The Electric Gini:  
Income Redistribution through Energy Prices

Arik Levinson  
Georgetown University and NBER  
arik.levinson@georgetown.edu

Emilson Silva  
University of Alberta  
emilson@ualberta.ca

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Abstract

Most electric utilities in the United States charge two-part tariffs to residential customers: fixed monthly fees insufficient to cover the fixed costs of power plants and transmission lines, and per-kWh volumetric prices in excess of the marginal cost of providing electricity. And more and more utilities charge increasing block prices, higher prices to ratepayers that use more electricity. One obvious reason is equity. We first show that in theory, price setters concerned about inequality will charge lower-than-efficient fixed monthly fees and higher-than-efficient per-kWh prices, and will target higher users with even higher prices. Then we use a new dataset of more than 1300 utilities across the US to show that these theoretical predictions are borne out in practice. Utilities whose ratepayers have more unequal incomes have more redistributive electricity pricing schemes, charging less to low users and more to high users. Utilities with more ratepayers who vote Democratic, with higher costs, and with higher fractions of commercial or industrial customers have more redistributive residential pricing. To quantify these comparisons, we develop a new measure of the redistributive extent of utility pricing that we call the “electric Gini.”

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Introduction

Electricity is a textbook high-fixed-cost, low-marginal-cost industry. Power plants and transmission lines cost billions of dollars to build, regardless of how many kilowatt-hours (kWh) are generated and transmitted. Once built, producing an extra kWh of energy costs only a few pennies. Consequently, the efficient way to charge customers for electricity is a two-part tariff (Coase, 1946). A fixed monthly access charge assessed to each household, regardless of how many kWh they use, covers the fixed cost of the power plant and transmission lines. And a per-kWh volumetric charge covers the marginal cost of producing an extra kWh of electricity.

In practice, electricity pricing departs from this simple two-part tariff in two important ways. First, in most places the monthly access fee is insufficient to cover utilities’ fixed infrastructure costs, while the volumetric price per kWh exceeds the marginal cost of producing electricity. That’s true even if we include external social costs of pollution. Utilities charge inefficiently low monthly access fees and inefficiently high per-kWh prices.¹

The second departure from efficient prices is newer. In more and more places, electric utilities charge increasing block prices (IBPs): a low per-kWh charge for the first block of electricity used each month, a somewhat higher per-kWh charge for a subsequent block, and so on. The price per kWh increases step-wise with consumption. Sixteen African countries surveyed in 2014 had this type of IPBs.² China introduced IBPs in 2012.³ Those tiered prices are plainly inefficient—different customers pay different marginal per-kWh prices, even though the electricity costs the same to produce.

Why do utilities charge inefficiently low access fees and non-marginal volumetric prices? One stated reason is to protect low-income households who use less electricity (Borenstein 2012, 2016). Low users, with presumably lower incomes, pay low access fees and low per-kWh rates. High users face the higher rates associated with upper tiers of increasing block prices. Utilities—or their regulators—trade off efficiency for distributional objectives.

As an aside, note that this discussion ignores the fact that electricity demand varies over time, suggesting that dynamic time-of-day or congestion pricing may be optimal. We sidestep

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that concern for several reasons. First, almost no utilities in the U.S. charge such real-time prices. Until recently the necessary smart-meter technology wasn’t available, and customers currently appear resistant to its implementation. Second, increasing block pricing may be a way of approximating congestion pricing even in the absence of smart meters. During hot months when air conditioning demand peaks, many customers are automatically shifted onto higher price blocks because they use more electricity. Finally and most importantly, residential electricity customers appear to ignore marginal prices anyway, focusing only on their total monthly bill (Ito, 2014). So even if utilities charge dynamic or increasing block prices, the primary economic consequence will involve equity, not efficiency.

We ask two questions here. First, do utilities that serve customers with more unequal incomes have prices structures that do more to protect low-income households? A utility with a homogenous customer base, in which all ratepayers have equal incomes, would have no reason to depart from the efficient two-part tariff. Access fees can be high enough to cover fixed costs, and per-kWh prices can match marginal costs. But if a utility’s ratepayers have unequal incomes, a price-setting regulator might want to favor low-income ratepayers who presumably use less electricity. Monthly access fees might be lowered and per-kWh prices raised, particularly on high users. And the size of that departure from efficient tariffs might depend on local politics.

Second, how much redistribution takes place via this mechanism? That question necessarily has two parts. How much do IBPs redistribute costs from low users of electricity to high users? And how much does that redistribution among users redistribute costs across incomes? Those parts can have different answers because electricity use and incomes are not perfectly correlated. Electricity use is an indirect tool for addressing income inequality. Borenstein (2012) poses similar questions and finds only “modest” redistribution in California. Our analysis covers all of the United States.

To answer these questions, we assemble a new dataset of electricity pricing schedules for more than 1500 electric utilities across the US, and we construct a new measure of the redistributional nature of those pricing schedules—the “electric Gini” of our title. We then match those price schedules to US Census data on the income inequality of their ratepayers, as measured by more familiar, standard income Gini coefficients. Those income Gini coefficients are correlated with electric Ginis, even after controlling for other utility and ratepayer characteristics. Utilities serving ratepayers with less equal incomes have price schedules with
more redistribution, evidence that electricity pricing has a redistributive goal. And utilities in
regions with more Democratic voters have higher electric Ginis, evidence that politics plays a
role in that redistribution.

We also discuss the magnitude of the redistribution that results from electricity pricing. Utilities that serve households with income Gini coefficients 0.1 points higher (on a 0-to-1 scale) have electric Ginis that are 0.02 points higher. That makes the redistribution sound large, offsetting 20 percent of income inequality differences. But income appears to be not very well correlated with electricity consumption. As a second measure of magnitude, we subtract monthly electric bills from a representative distribution of households’ electricity use. In utilities with high electric Ginis, that shrinks the net-of-electricity income inequality. In utilities with low electric Ginis, those utility bills enlarge the net-of-electricity inequality. The difference between the most and least redistributive utility is about 0.035 on the 0-to-1 Gini scale. By contrast, household income Ginis differ across states by 0.13. That makes the income redistribution via electricity prices seem small by comparison.

Before demonstrating those results, we frame the questions with some simple theory. The
theory shows the following. First, absent redistributive goals, a two-part tariff is efficient, as in Coase (1946). Second a utilitarian, welfare maximizing regulator will use a two-part tariff for redistributive purposes, with uniform per-kWh prices equal to marginal cost, and monthly access fees that vary with household income. Third, a welfare-maximizing regulator constrained to set uniform fixed access fees will set that access fee below average fixed costs, and will use individualized prices to redistribute income. Fourth, a regulator constrained to set prices based on electricity use, as with increasing block prices, will charge lower-than-efficient prices for low users and higher-than-efficient prices to high users.

