0	0	0	0
Technical and non-technical losses of distribution (percent)	20.9	20.7	21.1	20.8	20.8	20.8	20.8	20.8	20.8	20.8
Transmission fee (US$/MWh)	6.6	7.0	7.9	7.9	8.0	8.2	8.3	8.5	8.7	8.9
AVD in tariffs (US$/MWh)	22.1	24.1	24.4	15.9	19.5	21.7	23.3	24.8	25.8	26.4
WTI (US$/barrel)	105	104	96	51	76	91	101	110	115	118
Spread (price fuel oil no. 6 "Bunker" - WTI, US$/barrel)	-0.3	7.3	8.9	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Real GDP growth (percent)	5.1	4.5	4.7	4.0	4.2	4.0	4.0	4.0	4.0	4.0
US Inflation (percent)	2.1	1.5	1.6	0.1	1.1	1.9	2.2	2.3	2.4	2.2

Source: Bloomberg, Nicaragua Energy Institute, World Economic Outlook, and authors' calculations.

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