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Abstract[*]

The efficient deployment of green technologies, and more generally, the clean energy transition, will require electricity tariff reforms. Existing tariff schemes often fail to achieve basic economic objectives. They set prices per unit that either exceed or fall short of the social marginal cost, they produce unfair distributional outcomes, and they do not favor efficient adoption of green technologies or investment in energy efficiency. In many cases, they also contribute to unsustainable fiscal deficits due to (almost) generalized electricity subsidies. Using household data from Mexico, this paper shows how efficient pricing mechanisms (such as a two-part tariff scheme in the context of efficient nodal price systems), combined with well-designed environmental regulations (e.g., net-metering schemes) and correctly targeted transfer programs (e.g., means testing mechanisms) can improve economic, social, and environmental outcomes significantly, all at once.

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1 Introduction

The Mexican Congress approved in 2013 the most important reform of the Mexican energy market of the last fifty years. In the electricity industry, the state-owned company, *Comisión Federal de Electricidad* (CFE), was vertically and horizontally disintegrated. New private generators can now compete with existing CFE's plants and direct trade between producers and large consumers is feasible. Likewise, the electricity system operation is now under the responsibility of an independent entity, *Centro Nacional de Control de Energía* (CENACE), which operates both short- and long-term markets and plans for the expansion of the transmission network, among other duties.[1] Nevertheless, the rest of the industry –including transmission and distribution– still remains under CFE monopoly.

In addition, the energy reform together with Mexico's Intended Nationally Determined Contribution (INDC) created a national strategy against climate change. Concretely, the Electric Industry Act (2014), the Energy Transition Act (2015), the Law for the Use of Renewable Energies and the Financing of the Energy Transition (2013), and the Climate Change Act (enacted in 2013 and amended in 2018) established specific goals for the reduction of GHG emissions and for the increase in clean electricity generation sources.[2] For the particular case of the residential sector,[3] the promotion of distributed generation projects (mainly solar PV rooftop systems) is the main instrument to develop clean renewable energies.[4]

There are some issues, however, that deserve special attention and were not addressed in

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[1] In principle, private participation is also feasible in transmission expansion projects through auctions organized by CENACE.

[2] Mexico is committed to reach a 35% and 50% of electricity generation through clean sources by 2024 and 2050, respectively. Furthermore, it plans to achieve a 22% reduction of GHG by 2030 with respect to a business-as-usual scenario.

[3] There are two other schemes to promote the development of renewable energies. First, the introduction of Clean Energy Certificates (CELs), which were created to ensure increasing annual shares of clean energy production (consumption). Second, the implementation of auctions designed to provide CFE with renewable energy to meet medium- to long-run public service demand from small consumers.

[4] The Energy Transition Act (2015) mandated the Mexican Ministry of Energy to undertake technical analysis to evaluate the potential effects that clean distributed generation and energy efficiency programs would have on government subsidies, electricity industry, household welfare, and the environment. See, for example, Hancevic et al. (2017) and Hancevic and Lopez-Aguilar (2019).

the energy reform. Most importantly, they have been systematically overlooked by policymakers. The residential electricity sector in Mexico, like in many other emerging countries, is highly subsidized. On average, households only pay 46% of the total cost of the service –i.e., generation, transmission, and distribution costs. There is a complex and inefficient increasing block tariff (IBT) schedule that is based on a geographical household classification which in turn depends on the historical average temperature records at the municipality level. This complex setting relies on the erroneous idea that multiple objectives can be fulfilled with a reduced number of (imperfect) policy instruments.[5]

Under the circumstances described above, economic efficiency, environmental and distributional goals have not been achieved in a satisfactory manner. First, the current financial situation of the main utility, CFE, represents a critical problem for the federal administration, and the residential subsidy amounts to more than 0.5% of GDP.[6] Second, the subsidy is received by virtually all households independently of their wealth, income or any other objective measure of living conditions. As a reference, total subsidy represented 18% of the total government expenditures in education, more than 40% of the resources allocated to public health, and 47% of those channeled to reduce poverty in 2018. This situation happens in a country where poverty represents approximately 44% according to the National Council for the Evaluation of Social Development Policy (CONEVAL). Third, the current tariff scheme set marginal prices that either exceed or fall short the social marginal costs, generating a sizeable deadweight loss. Fourth, since the price signals received by consumers are incorrect, the investment in energy efficiency and the adoption of green technologies have moved slowly and, clearly, in a non-optimal fashion. That includes replacement of electric appliances[7] and installation of distributed Photovoltaic (PV) systems. The latter is remark-

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[5] In particular, the use of consumption-based subsidies that are embedded in almost every IBT scheme around the world has proved to be quite inefficient as an income redistribution device and well-targeted means tested mechanisms are preferable. See, for example, Angel-Urdinola and Wodon (2007), Hancevic and Navajas (2009), Dahan and Nisan (2007), Borenstein (2012), or Lin and Chen (2018)

[6] That percentage is quite significant in a relatively large (emerging) economy like Mexico. However, it is still below the number reported by Bella et al. (2015) who estimate a lower bound of 0.8% of GDP for electricity subsidies in Latin America and The Caribbean.

[7] Mexico has certain tradition in the application of energy efficiency standards and large appliance replace-

able since Mexico has an enormous potential for the development of PV technologies, and only 0.6% of households have adopted rooftop solar panels according to the National Survey on Energy Consumption in Private Homes (ENCEVI-2018) that was conducted by INEGI.[8] Previous studies (e.g. Banal-Estañol et al., 2017; McRae and Wolak, 2019; Winkler et al., 2011) looked at the main policies adopted in different regions, including Latin American countries. They assessed different aspects of the problem including energy coverage, clean energy penetration, affordability, and reliability. Most of them conclude that a combination of different strategies is required in order to increase them further.

In this paper we use an empirical approach to argue that the domestic electricity sector requires deep policy changes. These include a complete revision of the tariff scheme towards economic efficiency, a deep cut in the residential subsidy, and a new mechanism to better target the subsidy to the less favored households. In doing so, we use micro-data at the household level to simulate an alternative tariff scheme consisting of an efficient two-part tariff that is combined with means-testing. This way we avoid the traditional disadvantages of two-part tariff systems. In particular, we proposed a fixed charge that is reflective of the household total expenditure, which is a valid proxy variable for the true willingness-to-pay. Since the proposed fixed charges do not depend upon observed consumption and because the marginal prices are set equal to the social marginal costs, the differences across users do not distort the electricity consumption choices. Finally, using household data together with our simulated tariff schemes and the typical PV system characteristics (and prices), we simulate different adoption scenarios that are derived from a household optimization model. The simulations are also used to quantify the subsidy changes and the environmental impacts of the proposed policy reforms.

In the remainder of this study, we first analyze the current situation of the Mexican res-

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ment programs at the national level. See, for example, Davis et al. (2014) who evaluate refrigerator and air conditioner replacement between 2009-2012 and find that electricity consumption was barely reduced (due to the rebound effect), concluding that the program was a quite expensive way of reducing CO_2 emissions.

[8] The solar resources in Mexico are among the largest in the world. More than 75% of the territory in Mexico has an average isolation of 5 kWh/m2/day or greater.

idential electricity sector. We specially look at the tariff structure and the subsidy distribution. Second, we describe the ongoing and prospective regulations related to PV distributed generation. Third, we use microdata at the household level to analyze the effects of a tariff rebalacing policy that enhance economic efficiency and reduces the residential subsidy by 30%. Fourth, we simulate two scenarios of solar PV system adoption: one under the current IBT scheme and another that incorporates the efficient tariff rebalancing mentioned before. In both simulated scenarios we provide a complete distributional assessment and measure the effects on consumer welfare. We also compute the expected changes in government net revenues and the corresponding environmental impacts. In doing so, we evaluate the regulatory innovations Mexico transits, whether they facilitate or hinder the necessary adaptation of institutions, instruments and rules to accommodate the demands for technological, social and environmental changes.

2 The residential electricity sector in Mexico

2.1 Current tariff structure

Since the unbundling of CFE after the reform, there are sixteen regional distribution divisions that operate as independent distribution companies. There are seven tariff categories for residential users across the country: 01, 1A, 1B, 1C, 1D, 1E, and 1F. Each of them has an increasing block pricing structure with no fixed charge and with variable charges that are set differently for summer and non-summer periods. Table 1 illustrates the tariff structure in August 2016. Tariff categories are assigned at the municipality level according to average temperature records in a subsidized scheme where historical high temperature zones afford lower marginal prices and larger consumption blocks. For example, a municipality that has a minimum average summer temperature of 28° Celcius is categorized as 1B, whereas one with 30° Celcius is categorized as 1C. These complex category allocation across localities makes possible to have more than one tariff class in the same distribution division (e.g., the Noroeste distribution division has six tariff categories). For a complete historical description of changes in the tariff structure and the electricity subsidy see Komives et al. (2009).