**Theory: Efficiency vs Equity**

Start with a general, admittedly simplistic model. One representative household has
cost from electricity \( (e) \) and a numeraire good \( (x) \):

\[
u(e, x).
\]

The household has a budget constraint

\[
w = x + pe + t
\]
where \( w \) is exogenous income, \( p \) is the price per kWh of electricity, and \( t \) is the fixed monthly access fee. Both \( p \) and \( t \) are chosen by a welfare-maximizing regulator. That regulator has to ensure that the electricity producer breaks even, which means that revenues \((pe + t)\) equal costs, or

\[
pe + t = ce + F
\]  

(3)

where \( c \) is the marginal cost of producing electricity, and \( F \) is the fixed cost.

The household maximizes (1) subject to (2) leading to first-order conditions

\[
\frac{u_e}{u_x} = p
\]  

(4)

and equation (2), where \( u_x = \frac{\partial u(e, x)}{\partial x} \) and \( u_e = \frac{\partial u(e, x)}{\partial e} \). A utilitarian regulator maximizes (1) subject to (3), leading to first-order conditions

\[
\frac{u_e}{u_x} = c
\]  

(5)

and equation (3). Together, (3), (4), and (5) imply that

\[
c = p \text{ and } t = F.
\]  

(6)

The regulator should charge the representative household \( t \) for the fixed cost, and \( c \) for every kWh of electricity used. That’s intuitive. For efficiency, the households should pay a price per kWh equal to the marginal production cost, \( c \). The fixed cost \( F \) can then be covered by the fixed monthly access fee \( t \).

If there are multiple identical households the intuition isn’t much different. Each household \( i \) has a first-order condition analogous to equation (4):

\[
\frac{u_i^e}{u_i^x} = p \quad i=1,\ldots,n
\]  

(7)

where households are indexed with superscripts. The regulator maximizes

\[
\sum_i U(e^i, w - t - pe^i)
\]  

(8)

(substituting the household’s budget constraint in for \( x^i \)) such that the power company’s revenues equal costs, or

\[
p \sum_i e^i + nt = c \sum_i e^i + F
\]  

(9)
leading to first-order condition

\[ u'_e - pu'_e + \lambda (p-c) = 0 \]  \hspace{1cm} (10)

where \( \lambda \) is the Lagrange multiplier associated with constraint (9). Substituting in (7) leads to the result that

\[ c = p \text{ and } t = F / n. \]  \hspace{1cm} (11)

The regulator should charge each identical household \( c \) for every kWh of electricity used and \( t=F/n \) for a proportional share of the fixed cost.

Economists have recognized this simple result since at least Coase (1946). But here we are interested in the case where households have different incomes.

**Heterogeneous households and distributional concerns**

Now consider households with different incomes, \( w^i, i = 1, \ldots, n \). Begin by assuming the utility can charge each household a different price \( p^i \) and a different access fee \( t^i \). This allows us to characterize the first best, efficient, welfare-maximizing pricing scheme. Later we will analyze more realistic cases where the regulator cannot charge personalized access fees or prices. With individualized fees and prices each household’s budget constraint is \( x^i + p^i e^i = \hat{w}^i \equiv w^i - t^i \). Net income \( \hat{w}^i \) is just household \( i \)’s exogenous monthly income minus the fixed part of its monthly electricity bill. Each household \( i \) takes its individualized access fee \( (t^i) \) and price \( (p^i) \) as given, and chooses the amount of electricity \( (e^i) \) to maximize \( u(e^i, \hat{w}^i - p^i e^i) \). A utility-maximizing electricity regulator chooses prices \( \{p^1, \ldots, p^n, t^1, \ldots, t^n\} \) to maximize the sum of the indirect utilities of its customers \( \sum_{i=1}^{n} v(p^i, w^i - t^i) \), subject to the constraint that revenues cover costs:

\[ \sum_{i=1}^{n} \left[ t^i + (p^i - c) e^i \right] (p^i, w^i - t^i) = F. \]  \hspace{1cm} (12)

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4 Coase (1946) was writing to rebut Hotelling (1938) who argued that the fixed costs ought to be paid out of general tax revenues. In the face of demand uncertainty and increasing marginal production costs, a three-part tariff is optimal. See Back and Brueckner (2015).
Using the first-order condition from this utility maximization problem, Roy’s identity, and the Slutsky equation, we can then show that in the optimum, for all $i, j=1,\ldots,n \ i\neq j$,

\begin{align}
p^i &= p^j = c, \\
e^i &= e^j \\
\hat{w}^i &\equiv w^i - t^i = w^j - t^j \equiv \hat{w}^j.
\end{align}

The regulator should charge each person the same, constant, per-kWh electricity price equal to the marginal production cost, $c$, and an individualized access fee, $t^i$, so that each person’s budget net of that access fee, $\hat{w}^i$, is equal. (See Appendix A for a proof.)

Equations (13) through (15) are intuitive. Given the option of individual prices and access fees, the welfare maximizing regulator would choose uniform prices but individualized access fees. With a utilitarian goal of maximizing total welfare, the regulator should price electricity efficiently so that $p^i = c$ for everybody, and redistribute income via the fixed access fees $t^i$ to maximize welfare. In this simple case, where people differ only by their incomes, maximizing utility means equalizing incomes.

This setup—individualized electricity pricing—is obviously unrealistic. The fixed access fees, $t^i$, act as lump-sum taxes and transfers to redistribute income. Given declining marginal utility and a utilitarian objective, the regulator here uses the access fees to completely equalize incomes. That’s not only politically infeasible, but it’s also technically impractical given that incomes differ by far more than electricity bills. Such a scheme would likely require confiscatory access fees for some high-income ratepayers and large access subsidies for poor ones. As a step toward more realism, next we consider instead uniform monthly access fees, $t$, but individualized prices, $p^i$.

**Constrained optimum: Uniform access fees ($t$) and individualized prices ($p^i$)**

Consider now the same problem as above, but with an additional constraint that the regulator cannot set individualized access fees: $t^i = t$ for all $i$. The regulator’s problem becomes the choice of \{\(p^i,\ldots,p^n, t\)\} to maximize \(\sum_i v(p^i, w^i - t)\) subject to
\[ nt + \sum_i (p^i - c)e^i(p^i, w^i - t) = F. \tag{16} \]

In Appendix B we show that the solution to this problem implies that

\[
L^j \equiv \frac{p^j - c}{p^j} = -\frac{1}{\varepsilon_p^j} \left[ 1 - \left( \frac{\sum_{i} v^j_{e_i}}{\sum_{w} v^j_{w_i}} \right) \left( n - \sum_{i} (p^i - c)e^i_{w_i} \right) \right], \quad \forall j
\tag{17}
\]

where \( L^j \) is the Lerner index of monopoly power with respect to household \( j \), and \( \varepsilon_p^j \) is household \( j \)’s price elasticity of electricity demand: \( \left( p^j e^j / \partial p^j \right) (p/e) < 0 \).

