On the Efficiency of Connection Charges under Renewable Integration in Distribution Systems

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Abstract—The economic efficiency of two-part retail electricity tariffs in the presence of renewable resources in the distribution system is analyzed. Two integration models are considered: (i) a centralized model involving a regulated retail utility who owns the resources as part of its generation portfolio, and (ii) a decentralized model in which each consumer individually owns and operates the resources behind the meter and is capable of selling surplus electricity back to the retailer in a net-metering setting. The structure of the optimal two-part tariffs is obtained. For both integration models, it is shown that, under two-part tariffs, renewable resources generally improve efficiency and consumer surplus. In contrast, under linear tariffs, the integration of renewable resources by consumers may lower both consumer surplus and social welfare.

I. INTRODUCTION

The electric power industry is experiencing an important transformation driven by disruptive innovation in small-scale renewable generation and energy storage systems [1]. In fact, the increasing number of adopters of rooftop solar PV systems behind-the-meter is already challenging the financial model of traditional utilities [2], [4]. That is because under heavily volumetric tariff structures, the fixed costs of regulated utilities in combination with the decreasing net-metered consumption of PV adopters may put upward pressure on retail tariffs to maintain certain level of revenue. Tariff increases in turn provide an incentive to further reduce consumption and adopt such technologies, thus closing a feedback loop that has been called the death spiral hypothesis [3], [5]. Part of the risk is that large net load reductions could ultimately erode utilities' revenue for grid maintenance and investment [3] and increase electricity rates well above its marginal cost of production.

As a result, a debate within the US about retail tariff design is being held. Two main aspects of the discussion are the inefficiency of volumetric charges to recover utilities’ fixed costs and the inequity of net energy metering (NEM). One underlying challenge has thus become to characterize retail tariffs that best align the stakeholders’ individual interests with those of the society. Said challenge amounts to the design of retail tariffs that induce a socially optimal consumption of electricity, operation of storage, and usage of renewable resources, in the short-run.

A. Contributions

We consider the electricity retail tariff design problem from the perspective of a regulated retailer subject to a budget constraint, a fixed customer base, and the presence of renewables in the distribution system. In this setting, we analyze the effect of two-part tariffs on efficiency (social welfare) when renewables are integrated either by the retailer or by the customers. We focus our attention on dynamic day-ahead two-part tariffs and consider an uncertain demand model.

A dynamic day-ahead tariff is a form of dynamic pricing where the tariff is fixed and informed to customers on a day-ahead basis, thus providing them with some degree of certainty and time to plan consumption [5], [7]. Moreover, a two-part or affine tariff consists of a per unit charge (i.e., a linear or “volumetric” charge) for consumption plus a fixed “connection” charge that is independent of the level of consumption.

In standard economic theory, the use of a two-part tariff as a means to recover a public utility’s total costs is known to be efficient if distributional considerations between customers are ignored [8]. We show that this result can be extended to our specialized setting under both renewable ownership regimes. In particular, we show that two-part retail tariffs can eliminate the inefficiencies introduced by linear tariffs in both integration regimes. Moreover, under optimally designed two-part tariffs, consumer surplus and social welfare increase uniformly with renewables under both integration regimes (relative to a regime without renewables). This is in contrast to the outcomes induced by linear tariffs, where coordinated integrations of renewables by the retailer are generally superior to uncoordinated integrations by customers [11].

B. Related Work

The integration of distributed energy resources (DER) in distribution networks is a complex dynamic process that involves modeling the way millions of customers decide to adopt and use such technologies. To the best of our knowledge, the first study of this process and the death spiral hypothesis was conducted by Cai et al. [5]. Therein, authors model and analyze empirically the long-run closed loop dynamics of residential PV solar integration under California’s current increasing block rate (IBR) structure. Their model predicts that the upward pressure on the tariffs induced by the IBR structure is “unlikely to have a significant impact on future PV uptake rates in the next 10 years.” They also explore the delaying effect that connection charges may have on PV adoption rates.

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The long-term approach in [5] is in contrast with the more numerous works that have focused on understanding the problem as posed to the stakeholders in the short-term. This is the spirit of [10], [11], and our work. In [10], authors consider the dynamic tariff design problem of a regulated retailer with access to uncertain renewable energy in a two-settlement market. Their consumer model, based on multiple appliances (including thermostatically controlled loads, or TCLs, and energy storage), is versatile yet deterministic. We, instead, characterize customers with a random demand function and further incorporate the regulated retailer’s budget constraint.