In addition to the increasing block scheme mentioned before, each of the seven tariffs has an associated annual maximum consumption threshold (see last column in Table 1). When the threshold is crossed, the household is regraded to the high-consumption tariff, *Demanda de Alto Consumo* (DAC). Analogously, when the sum of consumption during the last 12 months falls below the threshold, the household returns to its original tariff category. DAC users afford a two-part tariff that is composed of a fixed charge and a uniform marginal price, which is applicable to any consumption level and is substantially more expensive than the seven regular IBP tariffs mentioned before. Table 2 presents the DAC tariffs for summer 2016.

DAC users share less than 5% of total residential consumption and pay a bill that, on average, is 58% above the total cost of service. On the contrary, users in the seven regular tariff classes receive, on average, a subsidy of 60% (see table 3). The number of users connected to the network has also increased and the current electricity penetration reaches 99% of Mexican households. The fiscal deficit associated to the residential electricity subsidy represents approximately 0.5% of the GDP. It is evident that the current cross subsidy situation is unsustainable: a reduced number of 'penalized' households classified as DAC users afford a price substantially above production costs but are far from offsetting the huge deficit caused by the remaining seven underpriced tariffs.[9]

The heavy fiscal burden is explained by the universality of the subsidy scheme. From a distributional perspective, the error of exclusion is minimized at the expense of maximizing the error of inclusion.[10] Table 4 presents the distribution of the subsidy across expenditure deciles. Users in the 10th decile of total household expenditure still receive, on average,

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[9] See Schoengold and Zilberman (2014) for a formal treatment of the trade-offs among cost recovery, economic efficiency and distributional goals in increasing block pricing schemes.

[10] The error of exclusion is the percentage of poor households that do not receive the subsidy. The error of inclusion is the percentage of rich households that receive the subsidy. Clearly, with increasing block tariffs, virtually all connected users generally receive a subsidy. Therefore, the exclusion error is driven by those poor households which are not connected to the grid. In Mexico, since the coverage rate is approximately 99%, the exclusion error is minimal. For a formal methodology to evaluate access and consumption subsidy schemes see Angel-Urdinola and Wodon (2007)

US$10.09 per month. That figure is almost equivalent to the monetary amount received by households in the 1st decile which receive US$11.43. However, when the subsidy is expressed as a percentage of total household expenditure, users in the lower deciles are relatively more favored than users in the higher deciles.

Finally, it is important to note that the subsidy benefits more those users located in the cities that register the highest temperatures, such as tariffs 1F, 1E and 1D which enjoy lower marginal prices and larger consumption blocks within the IBT structure. Figure 1 illustrates this point by showing the monthly subsidy per electricity consumption decile and tariff category.

2.2 Regulatory instruments for distributed generation under the Mexican energy reform

PV distributed generation, or distributed solar generation (DSG), has been steadily increasing in Mexico during the past few years. Starting from a meager installed capacity of 24 KW in 2008, it reached 460 MW in 2018. However, despite this (relatively) fast development of DSG, the country really ranks low compared to other regions. For instance, in 2017 DSG in California shared 9.1% of total generation capacity while in Mexico it only shared 0.22%. And looking at the residential sector alone, only 0.6% of households have rooftop solar panels according to the National Survey on Energy Consumption in Private Homes (ENCEVI) 2018 conducted by INEGI.

The Mexican energy reform has then designed regulatory mechanisms to upgrade the penetration of DSG. The new Law of the Electricity Industry ensures that DSG must have open access to distribution networks and markets in order to allow *prosumers* to sell and buy its own energy from the CFE distribution system.[11] Furthermore, the Interconnection Handbook for DSG projects (December 2016) determines the contract schemes for grid interconnection of DSG developments. The handbook also establishes precise remuneration

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[11] For a thorough analysis of a wide variety of issues on prosumers, see Hirschhausen (2017). See also all the remaining papers on issue 6-1 of that journal.

schemes developed by the Energy Regulatory Commission (CRE) like net metering and net billing.

On one hand, net billing schemes allow DSG prosumers to sell any excess energy they generate back to CFE at local nodal prices. Both consumption and generation are recorded and billed separately. As a result, customers get charged their full retail rate per kWh when they use energy from the grid and are paid the nodal price by CFE when they sell it back. On the other hand, net metering scheme regulates the selling of surpluses of DSG systems into the electricity market through CFE network. This scheme establishes different contractual regimes for small-scale (less than 1 Kv), medium-scale (between 1 Kv and 69 Kv) and community generation DSG projects. All energy that is injected to or taken away from the grid is accounted for by a bi-directional meter which calculates the difference between produced and consumed energy. At the end of a 12-month period, the electricity surplus must be credited or banked (or 'rollover') by CFE to the customer's account for future consumption. This is thought to encourage installation of solar panels.[12] Finally, the DSG interconnection handbook provides better conditions for interconnection into the grid. For instance, most DSG projects do not require a study by CFE to be connected into the grid, and CFE is required to connect them to its grid within 13 to 18 days.

Each type of contract has certain advantages and disadvantages. However, the net metering regime has proven to be the most popular among households adopting any sort of PV systems. And the main reason is that it is easily understood by residential users. In addition, for those sophisticated users that really compare relative prices in a rational way, they choose net metering over net billing because net metering allows the user to sell back electricity at the retail price while net billing makes it at the real-time wholesale price. If net metering included real-time pricing (and perhaps some fixed charge) the preferences for one scheme over the other would not be that clear. If in addition there is an increasing block

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[12] In addition to net-billing and net-metering schemes, the regulation allows for the so-called Total Sale (Wholesale) scheme, which was designed for projects, such as parking lots, where there is not much consumption so that most energy generated is to be uploaded into the grid, and paid according to locational marginal prices.

tariff the decision is even more complex. For simplicity, in all the simulations of section 4 we assume consumers adopt the PV technology under a net metering regime.

There are certain issues that still need to be properly defined. In the current regulation, there is no mention of network costs due to the operation, maintenance, and expansion of the distribution and transmission lines. There is an open debate in the literature about which costs should be included in the prosumer's electricity bill. On one hand, the reduction of purchases to the network caused by a massive adoption of distributed PV systems entails stranded costs. Only a subset of households adopts these systems, but all of them use the grid during some hours of the day.[13] As a result, transmission capacity and distribution capacity have to be made available, and someone has to pay for all these costs. On the other hand, the emergence of DSG impacts on the optimal expansion of the network by reducing the need of costly future investments. Unfortunately, we do not have specific data on transmission, distribution, and commercialization of electricity. The only piece of data we have related to electricity supply is the average integral cost of service for each tariff class. Similarly, we are unable to analyze the impact of the proposed scenario on the quality, safety and reliability of the electricity network.

Our empirical exercise is silent on all these issues and implicitly assumes a substitution at the household level only. This omitted point becomes particularly important as the penetration of distributed generation achieves a sizeable share of total generation. Its discussion, however, is beyond the scope of this manuscript and is left as a future research topic. In section 4 we simulate the PV system adoption choice and assume two extreme cases for the net metering scheme: i) the network costs are charged in full, and ii) they are set equal to zero for bills with zero net consumption.

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[13] In Mexico, the penetration of batteries to store energy is null.

3 Tariff rebalancing: efficient marginal cost pricing

Economic efficiency dictates that the marginal price paid for one extra unit of energy must be equal to the marginal cost of supplying it. Since mid 1970's, this rule has been disregarded in Mexico due to the preponderant role of the *de facto* income redistribution policy implemented by the government. However, the subsidy attached to the current IBT scheme is too expensive and ineffective, as it was shown in section 2. In this section we propose a tariff rebalancing to reestablish the efficient pricing and, at the same time, reduce the subsidy amount and improve its targeting to less favored households.[14]

3.1 Social marginal cost of electricity

The system operator, CENACE, uses a nodal price system in which almost every location along the transmission network has an associated hourly price that represents the marginal cost of supplying one additional MWh of demand in that precise location in that particular hour. Also, each price accounts for all transmission constraints (i.e., congestion) and transmission losses (both technical and non-technical). As a result, it is straightforward to calculate the marginal cost of meeting an increase in electricity demand.

There is a very significant variation in hourly nodal prices during the year, and even during a single day. Figure 2 presents a concrete example for one of the 2,251 nodes which was arbitrarily selected for illustration purposes. Nodal prices fluctuate and can reach a level as low as US$20 per MWh or as high as US$130 per MWh. The optimal pricing scheme should have a time-varying electricity price. In such a case, marginal prices included in the electricity bill calculations should be set each hour in order to mirror the real-time marginal cost.[15] At the moment, this policy is not feasible in Mexico since there are very few real-time or smart meters installed in the residential sector. In our empirical application,

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[14] McRae and Wolak (2019) carry out a similar analysis for the Colombian case.

[15] In an empirical application for Commonwealth Edison, Horowitz and Lave (2014) show that most customers will face loses under real time meters respect to flat tariffs due to their unresponsiveness to real prices; on the other hand, Green (2007) studies the case of England and Wales and finds that consumer welfare improves and at the same time consumers are less vulnerable to market power.

we consider tariffs that match CENACE average hourly nodal prices in each location with the corresponding household's location in the ENIGH-2016. The sample period considered is therefore June 2016-November 2016.[16] Also, to obtain more accurate measures of the marginal costs, the calculated average nodal prices in each location are weighted by the corresponding hourly energy demand.[17] Figure 4 shows the average hourly energy demand by CFE region during the sample period.