The left-hand side of (17) is just the markup (or mark-down) of prices relative to the marginal cost of electricity. On the right-hand side, the first term, \(-1/\varepsilon_p^j\), is the standard Lerner index. In this case the regulator cares about distributional effects, so equation (17) adjusts for each household’s share of the total marginal utility of income times the marginal revenue associated with incrementally raising the fixed access fee, the fraction inside the right-most bracketed term on the right side of (17). The whole term in square brackets in (17) can be positive or negative, so price \( p^j \) can be higher or lower than marginal cost \( c \). Since low-income customers have higher-than-average marginal utility of income, the they pay prices lower than marginal cost, and high-income customers pay prices higher than marginal cost.

As we show empirically later, households’ electricity demands differ for many reasons aside from income. That means that in practice varying electricity prices redistribute income from high electricity users to low users, but not necessarily from rich households to poor. To model that distinction, we add endowments of electricity consumption to the model.

*Solar panels and other sources of electricity use heterogeneity aside from income*

Some high income households do not use much electricity, and some low income households use a lot. Consider two high-earning spouses working long days outside their home. Or a wealthy family that travels a lot or has a weekend home. Or a homeowner with solar panels on the roof. These high-income households will demand less electricity from the grid—at any particular billing address—and contribute less to per-kWh revenues of the utility, \( p^i e^i \).

To capture this non-income heterogeneity, we modify the model by assuming household \( i \) is endowed with \( \tilde{e}^i \) units of electricity. Think of a solar roof that generates \( \tilde{e}^i \) per month, or a
periodic vacation during which household demand declines by $\tilde{e}^i$. These electricity endowments are not necessarily related to household incomes.

Household $i$’s budget constraint is then $x^i + p^i \left( e^i - \tilde{e}^i \right) = w^i - t$. Define $\tilde{w}^i$ as the household’s exogenous income, including the value of its electricity endowment and net of access fees: $\tilde{w}^i \equiv w^i + p^i \tilde{e}^i - t$. Household $i$’s net electricity demand is $e^i \left( p^i, \tilde{w}^i \right)$ and indirect utility is $v^i \left( p^i, \tilde{w}^i \right)$. The regulator chooses $\{p^1, \ldots, p^n, t\}$ to maximize $\sum_i v^i \left( p^i, \tilde{w}^i \right)$ subject to

$$nt + \sum_i (p^i - c)e^i \left( p^i, \tilde{w}^i \right) = F .$$

In Appendix C we show that the solution to this problem implies that

$$L^j \equiv \frac{p^j - c}{p^j} = \frac{-1}{\left( \tilde{e}^j \frac{\tilde{e}^j}{e^j} p^j e^j \right)} \left[ 1 - \left( \sum_i \frac{v^i}{e^i} \right) \left( e^i - \tilde{e}^i \right) \left( n - \sum_i (p^i - c)e^i \right) \right], \quad \forall j ,$$

(19)

where as before $L^j$ is the Lerner index of monopoly power and $\tilde{e}^j$ is household $j$’s price elasticity of electricity demand.

Equation (19) differs from (17) in two places. The new term in the denominator, $\frac{\tilde{e}^j}{e^j} p^j e^j$, is a function of the ratio of $j$’s electricity endowment $\tilde{e}^j$ to its electricity demand $e^j$. We know from the Slutsky equation that the whole denominator is negative (see Appendix C), and if electricity is a normal good ($e^j > 0$) then the second term in that denominator is positive. So the larger is $\tilde{e}^j$ relative to $e^j$, the smaller in absolute value is the entire denominator, and the larger in absolute value is the markup $p^j - c$. The difference between household $j$’s price and the marginal electricity price should be greater if household $j$’s endowment is larger.

The second difference between equations (19) and (17) is the term $\left( \frac{e^j - \tilde{e}^j}{e^j} \right)$ inside the square brackets. That’s the share of the household’s electricity purchased from the utility. The larger that share, the more likely is the entire right-hand side to be negative, and the more likely the optimal price charged to $j$ will be higher than marginal cost. So two conditions lead to
$p^j > c$. If the household has low marginal utility of income, presumably because it has high income as was discussed for equation (17); and now here if the household is endowed with a higher share of its electricity consumption.\(^5\)

In practice, most utilities do not charge prices that differ by household income, and instead charge prices that differ by usage, as with increasing block pricing (IBP). Some states do have income-based electricity price subsidies, like California’s CARE program, New York’s Utility Assistance Program, and Lite-up Texas. But many do not, and even those that do have income-based price subsidies also use IBPs. Thus as one final element of realism for the model, we add IBPs.

Increasing block pricing

Consider a regulator that cannot charge prices based on income, but can charge increasing block prices. To simplify as much as possible, we assume the access fee $t=0$, as in California, and that an exogenous rule determines the number of households facing each of two price tiers: $n_L$ low-using customers face price $p_L$ for each kWh of electricity up to threshold quantity $q$, and $n_H$ high-using customers face price $p_H$ for each kWh above $q$.

The regulator chooses the two prices and the threshold, $\{p_L, p_H, q\}$ to maximize the sum of the indirect utilities of the customers of both types, constrained such that total revenues equal total costs. In Appendix D we derive the resulting three first-order conditions (with respect to $p_L$, $p_H$, and $q$. We show that they can be rearranged to show that

$$p_L < c < p_H,$$ \hspace{1cm} (20)

and that the rate at which low-demand customers are subsidized with prices below marginal cost is proportional to the size of the gap between the high and low prices, and that the marginal

\(^5\) Note that if the endowed electricity $\bar{e}^j = 0$, equation (19) collapses to equation (17)
The social rate of substitution between the high and low electricity prices is proportional to the marginal social rate of transformation between high and low prices.\(^6\)

The summary so far is straightforward. If the regulator can set individualized prices and access fees, their solution is prices equal to marginal cost \((p=c)\) and access fees that redistribute income to equalize marginal utility. If individualized access fees are infeasible, but individualized prices are, the solution is to charge high-income households higher prices above marginal cost, and low-income households lower prices below marginal cost. And if income-based prices are infeasible, the solution involves usage-based prices like IBPs, where high users pay higher prices for electricity consumed above some threshold.

The actual realizations of access fees and prices thus depend the amount of redistribution desired, which in turn depends on two things: (1) the degree of income inequality among ratepayers, and (2) the ratepayers and voters preferences about income inequality and the welfare of lower-income households, which will be a function of local politics. In what follows we test both propositions, asking how much the redistributive nature of American electricity prices depends on the income inequality and political preferences of utilities’ ratepayers.