Conversely, authors in [11] analyze the distribution of the benefits brought by distributed integrations of renewables and storage between a regulated distribution utility and its customers. Their analysis is posed as a dynamic tariff design problem restricted to a day-ahead hourly pricing tariff with a linear structure, and it comprises the two integration ownership regimes on which our work leverages on. The demand response model for TCLs used in [11] to rationalize consumption behavior was proposed and further studied in [12], [9], and [13]. In this work we also use such model, which yields a linear demand function with random intercept and deterministic nonzero own-price and intertemporal cross-price elasticities. On a related work, Ferreira et al. [14] propose a consumer model with uncertain price-elasticity for the design of a static time-of-use tariff in a scenario-based stochastic programming approach. Other related models where responsive uncertain demand is incorporated in a tariff design problem are developed in [15], [16].

Our work relies on the widely studied concept of dynamic pricing [6], [17], a notion that broadly refers to retail prices that are allowed to vary in time in the short-term. Real-time pricing (RTP), a form of dynamic pricing, is widely known to be a critical feature of efficient electricity markets [6]. Until very recently, however, dynamic retail tariffs have been embraced in the US only by a few utility companies and on a voluntary basis [17]. A relevant analysis of the efficiency of RTP is [18], where authors derive the linear tariffs that emerge from a competitive equilibrium between generators and consumers which can endogenously invest in real-time meters. In a follow-up work [19], authors study two-part tariffs in a RTP scheme in both a regulated and a competitive retail market setting. They show how dynamic two-part tariffs are socially optimal among all nonlinear dynamic tariffs under certain conditions.

Two-part and other nonlinear tariffs have been widely studied in the broader context of public regulated utilities (see [8], [20] and references therein). In the electric power industry, two-part tariffs are prevalent everywhere in the US. However, in California, currently the solar market leader in the US, the three largest investor-owned utilities (IOU) currently use tariffs with virtually no connection charges.

II. MODEL

The state of nature is represented by a discrete random process $\xi_k \in \Xi$, where $k$ indexes discrete time periods $k = 1, \ldots, N$ in which the day in question ispartitioned. We define $\xi := (\xi_1, \ldots, \xi_N)$ and use $\pi := \mathbb{E}[x_\xi]$ to denote the expectation of a state-dependent vector $x_\xi$ with respect to the joint probability distribution of $\xi$. Similarly, we define $\Sigma_{x_\xi} := \text{Cov}(x_\xi, y_\xi)$.

One day ahead, the retailer offers to its customers a retail tariff $T : \mathbb{R}^N \rightarrow \mathbb{R}$ that maps the net-metered consumption vector $x \in \mathbb{R}^N$ of each customer to a scalar charge $T(x)$, where the $k$-th entry of $x$ ($x_k$) is a single customer’s net-metered consumption in period $k$, and the amount $T(x)$ (in dollars) are the total charges. Note that this general form of tariff captures the inter-temporal dependencies of pricing and consumptions within each day.

Subsequently, in real-time, each customer rationally chooses how much electricity withdraws from the grid. If they have access to behind-the-meter renewables, consumers choose the amount they withdraw from the grid knowing the renewable generation available for their immediate consumption. In general, we will reserve letter $q$ to refer to consumption profiles and $x$ for net-metered energy withdrawn from the grid.

Finally, the retailer is responsible for purchasing the aggregate net-metered consumption electricity of its customer base at the real-time energy market. This amounts to paying for such net-metered consumption profile at the real-time wholesale price of electricity.

A. Consumer Model

We consider $M$ risk-neutral customers (indexed by $i$) with TCLs whose consumption behavior we rationalize as in [12], [13]. In particular, we collectively characterize customers with a state-dependent aggregate linear demand function $D_\xi(\cdot) : \mathbb{R}^N \rightarrow \mathbb{R}^N$ and a state-dependent benefit function $S_\xi(\cdot) : \mathbb{R}^N \rightarrow \mathbb{R}$. While the demand function maps a (possibly state-dependent) price vector $\pi \in \mathbb{R}^N$ to a state-dependent aggregate consumption vector $D_\xi(\pi) \in \mathbb{R}^N$, the benefit function maps a (possibly state-dependent) aggregate consumption vector $q \in \mathbb{R}^N$ to a state-dependent gross surplus $S_\xi(q) \in \mathbb{R}$. In [12], [13], these functions are obtained from the solution of a stochastic dynamic program, and they can be written as