The social marginal cost of consuming electricity must include the external cost of pollution. Ideally, one would need precise data that reflects the additional emissions in response to the additional electricity generated. And that information should be available for the marginal power plants that are used in the corresponding nodes for each hour of the day. Unfortunately we only have aggregated data at the national level and are able to compute the average emissions per KWh from thermal units based on the emission factors published by SENER (2017). We then convert the emission factors to monetary values using the social cost associated to each pollutant.[18] Consequently, the average cost caused by air emissions is 1.63 US cents per KWh. This value is added to the marginal local price registered by the system operator for each location which mean is 5.22 US cents per KWh. As a result, the average variable charge (i.e., the social marginal cost) is 6.83 US cents per KWh.

3.2 Allocative inefficiency from the IBT structure

In this section, we measure the short-run distortions from the current inefficient electricity prices. We combine the results and the data from sections 2.1 and 3.1 to contrast the monthly social marginal costs of consuming energy with the corresponding marginal prices that households actually afford. The histogram in figure 3 shows the distribution of the

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[16] In fact, the ENIGH-2016 was collected between August 21 and November 28. However, since most users are under a two-month billing period scheme, we consider average marginal prices from June to November.

[17] Intuitively, consumption during peak hours might be substantially higher than consumption during off-peak hours. A proper measure of average marginal cost must use the hourly energy demand as weights.

[18] Concretely, the emission factors used in this paper are: 0.00283 kg/kWh for SO_2, 0.00186 kg/kWh for NO_X, and 0.47753 kg/kWh for CO_2. The corresponding costs are US$33.60 per ton of CO_2 (Nordhaus, 2018), US$70 per ton of SO_2 and US$16 per ton of NO_X.

ratio of marginal prices to marginal costs. Approximately 70% of the households face a marginal price that is below the social marginal cost, meaning a vast majority of users are overconsuming electricity. Conversely, 26% of the households pay a marginal price that is below the social marginal cost and therefore underconsume electricity. The remaining 4% of users face a marginal price quite similar to the social marginal cost.

For each household in our sample, we compute the allocative inefficiency, or simply deadweight loss (DWL). The DWL is calculated using the difference between the optimal consumption and the actual consumption –i.e., retrieved from the electricity expenditure data from the ENIGH 2016. The shaded areas in figure 5 illustrate how the DWL is measured for each household. In table 5 we present our calculations for the DWL by total expenditure decile assuming two distinct functional forms: a constant elasticity demand function and a linear demand function. In both cases, we calibrate the demand equations to match observed consumption levels and observed marginal prices. In doing so, we assume a price elasticity of demand equal to -0.2124, which was taken from Hancevic and Lopez-Aguilar (2019).[19] In monetary terms, the calculated average DWL is 78 US cents per household per month in the case of the constant elasticity specification, and 60 US cents in the case of the linear demand function. In both demand specifications the allocative inefficiency is increasing in total household expenditure –i.e., our measure of household income. As it was expounded before, many households are in a situation of overconsumption (demands D1 and D2 in the example of figure 5) while others are in one of underconsumption (D3 in figure 5). As a result, the sizes of the DWL might differ substantially among, a priori, similar households.

3.3 Revenue requirement in a two-part tariff setting

Since the restructuring of the electricity market following the Energy Reform, the CFE Distribution branch is in charge of several activities, including the financing, installation,

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[19] The authors estimate a structural discrete-continuous demand model for Mexican households using a maximum likelihood approach. A key aspect of their estimation is that they explicitly take into account the increasing block rate structure and address the typical endogeneity problem that emerges from it.

maintenance, management, operation, and expansion of the infrastructure necessary to provide the electricity distribution service. There are 16 distribution divisions (i.e., regions) across the country, each of them behaves as an independent distribution company. In the ideal situation the electricity bill should cover all variable and fixed costs, including the network expansion costs and the return on invested capital. The variable cost is precisely the private marginal cost computed in the previous section multiplied by the total residential consumption –i.e., it does not include the externality costs of air pollution. And the fixed cost is computed as follows[20]:

1. Calculate the total revenue requirement for each distributor –i.e., CFE distribution division. Since 2017 the electric bills incorporate the decomposition of total cost into different components, in particular supply and distribution costs (and other costs related to the wholesale electricity market)

2. Compute the total green tax collected. This is simply the average pollution cost –i.e., 1.63 US cents per KWh– times the total residential consumption in each distribution division

3. Subtract total variable costs and total green tax revenues (stage 2) from total revenue requirements (stage 1)

4. For each division, divide the amount calculated in stage 3 by the total number of residential users

In this setting, two households living in different localities but in the same distribution division afford the same fixed charge. The variable charges might differ, however, since they are equal to the nodal prices set at the locality level. Table 6 presents the estimated benchmark two-part tariff scheme that emerges from an efficient marginal cost pricing policy that fully eliminates the current residential electricity subsidy. The variable charges shown

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[20] Implicitly, we are assuming the allocation of the fixed costs between residential and non-residential users has been correctly set in a previous stage

in the table are the marginal social cost of electricity consumption –i.e., they also include the externality cost from air pollution. Hence, the average variable and fixed charges are \$0.0683 and \$7.52, respectively.

Table 7 presents the expected changes in household monthly consumption and electricity bill due to the implementation of the two-part tariff. On average, users in deciles 1 through 5 experience moderate drops in electricity consumption but face large increases in their bills. Users in decile 6 has no changes in consumption but still have to afford a significant bill increment. Households in deciles 7 through 9 slightly increase their consumption and also face large bill increases. Finally, users in decile 10 increase their consumption 8% and afford a marginal bill increment of 2%.

In order to better understand the above findings, figure 6 shows the proportion of households in each consumption block by decile. It is apparent that a larger proportion of households in the lower deciles is currently consuming in blocks 1 or 2. On the contrary, there are relatively more users in the upper deciles consuming in blocks 3 (or 4, if available in the corresponding distribution division). The uniform variable charge in the two-part tariff scheme (i.e., the social marginal cost, SMC) is above the marginal prices of blocks 1 and 2 but is below the marginal prices of block 3 and 4 in figure 5.

3.4 Improving targeting mechanisms to reach the poors

The alternative scenario presented in the previous section is, perhaps, unacceptable from most political perspective that has fairness and social equity among its main goals. As seen in table 7, households in deciles 1 through 3 would suffer the largest bill increments in percentage terms –167%, 135%, and 118% respectively. By contrast, users in decile 10 would experience the smallest bill increment, 2% on average. In addition, the application of a relatively large fixed charge could bring about a grid defection issue since several households have an estimated consumer surplus that is smaller than the proposed fixed charges. This phenomenon would be more severe for households in the lower deciles.[21]

The elimination of the large-scale electricity subsidy could imply the reallocation of public funds to any other social transfer program that correctly targets the poors. The regulatory best-practice manual recommends the use of marginal cost pricing.[22] Hence, the variable charge that we obtained for the two-part tariff scheme should not be modified. However, if the society accept that redistribution policies could be done through tariff policies, then the fixed charges could be easily adjusted using any mechanism that reflects the differences in the willingness to pay for the electricity service and generates a better income (re)distribution.[23]

The implementation of a well-designed and well-targeted social tariff scheme to alleviate the impact on low-income families precisely demands information on each household's income and/or wealth. Ideally, the cash-transfer program must minimize the errors of inclusion and exclusion. The alternative that is probably closest to that ideal situation is a direct means tested subsidy scheme, which for different utilities may perform better than IBT (e.g. Agthe and Billings, 1987; Barde and Lehmann, 2014; Nauges and Whittington, 2017) or lifeline (e.g. Wodon et al., 2003) schemes. Means-testing mechanism generally involves carrying out expensive surveys or censuses that can only be justified if there is a political will to use them as the primary source of social assistance allocation –e.g., subsidies to public services, employment and heath programs, financial aid for education, among other possibilities. It is therefore necessary to evaluate the administrative costs of the programs vis-a-vis the economic, social, and environmental gains derived from them. [24]

In this section, we simulate a means tested scheme that follows the approach of Hancevic and Navajas (2009) to alleviate the impact of fixed charges on poor households. We assume a

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[21] According to our estimates in the linear demand case, there are 6.75% of households for which grid defection would be a valid option since consumer surplus is smaller than the fixed charge. This percentage decreases monotonically from 21.15% in the first decile to 1.38% in decile 10.

[22] A seminal paper by Hotelling (1938) provided the basic principles of optimal tariff schemes.

[23] Our approach is static due to data limitations, but a dynamic pricing could adjust better as described in Borenstein and Bushnell (2017), Friedman (2011) and Dutta and Mitra (2017) among other

[24] Means tested mechanism have proved to be better than the IBT schemes, although they are still imperfect. For instance, Barde and Lehmann (2014) simulate a means-tested tariff and compare it with IBT in the Peruvian residential water sector. The authors find that the former scheme effectively reduces the error of inclusion at the expense of increasing the error of exclusion.