**Empirics**

To study the distributional consequences of electricity pricing in the United States, we start with the US Utility Rate Database.\(^7\) Those data cover 2,643 different utilities, with 8,498 different tariffs. We eliminate special tariffs, and we average across tariffs that apply to different jurisdictions within a utility’s service area, such as those applying to different towns, or separate rates for rural and urban customers.\(^8\) That leaves us with 1,551 tariffs, one for each utility.

The rate structures are described in Table 1. Because many utilities have rate structures that vary by season, we call the August rates for each utility “summer”, and the January rates “winter.” A plurality of the utilities have fixed monthly fees and uniform flat rates per kWh. But over 500 have a second tier, over 200 a third, and just a few dozen more than that. We merge

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\(^6\) In other words, the rate at which \(p_L\) can be lowered and \(p_H\) raised, holding utility constant, is proportional to the rate at which those two prices can be altered holding revenue constant.


\(^8\) In particular, we ignore special tariffs that apply to water heaters, pumps, three-phase wiring systems, irrigation, public housing, or homes with electric cars or solar panels. We eliminate time-of-use tariffs and special tariffs for senior citizens and people with medical needs.
those price data with US Energy Information Administration (EIA) data that contain information about each utility’s ownership, fuel sources, and the number of residential, commercial, and industrial customers.\textsuperscript{9}

For local population characteristics, including average household incomes and Gini coefficients of household income, we turn to the 2015 American Community Survey (ACS). Those data are organized by county. We combine them with county-level party vote shares for the 2012 presidential election.\textsuperscript{10}

To match those county characteristics to particular utilities, we create a concordance based on zip codes. We know the zip codes served by each utility, so to merge those data with the county demographic information, we need two more things: (1) the zip codes corresponding to each county, and (2) the population of each zip code. We then construct a weighted average of the county characteristics, weighted by the combined populations of the zip codes served by each utility.\textsuperscript{11} The zip code–to–county crosswalk comes from the US Department of Housing and Urban Development.\textsuperscript{12} The number of households per zip code come from the US Census Bureau, via American Factfinder.\textsuperscript{13}

Combining all of these sources yields a dataset of 1340 utilities, each matched with a set of local population demographics. Those utility-specific population characteristics—incomes, income inequality, and political vote shares—are the weighted average of the characteristics of the counties served by each utility, where the weights are the populations of the zip codes served by the utility in each county.

Figure 1 demonstrates two extremes. The lower, flatter line plots summer electricity bills by consumption for households served by the Florida Keys Electric Cooperative. It has 26,792 customers and charges a simple two-part tariff: $24.33 per month, and 2.4\textcent per kWh. That’s one of the least redistributive rate structures in the country. The upper, steeper line plots the bills for households in the City of Orrville, Ohio. That utility has 6,410 customers and charges $8.24 per month, 0.239\textcent per kWh for the first 50 kWh in a month, 10.28\textcent for the next 250 kWh, 9.6\textcent for the next 750 kWh, and 88\textcent per kWh above 1050. That’s one of the most redistributive rate

\textsuperscript{11} The zip codes served by each utility are at http://en.openei.org/.
\textsuperscript{12} The crosswalk from zip codes to counties is at https://www.huduser.gov/portal/datasets/usps_crosswalk.html.
structures. The Florida utility charges more to low users, and the Ohio utility charges more to high users.

*Calculating the Electric Gini*

The next step is to create a measure of the redistributive nature of the rate structures outlined in Table 1. Our approach involves examining what the hypothetical distribution of electricity bills would look like for each utility if it had customers that were representative of US households. In other words, the actual bills paid to each utility differ for two reasons: the utilities charge different prices, and their ratepayers choose different amounts of electricity. We want to focus solely on the first, the prices.

We examine each electric utility’s rate structure by constructing hypothetical electricity bills for customers that represent the distribution of electricity use across the US. To construct those hypothetical bills, we use data from the Residential Energy Consumption Survey (RECS), a nationally representative survey of more than 12,000 households conducted in 2009 by the US Department of Energy.\(^{14}\) The RECS reports annual electricity use, so we divide by 12 to get an average monthly use, in kWh, for each household. We then calculate how much that monthly use would cost, in August and January, in each of the 1,340 utilities for which we have matched income inequality data from the American Community Survey.

Those hypothetical sets of electricity bills vary across utilities solely based on differences in the utilities’ rate structures. In service areas with high fixed monthly charges and low per-kWh prices, households that use less electricity, and are presumably poorer, end up paying more, on average. In service areas with low monthly charges and high or increasing per-kWh prices, the heavy users pay more.

To quantify how redistributive those rate structures are, we plot Lorenz curves for the electricity bills from each utility, as if the RECS survey participants were customers of that utility. Figure 2 plots those Lorenz curves for the two utilities in Figure 1. We start with a 10 percent sample of RECS households, and calculate what those households’ monthly summer electricity bills would be if they lived in each of the two service areas.\(^{15}\)

\(^{14}\) [https://www.eia.gov/consumption/residential/](https://www.eia.gov/consumption/residential/)

\(^{15}\) Jacobson et al (2005) plot electricity consumption Lorenz curves, across countries and regions of the US. We are plotting the bill Lorenz curves, for the same distribution of consumption.
The upper line in Figure 2 plots the Lorenz curve for the Florida Keys ratepayers. The lower line in Figure 2 plots the Lorenz curve for the Orrville, OH utility, which has a more redistributive rates structure. Households that use the least electricity pay a much higher share of all costs in the Florida Keys than in Orrville.

For reference, the dashed line in Figure 2 plots the Lorenz curve for electricity use, in kWh. It displays the share of electricity consumed by each percentile of the population. That’s the same for each utility, by construction, since we used the same households in each service area. For the Florida utility, electricity bills are more equally distributed than electricity consumption (the bill Lorenz curve is above the electricity Lorenz curve). That’s because the Florida utility’s rate structure is regressive. For the Ohio utility, the reverse is true. Electricity bills are more skewed towards high users than electricity consumption, and the bill Lorenz curve lies below the electricity Lorenz curve, because the Ohio utility’s rate structure is progressive.

Those electricity Lorenz curves can be used to calculate the electricity Gini coefficients that give this paper its title. The Gini coefficient for the electricity bills of RECS households if they lived in Orrville would be 0.65. In the Florida Keys the Gini coefficient would be 0.17. The lower the Gini, the less redistributive the electricity prices. Figure 3 plots histograms of all 1340 utilities’ electric Ginis for their summer and winter rate structures. For comparison, Figure 4 plots the distribution of household income Ginis. The income Ginis are larger, but the variations is similar.

*Electric Ginis and income inequality*

The theoretical section suggests that monthly access fees and per-kWh prices depend on the underlying income inequality of ratepayers and their preferences for redistribution. In Table 2 we regress the electric Ginis, which measure the progressivity of the local utility’s pricing, on the household income Gini coefficients for the utility’s ratepayers. The coefficient on that income Gini is positive and significant. Utilities that serve ratepayers with more unequal incomes have more progressive electricity prices—utilities with higher income Ginis have higher electric Ginis.