$$D_\xi(\pi) = b_\xi - G\pi,$$

$$S_\xi(q) = c_\xi - \frac{1}{2}(b_\xi - q)\top G^{-1}(b_\xi - q),$$

where $G$ is deterministic, positive definite, and depends only on the HVAC system parameters and preferences of all customers, and $b_\xi$ is a Gaussian random vector that depends on the outdoor temperature. To ease exposition, we simplify the model by assuming individual consumers are homogeneous up to a scaling factor $\sigma_i > 0$ (with $\sum \sigma_i = 1$) as in [19]. That is, the behavior of an individual customer $i$ is similarly given by the demand and gross surplus functions $D_\xi(\pi) = \sigma_i D(\pi)$ and $S_\xi(q^i) = \sigma_i S_\xi(q^i/\sigma_i)$, where $q^i$ denotes customer $i$’s individual consumption vector. For more details of this TCL model the reader is referred to [12], [13].

1In [5], we introduce $c_\xi$ only to normalize $S_\xi(\cdot)$ so that $S_\xi(0) = 0$. 
According to this model, consumer surplus is given by the sum of the (net) surplus perceived by each customer

$$\text{CS}_i = \sum_{i=1}^{M} S_i^T(q^i(\xi)) - T(x^i(\xi)),$$

where \(q^i(\xi)\) denotes customer \(i\)'s state-dependent consumption vector when faced with an arbitrary day-ahead tariff \(T(\cdot)\). We assume here that \(q^i(\xi) = x^i(\xi)\) unless customer \(i\) has access to behind-the-meter renewables, in which case we offset the renewable supply from the consumption \(q^i(\xi)\) to obtain the net-metered profile \(x^i(\xi)\).

### B. Retailer Model

We consider the case of a regulated electricity retailer monopoly. To serve the net-metered demand \(x(\xi) = \sum_{i=1}^{M} x_i(\xi)\), the retailer incurs in a state-dependent cost \(\lambda(\xi)^\top x(\xi)\), where \(\lambda(\xi) \in \mathbb{R}^N\) denotes the real-time wholesale electricity price. Hence, given a retail tariff \(T(\cdot)\) and the corresponding rational net-metered consumption vector \(x^i(\xi)\) of each customer \(i\), the retailer profits can be written as

$$\text{rp}_i = \sum_{i=1}^{M} T(x^i(\xi)) - \lambda(\xi)^\top x^i(\xi).$$

In addition, we assume that the retailer incurs a fixed cost\(^2\) (i.e., independent of the amount of electricity procured) that can be expressed in a daily quantity \(F \in \mathbb{R}\). We choose not to discount \(F\) from \(\text{rp}_i\) to treat \(F\) as a parameter that we will vary as part of our analysis.

Lastly, we assume that a benevolent regulator maximizes the social welfare measured as the expected total surplus, i.e.,

$$\mathbb{E}[	ext{SW}_\xi] = \mathbb{E}[\text{CS}_\xi + \text{rp}_\xi],$$

and that his role is limited to choosing the retail tariff \(T(\cdot)\). In order to make the retailer business sustainable, the regulator guarantees the retailer to break even in expectation by means of the ex-ante budget balance constraint \(\mathbb{E}[\text{rp}_\xi] \geq F\).

### III. Retail Tariff Design

In our setting, the regulator’s problem is to design a (day-ahead) tariff \(T(\cdot)\) that maximizes the expected social welfare subject to the retailer budget balance constraint. That is,

$$\max_{T(\cdot)} \mathbb{E}[\text{SW}_\xi] \quad \text{s.t.} \quad \mathbb{E}[\text{rp}_\xi] \geq F. \quad (3)$$

Assuming we can further characterize the rational consumption of each customer when facing any arbitrary nonlinear tariff, problem (3) amounts to an infinite-dimensional optimization problem over the space of arbitrary functions \(T\). Many versions of such problem have been widely studied in economics \[20\].

\(^2\)The retailer fixed cost can be roughly divided into fixed costs intrinsically incurred by the retailer and external costs passed through the retailer onto the consumer (e.g., a transmission fixed charge). Moreover, to simplify exposition, we assume \(F\) does not depend on the number of customers served, \(M\). Such dependence does not alter the nature of our results.