30% subsidy reduction which, of course, is an arbitrary number but it helps us to quantify the effect of a partial (and, presumably, gradual) reduction of the current government subsidy.[25] The underlying idea in a means test is that households can be classified as poor or non-poor by some objective criterion. Here we are interested in the socioeconomic and demographic characteristics of households. The greatest challenge is to find a selection criterion that is accurate in the assessment of these characteristics and, at the same time, is both easy to administer and economically viable.

Our simulation procedure is as follows. We first regress total expenditure on a set of covariables that capture observable household and dwelling characteristics. The predicted values obtained from the regression represent a predictive index of household total expenditure. The closest this index correlates with the true total expenditure the better our prediction is. To make the system more operational, we construct deciles based on the index. Finally, we apply progressive discounts to the fixed charges so as to achieve the overall 30% subsidy reduction. Concretely, the discounts in percentage terms are: 100% for deciles 1,2, and 3; 80% for decile 4; 60% for decile 5; 40% for decile 6; 20% for decile 7; 10% for decile 8; and 0% for deciles 9 and 10. In Appendix A we present in more detail the (proxy) means test regression and the corresponding allocation of the subsidy using the index deciles just described.

Table 8 displays the electricity bill changes for a set of alternative tariff schemes. CASE 0 refers to the IBT structure in the status quo. The CASE A alludes to the two-part tariff setting where the residential electricity subsidy is completely eliminated (a situation that was already analyzed in the previous section). CASE B is again the two-part tariff scheme but assumes a 30% subsidy reduction using the means tested mechanism described in the previous paragraph. Finally, the CASE C assumes an optimal targeting for the 30% subsidy reduction. CASE C is equivalent to assuming the expenditure decile is directly observable so

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[25] This is also how we imagine it could occur in the near future since a shock policy that suppresses the subsidy at the stroke of a pen would be very unlikely in the current political context –and would also be undesirable given the vulnerability conditions of a significant segment of the population.

the discounts in the fixed charges are given according to the total expenditure deciles. It was included as a benchmark case for future tariff rebalacing policies. Notice that a more extreme possibility would be to cross subsidize consumption allowing for the application of negative fixed charges to a target group of the population –e.g., using a means tested scheme. That option would be perfectly feasible, at least theoretically, but the current Mexican regulations do not favor its implementation.

Once we depart from the (politically) impracticable scenario of full rebalacing with no subsidy (CASE A), the results of the means tested program (CASE B) are more encouraging in the sense that it seems possible for the government to start a consistent path of subsidy reduction and efficient pricing and, at the same time, do not affect the poors significantly. When one looks at the electric bills as percentage of household total expenditure, the jump for users in decile 1 is from 1.8% to 2.6%. That increase is substantially lower than the one expected in case A, approximately 5.2%. Finally, it is remarkable that the results in case B do not differ that much from the reference case C. That fact reinforces the idea of implementing a subsidy program based on a well-designed livelihood assessment method.

4 Scenarios for adoption of rooftop photovoltaic distributed generation

In this section we perform two simulations to evaluate the potential penetration of rooftop solar panels in the Mexican residential sector under the two main scenarios of the previous section and assuming a net metering scheme. Concretely, we contemplate the status quo –i.e., the current IBT schedule– and the case B –i.e., the two-part tariff with means testing. Our analysis is based upon the seminal work by Hancevic et al. (2017), but here we let each household to choose the optimal investment in PV systems instead of assuming that all electricity consumption comes from DSG. The latter resulted in less than 2 million users for whom adopting solar panels is economically feasible and profitable. Additionally, in case B we allow for two scenarios: 1) *Full fixed charge*: the fixed charge applies in full independently of the quantity consumed from any source, and 2) *No fixed charge*: the fixed charge is zero when net consumption from CFE is zero. As explained in section 2.2, the discussion about what network costs need to be included in a net-metering scheme is still open in the literature and the current Mexican regulation is silent on the subject. Therefore, we include these two extreme possibilities in the counterfactual scenario of case B.

To run the simulation, we first suppose all connections to the grid are done under the net metering scheme using the CFE tariffs registered during the summer months of 2016. Second, we assume residential users minimize the annualized cost of electricity which includes the distributed PV investment cost, the PV operating and maintenance costs, and the conventional electricity bill. The PV prices we use in the objective function are based upon information of a typical meteorological year and a standard investment cost of US$1.65 per WDC. We assume that the annual operation and maintenance costs are linear and amount to US$3.75 per KW of PV capacity installed.[26] For the conventional electricity purchased from CFE, we use the tariff schedules previously described for both scenarios.

The optimization problem for the residential user i who seeks to minimize the total cost of electricity, TC_i, is

$$\min_{\{q_{i,pv};q_{i,cfe}\}} TC_i \quad = I(q_{i,pv}) + \beta\left[C(q_{i,pv}) + T(q_{i,cfe})\right] \tag{1}$$

$$\text{s. t.}$$

$$q_{i,pv} + q_{i,cfe} \geq \bar{q}_i > 0$$

$$q_{i,pv} \leq q_{i,pv}^{max}$$

$$q_{i,pv}, q_{i,cfe} \geq 0$$

where $q_{i,cfe}$ is the quantity purchased to CFE and $q_{i,pv}$ is the quantity generated by the PV system. $T(\cdot)$ is the CFE tariff which in the CASE B is a two-part tariff whereas in the status quo it is the current IBT. $I(\cdot)$ and $C(\cdot)$ are the investment cost, and the operating

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[26] A more realistic calculation, however, should assume a decreasing marginal cost for PV systems.

and maintenance costs of the solar panels, respectively. We assume the average lifespan of a PV system is 25 years, and the associated discount factor is β. The objective function is subject to the following two constraints: i) the sum of conventional and DPV consumption must be greater than or equal to the consumption calculated from the ENIGH-2016, $\bar{q}_i$, and ii) distributed PV consumption has to be less than or equal to the maximum production capacity in each household, $q_{i,pv}^{max}$.

In order to calculate the maximum generation capacity we use the 2017.1.17 version of the System Advisor Model (SAM) gently provided by the National Renewable Energy Laboratory (NREL) and simulate the performance of typical residential PV systems. We consider the system has one single orientation (190° azimuth and 5° inclination), 1:1 DC-AC conversion efficiency, 1.6% inverter efficiency, and 0.5% performance degradation per year. Then, for each household reported in the ENIGH-2016, we restrict our attention to dwellings with roof, wall and floor materials that can support a solar panel structure. We only include independent houses and exclude departments in multi-floor buildings, or any sort of commercial premises used as housing. We assume solar panels can only be installed in dwellings that are occupied by their owners and exclude rented properties. After applying these filters, we end up with 25,470 out of 52,884 household observations to run the optimization model. Finally, we apply the ENIGH-2016 expansion factors to make results representative at the national level.

The optimization results for the simulated scenarios are reported in table 9. In the status quo, the percentage of residential users that optimally adopt a PV system is 12.2%. Clearly, the adoption increases with the total household expenditure, from only 2.9% of adopters in decile 1 to 28.6% of adopters in decile 10. In case B with full fixed charge, the total number of adopters slightly increases with respect to the status quo (13.5%) but now adoption is decreasing in household total expenditure. Instead, when no fixed charge is included for zero net bills, DPV adoption becomes a massive phenomena, reaching 38.8% of households.

That figure represents more than 13 million households.[27] As stated before, we consider that charging the full cost of the grid (i.e., operating, maintenance and expansion costs) or providing the grid usage for free is equally unfair for both adopters and non-adopters of solar panels. In that sense, the two extreme scenarios for case B constitute the lower and upper bounds for DPV adoption in the proposed two-part tariff scheme. In any case, the percentage of adoption in the status quo lies completely outside that interval.

There are substantial differences when looking at the share of PV generation in total residential electricity consumption. In the status quo, PV only represents 5.2%. In case B with the full fixed charge, it represents 9.3% whereas in case B with no fixed charge it accounts for 41.8%. These results imply two things. First, in the current IBT scheme, many households with relatively high consumption adopt small PV systems to avoid being recategorized as DAC users or to jump back to the first two blocks of the original tariff and pay lower marginal prices. Second, in the two-part tariff, the removal of the fixed charge enhances adoption considerably. Also, the systems installed by the households are able to supply the electricity needed in full. In addition, the distribution across expenditure deciles is quite unequal and, once again, it depends upon the incentives derived from the tariff schedules –i.e., uniform marginal price with and without fixed charges versus no fixed charge and increasing block rates. In sum, the two-part tariff schedule encourages adoption and installed generation capacity becomes considerably larger than in the status quo. However, the penetration of the PV technology will critically depend on the size of the fixed charge to be included in the two-part tariff and on whether (or how) it is included in the net-metering scheme.