Other coefficients in Table 2 also make sense in this context. Utilities serving higher-income ratepayers also do more redistribution. Utilities with more progressive state income taxes, as measured by the difference between pre- and post-tax-and-transfer Gini coefficients,
also have more progressive electricity rate structures. Utilities with more democratic-leaning ratepayers have more redistributive electricity prices. Utilities that sell more electricity to non-residential customers—industrial or commercial customers—have more redistributive residential prices. Utilities with more expensive electricity have more redistributive prices. The only variable that is not consistently important is the number of customers. Larger utilities do not have significantly more redistributive prices once we control for other things.

One obvious concern is regional correlation. We might just be picking up the fact that the South has lower and less equally distributed incomes. The maps in Figure 5 and Figure 6 dispel that. And versions of Table 2 with region fixed effects show similar results.

**Magnitudes: How much do electricity prices redistribute income?**

It appears from Table 2 that electricity pricing serves a redistributive goal. Utilities whose ratepayers have more unequal incomes set prices more favorable to ratepayers who use less electricity. But how large is that redistribution? Figure 2 makes it seem as though that redistribution is large, because the electricity Lorenz curves differ so much across utilities. But that’s about electricity bills, not income, which diminishes the importance of that redistribution for two reasons. Electricity bills are only one part of a households’ costs, and electricity use is not perfectly correlated with income. So even though utilities whose ratepayers have unequal incomes may favor low users, that only redistributes income to the extent that electricity bills are large and correlated with income.

Figure 7 starts to assess this by plotting the electricity bills for two particular utilities with similar average bills (around $100 per summer month) and very different electric Ginis. Fort Collins, Colorado, with the outlined bars, has a high electricity Gini of 0.39, meaning it is favorable to low users. It charges $5.37 per month, 8.9¢ for the first 500 kWh, 10.7¢ for the next 500, and 14.2¢ thereafter. Fall River, Idaho, with the solid shaded bars, has a low electric Gini of 0.24. It charges $36 per month, 7.4¢ for the first 2000 kWh, and 8.8¢ thereafter.

---

16 In theory, state tax progressivity could be a substitute for electricity pricing progressivity. States with progressive income taxes might worry less about redistributing income via electricity prices. But the coefficient here suggests the opposite, probably due to underlying and unmeasured taste for redistribution. States that have more progressive income taxes also have more progressive electricity prices.
The difference in monthly bills depicted in Figure 7 is surprising small, despite the large difference in the electric Ginis. Low users pay about $10 per month more in Fort Collins than they would in Fall River, and the highest users pay about $10 per month more.

Figure 8 partially explains this distinction. It plots the same data as Figure 7, but reported by decile of electricity use rather than by income category. Figure 8 makes the difference between the two utilities look much starker. Low users of electricity pay would about $25 more in Fall River than in Fort Collins, more than double. Meanwhile the highest users pay about $75 per month less. Why does the plot of electricity bills by consumption decile look so much more redistributive than by income category? Because income is not perfectly correlated with consumption.

Figure 9 illustrates this last point. It simply plots electricity use by income from the RECS. The distribution is fairly flat. The highest income households do use about twice as much electricity as the poorest households, but they have 10 or 20 times as much income. There are some high-income households with low electricity use, and some low-income households with high electricity use. Charging steeply rising block prices ends up favoring some high-income households that do not use very much electricity, and hurting some low-income households that use a lot.

Figure 10 presents this in even starker terms. We first approximated households’ incomes by taking midpoints of the income categories in the RECS.\(^\text{17}\) We then calculated the average electricity bill for each income category, in each utility, and subtracted that from our approximated incomes to get net-of-electricity incomes. Those differ across utilities based solely on the utilities’ pricing schemes. We can then calculate Gini coefficients for these net-of-electricity-bill incomes. Figure 10 plots Lorenz curves for two utilities with the most extreme net-of-electricity Ginis: PSC of Colorado, and the Tri-County Electric Coop. PSC Colorado has a net-of-electricity Gini of 0.385, and Tri-county’s is 0.420. Those are not terribly far apart, as depicted by the Lorenz curves in Figure 10.

Conclusions

[TO BE ADDED]

\(^{17}\) The categories are those listed on the bottom axes of Figure 7 and Figure 9. We arbitrarily assume the averaged income in the top-coded category is $135,000
References


**Table 1. Characteristics of US Residential Summer Electricity Bills**

<table>
<thead>
<tr>
<th></th>
<th>Average ($)</th>
<th>Number of utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed monthly charge</td>
<td>14.21</td>
<td>1,290</td>
</tr>
<tr>
<td><strong>Summer rates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>0.100</td>
<td>1,345</td>
</tr>
<tr>
<td>Second</td>
<td>0.106</td>
<td>517</td>
</tr>
<tr>
<td>Third</td>
<td>0.112</td>
<td>219</td>
</tr>
<tr>
<td>Fourth</td>
<td>0.137</td>
<td>56</td>
</tr>
<tr>
<td>Fifth</td>
<td>0.121</td>
<td>23</td>
</tr>
<tr>
<td>Sixth</td>
<td>0.085</td>
<td>3</td>
</tr>
<tr>
<td><strong>Summer thresholds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>680</td>
<td>517</td>
</tr>
<tr>
<td>Second</td>
<td>1,426</td>
<td>219</td>
</tr>
<tr>
<td>Third</td>
<td>2,340</td>
<td>56</td>
</tr>
<tr>
<td>Fourth</td>
<td>1,522</td>
<td>23</td>
</tr>
<tr>
<td>Fifth</td>
<td>1,933</td>
<td>3</td>
</tr>
</tbody>
</table>