A. Linear Tariff

By restricting the regulator to a linear tariff \(T(\eta) = \pi^\top \eta\), problem (3) can be formulated as a convex optimization problem over a price vector \(\pi \in \mathbb{R}^N\). The structure of the solution to such restricted problem is well known in economics for more standard settings \[21\], \[22\], yet it was first derived for a setting closer to ours in \[23\]. Therein, translated to our setting, authors show that the price vector \(\hat{\pi}\) that maximizes social welfare in the absence of renewable integrations is characterized by the price markup relative to \(\lambda\)

$$\hat{\pi} = \lambda + \eta \frac{1}{2} G^{-1} D(\lambda), \quad (4)$$

where either (i) \(\eta = 0\) if \(\mathbb{E}[\text{rp}_\xi(\lambda)] \geq F\), or (ii) \(\eta \in (0,1]\) such that \(\mathbb{E}[\text{rp}_\xi(\hat{\pi})] = F\), otherwise. It is easy to check that \(\mathbb{E}[\text{rp}_\xi(\lambda)] = -\text{Tr} (\Sigma_{\lambda,b})\).

The choice of tariff structure is usually made by regulators considering various policy objectives not limited to efficiency (e.g., fairness). In terms of efficiency (unweighted social welfare), however, the use of linear tariffs is often restrictive as it introduces inefficiencies when the retailer budget constraint is binding at optimality. This is evident from the structure of the solution where a positive markup relative to \(\lambda\), the expected marginal cost of electricity, may be required to raise enough profits for the retailer to collect \(F\).

Following the analysis in \[11\], we now consider integration regimes where either the retailer or customers (collectively) have access to a total supply \(r_\xi \in \mathbb{R}^N\) of random renewable energy free of charge. While we do not allow the retailer to sell back energy to the wholesale market, the net-metering setting we consider allows customers to sell back energy generated behind-the-meter to the retailer at the retail tariff. In \[11\], authors provide some results for such integration regimes under linear tariffs.

Figure 1 illustrates relevant results obtained in \[11\] for linear tariffs in three different regimes (no renewables, retailer-owned integration, and consumer-owned integration) adapted to our slightly different setting. In Figures 1a and 1b each point along the three different curves (corresponding to the three regimes) indicates the expected consumer surplus and retailer profit induced by the optimal linear tariff for a particular \(F\). Hence, these curves can be interpreted as Pareto fronts that illustrate (i) the way the achieved level of social welfare is distributed between consumers and retailer, and (ii) the increasing rate at which \(\text{CS}\) has to be sacrificed for increasing an additional dollar in \(\text{rp}\). An implication is that under linear tariffs social welfare is maximum at the right extreme of each Pareto front. Without renewables, for example, this happens only when \(F = 0\).

In particular, Fig. 1a reveals that renewable integrations by the retailer shift the Pareto front upwards by \(V^r := \mathbb{E}[r^i \lambda E]\) (i.e., by the value of the supply), thus implying that centralized integrations generally increase consumer surplus (i.e., for

\(^1\)In \[11\], instead of a budget constraint in the regulator’s problem (3), authors maximize a weighted social welfare function and vary the retailer profit weight to increase the collected retail profit.
each fixed $F$). In contrast, Fig. [1b] shows that decentralized renewable integrations transform the Pareto front in a way that social welfare and consumer surplus decrease for sufficiently large $F$. This is caused by the reduction in the net-metered consumption, which in turn induces a larger price markup required to recover $F$, thus causing an additional endogenous reduction in consumption.

Fortunately, the inefficiency introduced by linear tariffs can be mitigated by means of tariffs that better reflect the marginal cost of electricity. We now consider the simplest form of nonlinear tariffs which has been traditionally used in the electric power industry [20] Sec. 1.4]. [19].

B. Two-Part Tariff

We now restrict the regulator to a two-part tariff $T(q) = A + \pi^* q$, where $A$ represents a daily connection charge. This restriction simplifies problem (3) to a convex optimization problem over $(\pi, A)$. To characterize the solution of such problem we define $SW^* = \mathbb{E}[S_\xi(D_\xi(\lambda)) - \lambda^T \mathbb{D}_\xi(\lambda)]$ and $CS^* = \mathbb{E}[S_\xi(D_\xi(\lambda)) - \lambda^T \mathbb{D}_\xi(\lambda)]$ as the levels of $SW$ and $CS$ achieved under a plain (expected) marginal pricing tariff (i.e., $T(q) = \lambda^T q$) and no budget constraint.

We can now characterize the optimal two-part tariff without renewable integration. To simplify our analysis, we rule out the possibility that customers reject the offered tariff (e.g., for being too expensive).