Finally, table 10 presents the impacts that DPV adoption would have on air pollution emissions (CO_2, SO_2, and NO_X and the associated cost) and the electricity consumption subsidy. The calculations for each simulated scenario combine the number of adopters and

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[27] It is worth noticing that the fraction of qualified users or potential adopters (i.e., users for whom adoption is feasible according to their dwelling and ownership characteristics) is 48.8%. That percentage is increasing in household total expenditure, going from 42.6% in decile 1 to 51.4% in decile 10.

the corresponding quantities of conventional electricity saved with the emission factors used in section 3. Since the cut in emissions are proportional to the reduction in conventional electricity consumption, it is not surprising that the lowest savings are associated with the status quo and the largest with Case B with no fixed costs. Similarly the fiscal savings due to the subsidy reduction are closely related to the decrease in conventional electricity. However, the outcomes for case B with and without fixed charges incorporate the extra 30% savings from the original rebalacing exercise in section 3.[28]

5 Concluding comments and policy recommendations

The current residential tariff scheme in Mexico fails to achieve economic efficiency. Moreover, it neither produces a fair distributional outcome nor provides the right incentives for optimal decisions on green technology adoption and energy efficiency investments. In addition, it generates an unsustainable fiscal deficit due to the (almost) universal electricity subsidy. In this paper we illustrate with real household data how an efficient pricing mechanism –i.e., a two-part tariff in the context of an efficient nodal price system– combined with well-design environmental regulations –i.e., net-metering schemes– and a well-targeted transfer program –i.e., means testing– can improve economic, social and environmental outcomes all at once.

Concretely, we first correct the marginal price of electricity by using the nodal prices at the locality level and computing the external cost of air pollution in order to obtain the social marginal cost of electricity. Second, we allow for the full cost recovery of the value chain incorporating a fixed charge to the marginal price mentioned before and obtain a classical two-part tariff. Third, since the implementation of this efficient two-part tariff scheme has very negative distributional consequences and is politically (and perhaps socially) unacceptable, we propose a similar scheme but applying discounts in the fixed charges with the help of a means tested mechanism. Specifically, we allow for subsidies in the fixed charges afforded by households. Those subsidies are decreasing in out means tested index. For expository

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[28] Reception of any incentive deserves a deeper study such as Borenstein (2017) pointed out.

purposes, we assume an overall subsidy reduction of 30%. Fourth, we identified the set of potential PV system adopters, which roughly amounts to 49% of Mexican households, and then simulate the optimal adoption choice. We find that under the current IBT structure, the predicted PV penetration could 'only' reach 12.2% of residential users, whereas under the two-part tariff scheme with subsidized fixed charges, it could reach between 13.5% and 38.8% of users, depending on the network costs recovered from the net-metering bills. This latter point is still part of an open discussion that goes well beyond the Mexican current regulation (e.g. Passey et al., 2017). Fifth, the proposed alternative tariff scheme would reduce air pollution bringing important environmental savings. The latter could be even more significant if the tariff rebalancing comes along with a DPV adoption subsidy program –i.e., any sort of financial aid program that could, for example, transfer money from the current electricity consumption subsidy to an adoption subsidy –see Hancevic et al. (2017) for a deeper discussion of this point.

It is worth emphasizing that all the assumptions and numbers used in this research are subject to be recalculated and improved. Therefore, one should be cautious when using the results presented here with any policy design intention. The main point of this paper is to show that a complete tariff rebalancing towards a social efficient scheme would have very positive outcomes. It would enhance economic efficiency, improve air quality, and reduce the fiscal resources needed for the electricity subsidy. These resources, in turn, could be used for a long list of better purposes.

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Appendices

A Simulating a means tested mechanism

The general idea is to replicate the performance of a means tested mechanism that should reveal the household total expenditure – income or any other objective measure of willingness to pay. Based on the variables collected in the ENIGH 2016, we run the total expenditure regression which includes the following covariates: age, education, and gender of household head, household size (i.e., number of household members), overcrowding (=1 if household size divided by number of rooms>3), kids (=1 if there is some kid of age$\leq$ 12), elder (=1 if there is some adult of age$\geq$ 65), ownership status, rural (=1 if located in a rural area), roof and floor materials, dwelling type, and several interactions with the distribution areas (i.e., distribution firms) to account for geographical differences. Table 11 presents the estimation results.

We calculate our index by simply computing the predicted values from the regression. We then construct deciles based on that index. The correlation between the true household expenditure decile and the constructed index decile is 0.6233. The idea is that a well-designed tool should reveal the poverty condition of each household and allow the authorities (e.g., a government agency) to rank or classify the residential electricity users. This should be based upon the information gathered from a dynamic survey or census. As it was already explained in the main text, the advantages of such a mechanism are apparent when several transfer programs depend on the same allocation mechanism. The existence of economies of scale and scope clearly justify its usage.

Having calculated the index deciles, we are now able to apply differential discounts on the fixed charges face by the households. In our simulation, we apply the following discounts in percentage terms: 100% for deciles 1,2, and 3; 80% for decile 4; 60% for decile 5; 40% for decile 6; 20% for decile 7; 10% for decile 8; and 0% for deciles 9 and 10. This way we are able to achieve the (arbitrarily) proposed electricity subsidy reduction of 30%.

Tables and Figures.

Table 1: Residential tariff schedules for Summer 2016

Tariff	**Block 1**	**Regular tariff** **Block 2**	**Block 3**	**Block 4**	**Annual threshold**
01	0–75 $ 0.0424	76–140 $ 0.0512	>140 $ 0.1499		3,000
1A (>25 Celcius)	0–100 $ 0.0373	101–150 $ 0.0440	>150 $ 0.1499		3,600
1B (>28 Celcius)	0–125 $ 0.0373	126–225 $ 0.0440	>225 $ 0.1499		4,800
1C (>30 Celcius)	0–150 $ 0.0373	151–300 $ 0.0440	301–450 $ 0.0562	>450 0.1499	10,200
1D (>31 Celcius)	0–175 $ 0.0373	176–400 $ 0.0440	401–600 $ 0.0562	>600 $ 0.1499	12,000
1E (>32 Celcius)	0–300 $ 0.0312	301–750 $ 0.0388	751–900 $ 0.0507	>900 $ 0.1499	24,000
1F (>33 Celcius)	0–300 $ 0.0312	301–1200 $ 0.0388	1201–2500 $ 0.0507	>2500 $ 0.1499	30,000

Source: CFE.
Rates are in U.S. Dollars (average exchange rate in 2016: 18.69 pesos/US$)

Table 2: DAC tariffs for Summer 2016

Region	Fixed charge (US$/month)	Variable charge (US$/KWh)
Baja California	$ 4.9105	$ 0.1927
Baja California Sur	$ 4.9105	$ 0.2100
Central	$ 4.9105	$ 0.1982
Noroeste	$ 4.9105	$ 0.1856
Norte y Noreste	$ 4.9105	$ 0.1811
Sur y Peninsular	$ 4.9105	$ 0.1839

Source: CFE.

Charges are in U.S. Dollars (average exchange rate in 2016: 18.69 pesos/US$)

Table 3: Energy consumption, sales, costs, and subsidies by residential tariff category in 2015.

Tariff	Number of users	Energy (GWh)	Sales (million $)	Avg price ($/MWh)	Total cost (million $)	Avg cost ($/MWh)	Subsidy (million $)	Price/Cost ratio
01	19,264,114	20,139	1,391	69.1	3,759	186.7	2,368	0.37
1A	2,051,397	2,314	152	65.9	421	182.1	269	0.36
1B	3,910,140	5,807	394	67.8	948	163.3	554	0.42
1C	5,432,016	12,186	891	73.1	1,810	148.5	919	0.49
1D	1,127,508	3,007	214	71.2	440	146.3	226	0.49
1E	1,156,322	3,861	239	61.8	552	142.9	313	0.43
1F	1,247,839	6,288	375	59.6	865	137.6	490	0.43
DAC	419,678	2,384	512	214.7	325	136.2	-187	1.58
Total	34,609,015	55,986	4,168	74.4	9,119	162.9	4,951	0.46

Source: CFE. Prices and costs are in U.S. Dollars.

Table 4: Monthly subsidy per total household expenditure decile.

Decile	US Dollars/month		% of total expenditure	
1	\$11.45	(\$6.29)	4.2%	(3.7%)
2	\$13.03	(\$8.09)	2.4%	(1.5%)
3	\$13.75	(\$8.82)	1.9%	(1.2%)
4	\$14.35	(\$9.87)	1.6%	(1.1%)
5	\$15.09	(\$11.39)	1.4%	(1.0%)
6	\$14.94	(\$11.38)	1.2%	(0.9%)
7	\$15.91	(\$13.04)	1.0%	(0.8%)
8	\$15.75	(\$14.41)	0.8%	(0.7%)
9	\$15.07	(\$18.02)	0.6%	(0.7%)
10	\$10.09	(\$23.74)	0.3%	(0.5%)
Total	\$13.93	(\$13.55)	1.5%	(1.8%)

Source: own calculations using ENIGH-2016 and CFE tariff data.
Standard deviations are shown in parenthesis.