Source: US Utility Rate Database [https://openei.org/](https://openei.org/)
Table 2. Electricity Gini and Local Population Characteristics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Means (1)</th>
<th>Summer Electric Gini (2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent variable: Electric Gini</td>
<td>0.300</td>
<td>0.174*</td>
<td>0.079*</td>
</tr>
<tr>
<td>(0.001)</td>
<td></td>
<td>(0.034)</td>
<td>0.035)</td>
</tr>
<tr>
<td>Household income Gini 2015</td>
<td>0.444</td>
<td>0.00191*</td>
<td>0.00134*</td>
</tr>
<tr>
<td>(0.001)</td>
<td></td>
<td>(0.00066)</td>
<td>(0.00065)</td>
</tr>
<tr>
<td>Average household income 2015 ($10,000)</td>
<td>6.441</td>
<td>-0.793*</td>
<td>-1.059*</td>
</tr>
<tr>
<td>(0.037)</td>
<td></td>
<td>(0.214)</td>
<td>(0.215)</td>
</tr>
<tr>
<td>State tax and transfer effect on Gini</td>
<td>-0.0652</td>
<td>0.0070</td>
<td>0.0046</td>
</tr>
<tr>
<td>(0.0001)</td>
<td></td>
<td>(0.0074)</td>
<td>(0.0073)</td>
</tr>
<tr>
<td>Obama vote share 2012</td>
<td>0.416</td>
<td>-0.0290*</td>
<td>-0.0284*</td>
</tr>
<tr>
<td>(0.0053)</td>
<td></td>
<td>(0.0053)</td>
<td>(0.0053)</td>
</tr>
<tr>
<td>Fraction of sales residential</td>
<td>0.457</td>
<td>-0.0277*</td>
<td>-0.0264*</td>
</tr>
<tr>
<td>(0.0053)</td>
<td></td>
<td>(0.0021)</td>
<td>(0.0021)</td>
</tr>
<tr>
<td>Residential customers (millions)</td>
<td>0.0598</td>
<td>0.0055</td>
<td>0.0034</td>
</tr>
<tr>
<td>(0.0069)</td>
<td></td>
<td>(0.0039)</td>
<td>(0.0038)</td>
</tr>
<tr>
<td>Average electricity price ($/kWh)</td>
<td>0.107</td>
<td>0.176*</td>
<td>0.109*</td>
</tr>
<tr>
<td>(0.001)</td>
<td></td>
<td>(0.033)</td>
<td>(0.036)</td>
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<tr>
<td>Investor owned utility</td>
<td>0.080</td>
<td>0.0019</td>
<td>0.0029</td>
</tr>
<tr>
<td>(0.0038)</td>
<td></td>
<td>(0.0037)</td>
<td>(0.0037)</td>
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<tr>
<td>Cooperative utility</td>
<td>0.386</td>
<td>-0.0277*</td>
<td>-0.0264*</td>
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<tr>
<td>(0.0021)</td>
<td></td>
<td>(0.0021)</td>
<td>(0.0021)</td>
</tr>
<tr>
<td>Share electricity from gas</td>
<td>0.176</td>
<td>0.0436*</td>
<td>0.0436*</td>
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<tr>
<td></td>
<td></td>
<td>(0.0056)</td>
<td>(0.0056)</td>
</tr>
<tr>
<td>Share electricity from nuclear</td>
<td>0.185</td>
<td>0.0143*</td>
<td>0.0143*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0059)</td>
<td>(0.0059)</td>
</tr>
<tr>
<td>Share electricity from hydro</td>
<td>0.069</td>
<td>-0.0038</td>
<td>-0.0038</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0059)</td>
<td>(0.0059)</td>
</tr>
<tr>
<td>Share electricity from petroleum</td>
<td>0.007</td>
<td>0.0180</td>
<td>0.0180</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0223)</td>
<td>(0.0223)</td>
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<tr>
<td>Constant</td>
<td>0.161*</td>
<td>0.186*</td>
<td>0.186*</td>
</tr>
<tr>
<td>(0.023)</td>
<td></td>
<td>(0.023)</td>
<td>(0.023)</td>
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<tr>
<td>R-squared</td>
<td>0.30</td>
<td>0.33</td>
<td>0.33</td>
</tr>
<tr>
<td>Observations</td>
<td>1,345</td>
<td>1,345</td>
<td>1,345</td>
</tr>
</tbody>
</table>

Notes: Column (1) reports the means and standard deviations of all variables. Columns (2) and (3) report coefficients and standard errors from a regression of the summer electric Gini on the other variables. Asterisks (*) denote statistically significance at 5%.
Figure 1. Example Utility Bills

Figure 2. Electricity Lorenz Curves for Example Utilities
Figure 3. Distribution of Electric Ginis

(a) Summer Rates  
(b) Winter Rates

Figure 4. Distribution of Household Income Ginis, 2015
Figure 5. Gini Coefficients for 2015 Household Incomes, by US County.


Figure 6. Electric Ginis

Source: Authors’ calculations from Utility Rate Database, summer electricity prices.
Figure 7. Average Electricity Bills for Two Particular Utilities, by Income

Figure 8. Average Electricity Bills for Two Particular Utilities, by Electricity Use
Figure 9. Electricity Use by Income: RECS 2009

Figure 10. Lorenz Curves by Net-of-electricity Income for Two Particular Utilities
Figure 11. Income Lorenz Curves by Groups of States

Source: Authors’ calculations from 2009 RECS.
Appendixes

A. First best: Individualized prices and access fees

Consider an economy with \( n \) households, distinguished according to their income levels. Let \( w^i \) denote the income level of a household of \( i, \ i = 1, \ldots, n \). Household \( i \) derives utility \( u(e^i, x^i) \) from consumption of \( x^i \) units of a numeraire good and \( e^i \) units of electricity, where \( u_s > 0, \ u_e > 0, \ u_{sx} < 0, \ u_{se} < 0, \ u_{ee} \geq 0, \ u_{se}u_{ee} \geq u_{se}^2 \). The household’s budget constraint is

\[
x^i + p^ie^i = \hat{w}^i \equiv w^i - t^i,
\]

where \( p^i \) is the price faced this household per unit of electricity and \( t^i \) is a fixed fee the household pays to have access to the electricity system. We allow the electricity and access fee to be personalized in order to study departures from the first best when the regulator faces constraints that make it impossible to personalize the access fee and the electricity price.

Taking the access fee and the price of electricity as given, household \( i \) chooses the amount of electricity to consume in order to maximize \( u(e^i, \hat{w}^i - p^ie^i) \). Assuming an interior solution, the first-order condition yields

\[
\frac{u_i^e}{u_i^s} = p^i, \quad i = 1, \ldots, n, \tag{A.1}
\]

where \( u_i^e \equiv \partial u(e^i, x^i)/\partial e^i \) and \( u_i^s \equiv \partial u(e^i, x^i)/\partial x^i \). Let \( e'(p^i, \hat{w}^i) \) and \( x'(p^i, \hat{w}^i) = \hat{w}^i - p^i e'(p^i, \hat{w}^i) \) denote the quantities demanded of electricity and numeraire good, respectively. Household \( i \)'s indirect utility function is

\[
v(p^i, \hat{w}^i) = u(x'(p^i, \hat{w}^i), e'(p^i, \hat{w}^i)), \quad i = 1, \ldots, n. \tag{A.2}
\]

The electricity supplier can produce \( E \) units of output at the total cost \( F + cE \), where \( F > 0 \) is the fixed cost and \( c > 0 \) is the per unit cost. In any equilibrium, \( E = \sum_{i=1}^{n} e'(p^i, \hat{w}^i) \), since the quantity supplied must be equal to the quantity demanded.

Electricity supply is regulated. The regulator chooses \( \{p^1, \ldots, p^n, t^1, \ldots, t^n\} \) to maximize

\[
\sum_{i=1}^{n} v(p^i, \hat{w}^i - t^i) \]

subject to the following feasibility constraint:
\[
\sum_{i=1}^{n} \left[ t^i + (p^i - c) e^i \left( p^i, w^i - t^i \right) \right] = F
\] (A.3)

Letting \( \lambda \) denote the multiplier associated with constraint (A.3), the first-order conditions are equation (A.3) and the following, for \( j = 1, \ldots, n \):

\[-v^i_p = \lambda \left( e^i + (p^i - c) e^i_p \right) \quad \text{(with respect to } p^i \text{)}, \quad (A.4)\]
\[v^i_w = \lambda \left( 1 - (p^i - c) e^i_w \right) \quad \text{(with respect to } t^i \text{)}, \quad (A.5)\]

where \( v^i_p \equiv \partial v \left( p^i, \hat{w}^i \right) / \partial p^i \), \( v^i_w \equiv \partial v \left( p^i, \hat{w}^i \right) / \partial \hat{w}^i \), \( e^i_p \equiv \partial e^i \left( p^i, \hat{w}^i \right) / \partial p^i \) and \( e^i_w \equiv \partial e^i \left( p^i, \hat{w}^i \right) / \partial \hat{w}^i \).

Combining equations (A.4) and (A.5) in order to eliminate the multiplier yields, for \( j = 1, \ldots, n \)

\[-v^i_p / v^i_w = e^i + (p^i - c) e^i_p / 1 - (p^i - c) e^i_w > 0 \] \quad (A.6)

Roy’s identity \((-v^i_p / v^i_w = e^i)\) means that the left side of equation (A.6) equals \( e^i \), \( \forall j \). That in turn means that

\[(p^i - c) \left[ e^i e^i_p + e^i_w \right] = 0. \] \quad (A.7)

By the Slutsky equation, the term in square brackets in (A.7) is the derivative of the Hicksian electricity demand function, which is strictly negative for any well-behaved preferences:

\( h^i_p \equiv \partial h^i \left( p^i, u^i \right) / \partial p^i < 0 \). So

\[(p^i - c) h^i_p = 0 \Rightarrow p^i - c = 0. \] \quad (A.8)

Every household is charged the same price, \( p^i = c \).

Since \( v^i_w = u^i_x, \forall j \), equations (A.5) and (A.8) imply

\[u^i_x = u^i_x, \quad \forall i, j = 1, \ldots, n, i \neq j. \] \quad (A.9)

Since \( p^i = c, \forall j \), equations (A.1) imply

\[u^i_c = u^i_c, \quad \forall i, j = 1, \ldots, n, i \neq j. \] \quad (A.10)
Equations (A.9) and (A.10) hold simultaneously if and only if, for \( \forall i, j = 1, \ldots, n, i \neq j \):

\[ e^j = e^i, \quad (A.11) \]
\[ \chi^j = \chi^i. \quad (A.12) \]

Now, note that equations (A.11) and (A.12) imply

\[ \hat{w}^j \equiv w^j - t^i = w^j - t^j \equiv \hat{w}^j, \quad \forall i, j = 1, \ldots, n, i \neq j. \quad (A.13) \]

If \( w^j = w^j, \forall i, j = 1, \ldots, n, i \neq j \), then equations (A.13) imply \( t^i = t^j = t \). In this case, \( t = F/n \) according to (A.3).

B. Uniform access fees and individualized prices.

Consider the case where the regulator can set individual prices, \( p^i \), but cannot set individualized access fees: \( t^i = t \) for all \( i \). The regulator chooses \( \{p^i, \ldots, p^n, t\} \) to maximize

\[ \sum_i v(p^i, w^j - t) \]

subject to

\[ nt + \sum_i (p^i - c)e^i(p^i, w^j - t) = F. \quad (B.1) \]

Letting \( \lambda \) denote the multiplier associated with (B.1), and assuming an interior solution (\( t > 0 \) and \( p^j > 0 \)), the first-order conditions are (A.4) and

\[ \sum_i v_i^j = \lambda \left( n - \sum_i (p^i - c)e_i^j \right). \quad (B.2) \]

Since \( \lambda > 0 \) and \( \sum_i v_i^j > 0 \), \( n - \sum_i (p^i - c)e_i^j > 0 \). Combining conditions (A.4) and (B.2) yields

\[ \sum_i v_i^j = -\left( \frac{v_i^j}{e^i +(p^j - c)e_p^j} \right) \left( n - \sum_i (p^i - c)e_i^j \right), \quad \forall j. \quad (B.3) \]

Using Roy’s identity, \( -v_p^j = e^jv_p^j \), and cross-multiplying by \( (e^i + (p^j - c)e_p^j)/e^i \), equations (B.3) then imply

\[ L^j \equiv \frac{p^j - c}{p^j} = -\frac{1}{e_p^j} \left[ \frac{v_i^j \left( n - \sum_i (p_i - c)e_i^j \right)}{\sum_i v_i^j} \right], \quad \forall j \quad (B.4) \]

which is equation (17) in the main body of the paper.
C. Solar roofs and other electricity endowments.

To capture non-income heterogeneity, we assume household $i$ is endowed with $\bar{e}^i$ units of electricity. Household $i$’s budget constraint is then $x^i + p^i (e^i - \bar{e}^i) = w^i - t$. Define $\tilde{w}^i$ as the household’s exogenous income, including the value of its electricity endowment and net of access fees: $\tilde{w}^i \equiv w^i + p^i \bar{e}^i - t$. Household $i$’s electricity demand is $e^i (p^i, \tilde{w}^i)$ and indirect utility is $v^i (p^i, \tilde{w}^i)$. The regulator chooses $\{p^1, ..., p^n, t\}$ to maximize $\sum_i v^i (p^i, \tilde{w}^i)$ subject to

$$nt + \sum_i (p^i - c) e^i (p^i, \tilde{w}^i) = F.$$ (C.1)

Letting $\lambda$ denote the Lagrange multiplier associated with constraint (C.1), the first-order conditions of the regulators problems are

$$v^i_p + v^i_{\tilde{w}} e^i + \lambda \left[ e^i + \left( p^i - c \right) (e^i + e^i_{\tilde{w}}) \right] = 0 \quad \forall j \quad \text{(with respect to } p^i),$$ (C.2)

$$-\sum_i v^i_{\tilde{w}} + \lambda \left[ n - \sum_i (p^i - c) e^i_{\tilde{w}} \right] = 0 \quad \text{(with respect to } t).$$ (C.3)

Applying Roy’s identity ($v^i_p = v^i_{\tilde{w}} e^i$), equation (C.2) becomes

$$v^i_{\tilde{w}} (e^i - \bar{e}^i) = \lambda \left[ e^i + \left( p^i - c \right) (e^i + e^i_{\tilde{w}}) \right] \quad \forall j.$$ (C.4)