Table 5: Deadweight loss from current IBP tariff structure, by decile, in US$ per household per month

Decile	Constant elasticity		Linear demand	
1	0.2397	(1.0995)	0.1602	(0.4630)
2	0.3650	(1.4109)	0.2477	(0.6871)
3	0.4316	(1.4677)	0.3087	(0.7705)
4	0.5058	(1.6012)	0.3712	(0.8957)
5	0.5823	(1.6454)	0.4283	(0.9331)
6	0.6453	(1.6737)	0.4856	(1.0117)
7	0.8264	(1.8473)	0.6253	(1.1885)
8	0.9882	(1.9323)	0.7728	(1.3728)
9	1.2533	(2.1628)	0.9946	(1.6088)
10	1.9478	(2.5502)	1.5848	(2.0221)
Total	0.7789	(1.8471)	0.5982	(1.2496)

Notes: standard deviations are shown in parenthesis. The calibrated price elasticity is -0.2124 and was taken from Hancevic and Lopez-Aguilar (2019).

Table 6: Full rebalacing: A two part tariff with no subsidy
(All values are in U.S. Dollars)

	Variable charge	Fixed charge
Bajio	0.0678	5.83
Baja California	0.0793	8.57
Noroeste	0.0732	17.03
Norte	0.0687	7.97
Golfo Norte	0.0666	11.82
Centro Occidente	0.0678	5.92
Centro Sur	0.0679	5.94
Oriente	0.0665	6.95
Sureste	0.0683	6.27
Valle de México Norte	0.0670	5.72
Valle de México Centro	0.0670	5.72
Valle de México Sur	0.0672	5.81
Golfo Centro	0.0654	7.36
Centro Oriente	0.0668	5.12
Peninsular	0.0731	9.08
Jalisco	0.0693	6.17
Total	0.0683	7.52

Source: own calculation.

Table 7: Full rebalacing: changes in consumption and electric bill

	Consumption (KWh/month)			Electricity bill (US$/month)		
Decile	Status quo	Full rebalancing (no subsidy)	Percentage change	Status quo	Full rebalancing (no subsidy)	Percentage change
1	101.7	96.5	-5.1%	5.24	14.00	167.2%
	(88.9)	(84.9)		(4.67)	(7.86)	
2	128.8	124.2	-3.6%	6.87	16.11	134.5%
	(116.8)	(114.8)		(6.68)	(10.35)	
3	143.2	139.7	-2.4%	7.85	17.10	117.8%
	(126.2)	(124.1)		(7.58)	(10.92)	
4	156.9	154.9	-1.3%	8.87	18.22	105.4%
	(145.8)	(147.5)		(9.42)	(12.72)	
5	171.6	169.8	-1.0%	9.87	19.35	96.0%
	(165.7)	(165.0)		(10.27)	(14.12)	
6	174.6	174.6	0.0%	10.37	19.61	89.1%
	(163.8)	(165.6)		(11.31)	(14.21)	
7	199.7	201.7	1.0%	12.36	21.62	74.9%
	(189.4)	(193.9)		(13.35)	(16.33)	
8	213.2	218.6	2.5%	14.12	22.77	61.3%
	(198.6)	(207.0)		(16.77)	(17.43)	
9	234.5	244.3	4.2%	17.32	24.53	41.6%
	(228.3)	(242.7)		(25.03)	(19.71)	
10	281.7	304.2	8.0%	27.88	28.42	1.9%
	(269.9)	(295.7)		(35.42)	(23.45)	
All users	180.6	182.9	1.3%	12.08	20.18	67.1%
	(184.1)	(193.1)		(17.84)	(15.89)	

Source: own calculations based on ENIGH-2016 and CFE data.
Standard deviations are shown in parenthesis.

Table 8: Electricity bill changes: comparing alternative tariff designs

	CASE 0 Status quo		CASE A Full rebalacing (No subsidy)		CASE B Means tested scheme (30% subsidy reduction)		CASE C Optimal targeting (30% subsidy reduction)	
Decile	US$/month	% of expend.	US$/month	% of expend.	US$/month	% of expend.	US$/month	% of expend.
1	5.24	1.84%	14.00	5.18%	7.42	2.59%	6.64	2.34%
	(4.67)	(1.81%)	(7.86)	(5.30%)	(6.80)	(2.65%)	(6.11)	(2.41%)
2	6.87	1.24%	16.11	2.92%	10.14	1.83%	8.61	1.56%
	(6.68)	(1.22%)	(10.35)	(1.90%)	(9.53)	(1.73%)	(8.42)	(1.53%)
3	7.85	1.07%	17.10	2.33%	11.76	1.60%	9.63	1.31%
	(7.58)	(1.04%)	(10.92)	(1.50%)	(10.10)	(1.38%)	(8.96)	(1.22%)
4	8.87	0.97%	18.22	2.01%	13.46	1.48%	12.20	1.34%
	(9.42)	(1.03%)	(12.72)	(1.39%)	(12.12)	(1.32%)	(11.08)	(1.21%)
5	9.87	0.91%	19.35	1.78%	15.05	1.38%	14.79	1.36%
	(10.27)	(0.94%)	(14.12)	(1.30%)	(13.53)	(1.24%)	(12.82)	(1.18%)
6	10.37	0.80%	19.61	1.51%	16.06	1.24%	16.60	1.28%
	(11.31)	(0.87%)	(14.21)	(1.09%)	(13.70)	(1.06%)	(13.38)	(1.03%)
7	12.36	0.79%	21.62	1.39%	18.58	1.19%	20.10	1.29%
	(13.35)	(0.86%)	(16.33)	(1.05%)	(15.79)	(1.02%)	(15.90)	(1.03%)
8	14.12	0.73%	22.77	1.18%	20.40	1.06%	22.01	1.14%
	(16.77)	(0.86%)	(17.43)	(0.91%)	(17.08)	(0.89%)	(17.21)	(0.90%)
9	17.32	0.68%	24.53	0.96%	22.95	0.90%	24.53	0.96%
	(25.03)	(1.00%)	(19.71)	(0.77%)	(19.51)	(0.76%)	(19.71)	(0.77%)
10	27.88	0.56%	28.42	0.61%	27.70	0.60%	28.42	0.61%
	(35.42)	(0.73%)	(23.45)	(0.54%)	(23.30)	(0.53%)	(23.45)	(0.54%)
All users	12.08	0.96%	20.18	1.99%	16.35	1.39%	16.36	1.32%
	(17.84)	(1.13%)	(15.89)	(2.39%)	(16.02)	(1.47%)	(16.19)	(1.34%)

Source: own calculations based on ENIGH-2016 and CFE data. Standard deviations are shown in parenthesis.

Table 9: Distributed PV solar panel adoption in the residential sector

	% of adopters w.r.t. all residential users			distributed PV as % of total residential consumption		
	CASE 0	CASE B		CASE 0	CASE B	
Decile	Status quo	Full fixed charge	No fixed charge	Status quo	Full fixed charge	No fixed charge
1	2.9%	17.0%	24.2%	0.8%	9.2%	21.1%
2	4.5%	16.2%	29.4%	1.2%	11.3%	29.8%
3	7.0%	15.2%	34.4%	1.7%	10.3%	35.5%
4	8.2%	14.5%	35.6%	2.1%	10.2%	35.7%
5	10.2%	13.4%	37.5%	3.1%	10.7%	39.1%
6	11.2%	14.6%	42.0%	3.0%	9.9%	41.6%
7	13.9%	13.1%	44.4%	4.2%	8.3%	44.1%
8	16.9%	11.3%	45.6%	5.5%	9.7%	48.9%
9	19.1%	10.6%	46.2%	7.0%	8.5%	47.5%
10	28.6%	9.4%	48.5%	13.6%	7.6%	50.0%
Total	12.2%	13.5%	38.8%	5.2%	9.3%	41.8%

Source: Own calculations based on the cost minimization problem of equation 1.
Standard deviations are shown in parenthesis.

Table 10: DPV generation: Air pollution reduction and subsidy savings

	Energy	Subsidy	Air emissions			
			CO_2	SO_2	NO_X	Cost
Scenario	(GWh/year)	(MM US$)	(MM ton)	(MM ton)	(MM ton)	(MM US$)
Case 0 - Status quo	3879.1	25.0	1.9	0.0110	0.0072	62.8
Case B - Full FC	7060.7	184.0	3.4	0.0200	0.0131	114.4
Case B - No FC	31642.6	340.8	15.1	0.0895	0.0589	512.6

Source: own calculation based on adoption simulations using CFE data and ENIGH-2016.