Combining equations (C.3) and (C.4) yields

$$\sum v^i_{\tilde{w}} = \frac{v^i_{\tilde{w}} (e^i - \bar{e}^i)}{\left( e^i + \left( p^i - c \right) (e^i + e^i_{\tilde{w}}) \right)} \left[ n - \sum_i (p^i - c) e^i_{\tilde{w}} \right], \quad \forall j.$$ (C.5)

which can be rewritten as

$$L^i \equiv \frac{p^i - c}{p^i} = \frac{-1}{e^i + \frac{\bar{e}^i}{e^i} p^i} \left[ 1 - \left( \frac{v^i_{\tilde{w}}}{v^i_{\tilde{w}}} \right) \left( \frac{e^i - \bar{e}^i}{e^i} \right) \left( n - \sum_i (p^i - c) e^i_{\tilde{w}} \right) \right], \quad \forall j.$$ (C.6)
which is equation (19) in the main paper. $L^j$ is the Lerner index of monopoly power with respect to household $j$, and $\varepsilon^j_p$ is household $j$’s price elasticity of electricity demand: \( \frac{\partial e^j}{\partial p^j} \frac{(p/e)}{e} < 0 \).

The Slutsky equation in this context says that compensated electricity demand, $h_p^j = e^j + e^j e^j < 0$. Multiplying the right side of that that expression by $p^j/e^j$ yields the expression $\varepsilon^j_p + p^j e^j_p$. We know that is negative, from Slutsky, so multiplying the second term by $\varepsilon^j/e^j < 1$ to get the denominator in (C.6) tells us that denominator is negative, since $\varepsilon^j < e^j$ by assumption.

**D. Increasing block pricing**

To simplify, we assume the access fee $t=0$, and that an exogenous rule determines the number of households facing each of two price tiers: $n_L$ low-using customers face price $p_L$ for each kWh of electricity up to threshold quantity $q$, and $n_H$ high-using customers face price $p_H$ for each kWh above $q$. The budget constraint for the low types is

$$x^j + p_L (e^j - \bar{e}^j) = w^j$$

and the budget constraint for the high types is

$$x^j + p_L q + p_H (e^j - \bar{e}^j - q) = w^j.$$  \hspace{2cm} (D.2)

As before, define $\tilde{w}_L = w^j + p_L \bar{e}$ and $\tilde{w}_H = w^j + p_H \bar{e} + (p_H - p_L)q$. The higher users problem is equivalent to paying a fixed fee $p_L q$ and per-kWh price $p_H (e^j - \bar{e}^j - q)$.

The regulator chooses the two prices and the threshold, $\{p_L, p_H, q\}$ to maximize

$$\sum_{i \in L} v'(p_L, \tilde{w}_L^i) + \sum_{i \in H} v'(p_H, \tilde{w}_H^i).$$  \hspace{2cm} (D.3)

subject to the zero profit constraint that
\[
(p_L - c) \left[ n_H q + \sum_{i \in L} e^i (p_L, \bar{w}^i_L) \right] + (p_H - c) \left[ \sum_{i \in H} e^i (p_H, \bar{w}^i_H) \right] = F.
\]  \hspace{1cm} (D.4)

Letting \( \lambda \) be the constraint on (D.4), and using Roy’s identity to rewrite \( v_p^i \) as \( -e^i v_p^i \), the three first-order conditions are

\[
-\sum_{i \in H} v_p^i \left( e^i - \bar{e}^i - q \right) + \lambda \sum_{i \in H} \left( e^i + (p_H - c)(e_p^i + e_w^i(\bar{e}^i - q)) \right) = 0 \hspace{1cm} \text{(with respect to \( p_H \)),} \]  \hspace{1cm} (D.5)

\[
-\sum_{i \in L} v_p^i \left( e^i - \bar{e}^i \right) - q \sum_{i \in H} v_w^i + \lambda \left[ n_H \left( p_L - c \right) + \left( p_H - c \right) \left( p_H - p_L \right) \sum_{i \in H} e_w^i \right] = 0 \hspace{1cm} \text{(with respect to \( p_L \)),} \]  \hspace{1cm} (D.6)

\[
(p_H - p_L) \sum_{i \in H} v_w^i + \lambda \left[ n_H \left( p_L - c \right) + \left( p_H - c \right) \left( p_H - p_L \right) \sum_{i \in H} e_w^i \right] = 0 \hspace{1cm} \text{(with respect to \( q \)).} \]  \hspace{1cm} (D.7)

Consider equation (D.7). The first term is positive, so the bracketed term that multiplies \( \lambda \) must be negative. So either \( p_L < c \) or \( (p_H - c)(p_H - p_L) < 0 \). Since \( p_H > p_L \) by assumption, and since equation (D.4) must hold, it must be the case that that \( p_H > c > p_L \). That’s intuitive.

Customers using less than \( q \) will pay below marginal cost, \( p_L < c \), and customers using more than \( q \) will pay above marginal cost \( p_H > c \) for all electricity above \( q \).

Combining equations (D.5) and (D.7) yields

\[
-\frac{(p_L - c)}{p_L} = \left( \frac{p_H - p_L}{p_L} \right) \times \frac{(p_H - c) \sum_{i \in H} e_w^i \sum_{i \in H} v_w^i \left( e^i - \bar{e}^i - q \right) + \sum_{i \in H} v_w^i \left( \sum_{i \in H} e_w^i e^i + \sum_{i \in H} (p_H - c) \sum_{i \in H} \left( e_p^i + e_w^i (\bar{e}^i + q) \right) \right)}{n_H \sum_{i \in H} v_w^i \left( e^i - \bar{e}^i - q \right)} = 0. \]  \hspace{1cm} (D.8)

Intuitively, the rate at which low-demand customers are subsidized is proportional to the size of the gap between the high and low prices. Lowering \( p_L \) requires raising \( p_H \).

Combining equations (D.5) and (D.6) yields
\[
\frac{\sum_{i \in H} v^i_w (e^i - \bar{e}^i - q)}{\sum_{i \in L} v^i_w (e^i - \bar{e}^i) + q \sum_{i \in H} v^i_w} = \frac{E^H + (p_H - c) \sum_{i \in H} (e^i_p + e^i_w (\bar{e}^i + q))}{E^L + (p_L - c) \sum_{i \in L} (e^i_p + e^i_w \bar{e}^i) + n_H q - (p_H - c) q \sum_{i \in H} e^i_w},
\]

where \(E^H = \sum_{i \in H} e^i\) and \(E^L = \sum_{i \in L} e^i\). The left side of (D9) is the rate at which \(p_L\) can be lowered and \(p_H\) raised, holding total utility constant. It’s the marginal social rate of substitution between the high and low electricity prices. The right side of (D9) is the rate at which \(p_L\) can be lowered and \(p_H\) raised, holding total revenue constant. It’s the marginal social rate of transformation between high and low electricity prices.