Table 11: Means testing regression

Dependent variable: total expenditure	Coefficient	Standard Error
overcrowding	138.89	(1.75)
preschool	-118.59	(8.79)
incomplete primary school	-31.83	(1.10)
complete primary school	45.17	(1.13)
incomplete middle school	84.97	(1.63)
complete middle school	165.40	(1.14)
incomplete high school	321.09	(1.69)
complete high school	440.25	(1.29)
incomplete bachelor (or similar) degree	989.92	(1.72)
complete bachelor (or similar) degree	1353.25	(1.32)
graduate studies (complete or incomplete)	2670.13	(1.81)
household head age	4.72	(0.10)
household head age squared	-0.04	(0.00)
gender	-77.26	(0.56)
kids	-117.86	(0.65)
elder	-113.37	(0.89)
household size	141.17	(0.20)
ownership	-157.03	(0.60)
rural	-156.18	(0.70)
number of rooms	233.17	(0.19)
constant	-555.63	(28.30)
R-squared	0.3330	
Observations	52,884	

Notes: the estimated equation includes dummy variables for dwelling type, type of household, construction materials, and the corresponding interactions with the distribution areas to account for geographical differences.

Figure 1: Monthly subsidy per electricity consumption decile and tariff category

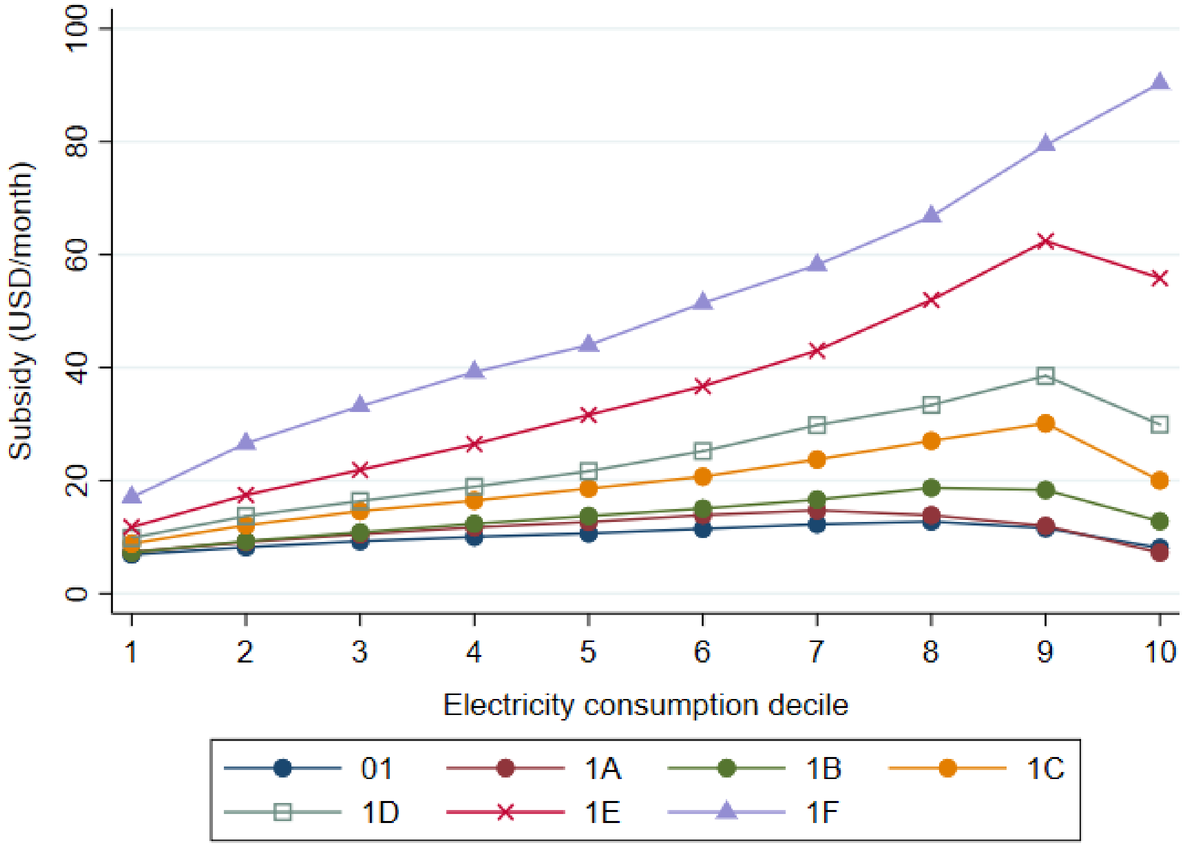

Figure 2: Hourly nodal prices: Tepotzotlan, Estado de México (June 1, 2016 – Nov 30, 2016)

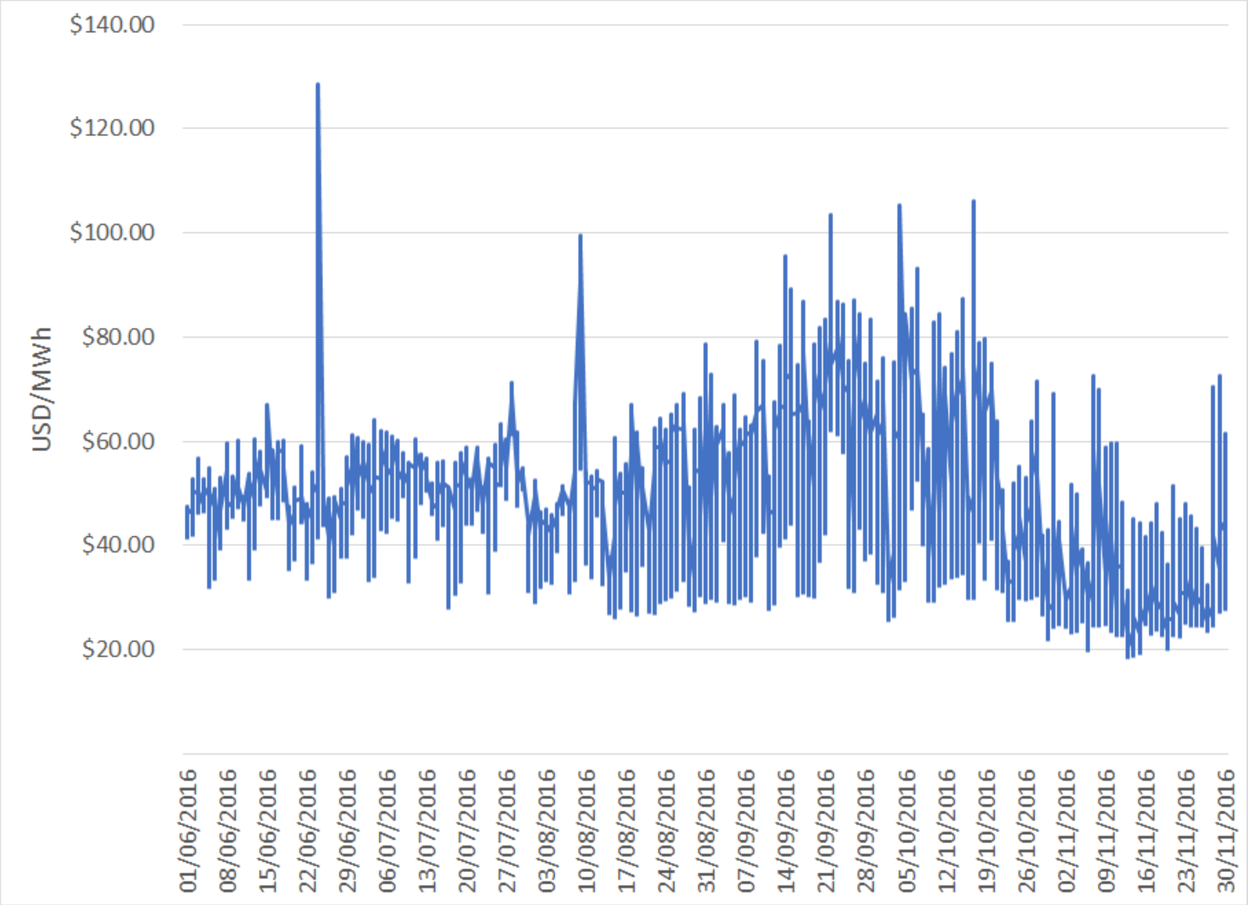

Figure 3: Distribution of residential marginal prices relative social marginal cost

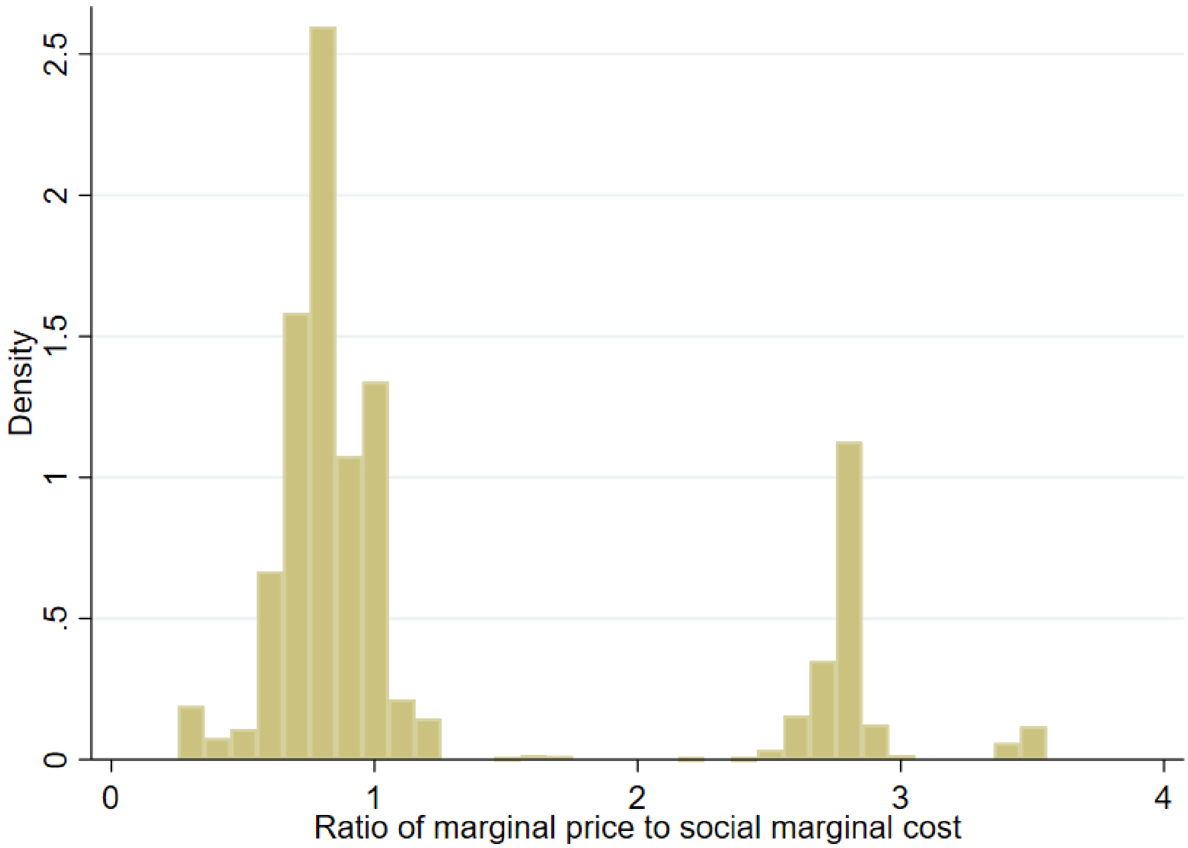

Figure 4: Hourly energy demand curve by region

(Average values between June 2016 and November 2016)

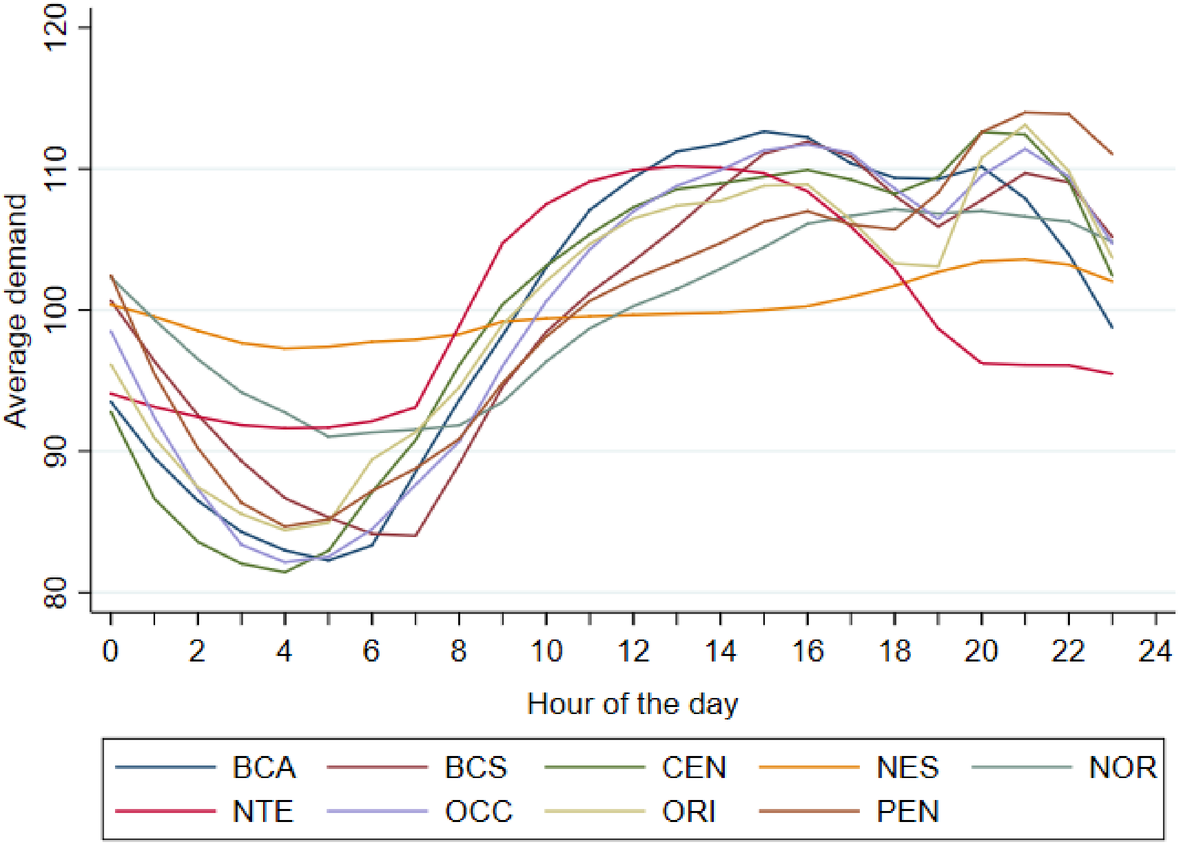

Figure 5: Increasing block pricing, social marginal cost and the associated deadweight loss

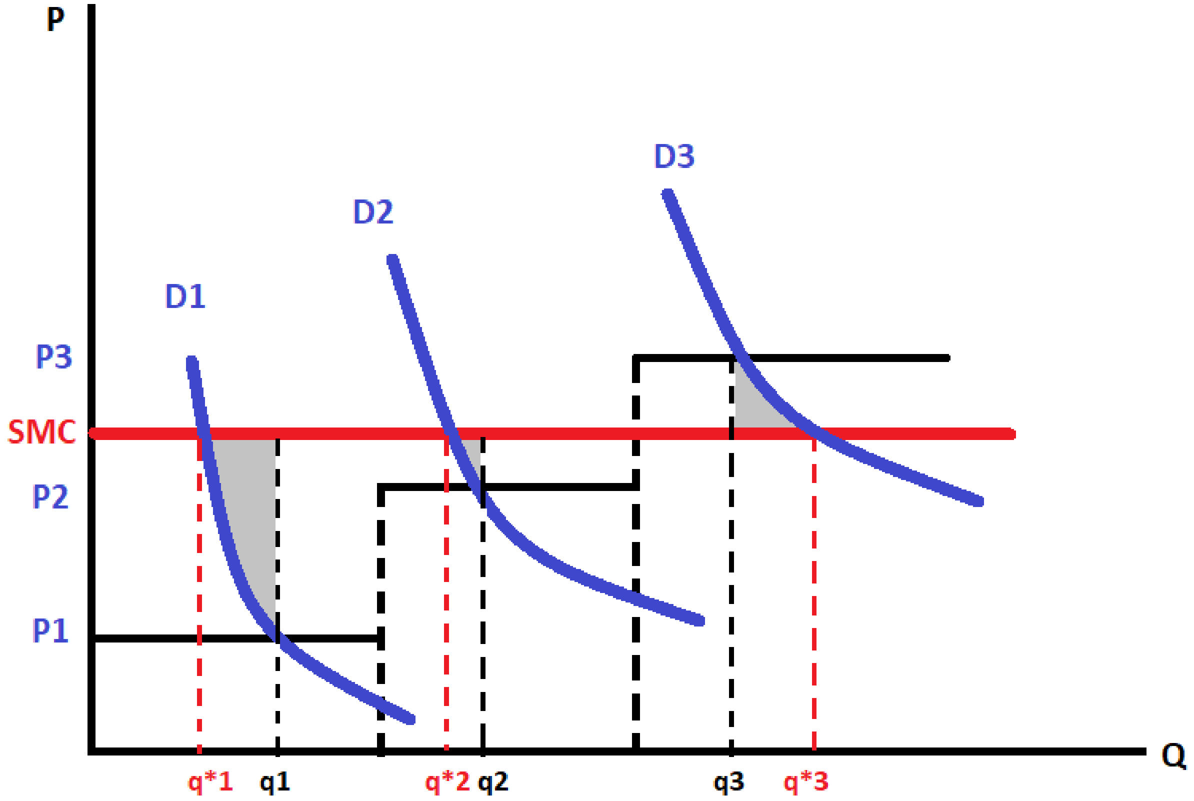

Figure 6: Percentage of households in each consumption block of the current IBT scheme by total expenditure decile