Proposition 1. The day-ahead two-part retail tariff that solves the regulator’s problem is characterized by a price $\pi^*$ that matches the expected wholesale price, $\pi^* = \lambda$, and a connection charge $A^*$ that recovers $F$ plus the price-demand correlation effect,

$$A^*(F) = \frac{F + Tr(\Sigma_{\lambda,b})}{M}. \quad (5)$$

Corollary 1. For a fixed $F$, the tariff $(\pi^*, A^*)$ yields $\bar{c} = F$, $CS = CS^* - F - Tr(\Sigma_{\lambda,b})$, $SW = SW^*$.

The main implication of these results can be seen in Fig. [2]. Without renewables, the Pareto front induced by $(\pi^*, A^*)$ is a straight line with a one-to-one $CS$-$TP$ tradeoff. Clearly, $SW$ is maximized along the Pareto front regardless the value of $F$.

We now consider the case where the retailer has access to a total supply of random renewable energy $r_\xi \in \mathbb{R}^N$ at zero variable cost. We have the following result.

Proposition 2. Consider the case of retailer-owned renewable resources. If $r_\xi \leq D_\xi(\lambda)$, $\forall \xi \in \Xi$, then the day-ahead two-part tariff that solves the regulator’s problem is characterized by a price vector $\pi^* = \lambda$ and a connection charge $A^*$ that recovers $F$ offset by the price-load correlation effect and the value of the random supply ($V^R$),

$$A^*(F) = \frac{F + Tr(\Sigma_{\lambda,b}) - V^R}{M}. \quad (6)$$

Corollary 2. For a fixed $F$, the tariff $(\pi^*, A^*)$ yields $\bar{c} = F$, $CS = CS^* - F - Tr(\Sigma_{\lambda,b}) + V^R$, $SW = SW^* + V^R$.

These results indicate that centralized renewable integrations do not change the structure of the optimal two-part tariff. In fact, only the connection charge is reduced to discount the savings the retailer derives from the random supply. Corollary 2 further reveals that, relative to the no integration case, both $SW$ and $CS$ increase uniformly by $V^R$. Thus, all the value brought by the random supply is credited to consumers through a reduced connection charge. This means the Pareto front is simply shifted rightwards (or equivalently upwards) by $V^R$.

Finally, we consider the regime in which customers have access to some form of renewable generation behind-the-meter. In particular, suppose that each customer $i$ has access to a supply of random renewable energy $r^i_\xi(\xi) \in \mathbb{R}^N$ at zero variable cost. For notational convenience, we let $r_\xi = \sum_{i=1}^M r^i_\xi$ also denote the aggregate renewable supply. We have the following result.

Proposition 3. Consider the case of consumer-owned renewable resources. Under a net-metering setting, if $r_\xi \leq D_\xi(\lambda)$, $\forall \xi \in \Xi$, then the day-ahead two-part tariff that solves the regulator’s problem is given by

$$\pi^c = \lambda, \quad A^c(F) = \frac{F + Tr(\Sigma_{\lambda,b}) - Tr(\Sigma_{\lambda,r})}{M}. \quad (6)$$

Corollary 3. For a fixed $F$, the tariff $(\pi^c, A^c)$ yields $\bar{c} = F$, $CS = CS^* - F - Tr(\Sigma_{\lambda,b}) + V^R$, and $SW = SW^* + V^R$.

Notably, the optimal two-part tariff in this regime is likely to be very close to that of the no integration regime. This is because it may be reasonable to expect $Tr(\Sigma_{\lambda,r})/M$, the difference between the connection charges, to be small. Corollary 3 further indicates that decentralized integrations have the same effect on $CS$ and $SW$ as centralized integrations.
(of the same aggregated magnitude, \( r_\xi \)). Consequently, under two-part tariffs, the Pareto fronts induced by both types of integrations coincide (clearly this is provided the aggregated supplies coincide), as shown in Fig. 2.

These results for two-part tariffs are particularly interesting if put in perspective with those described for linear tariffs. We compare all the resulting Pareto fronts in Fig. 3. While centralized renewable integrations yield increases in \( \text{CS} \) and \( \text{SW} \) for all relevant values of \( F \) under both tariffs, linear and two-parts, the corresponding effect of decentralized renewable integrations differs for both tariffs. In particular, under two-part tariffs the effect is as before whereas under linear tariffs the effect can be undesirable: by installing behind-the-meter renewables customers collectively trigger price increases that introduce endogenous inefficiencies that may be large enough to them make worse-off than without renewables at all.

C. An Numerical Example

We illustrate numerically the outcomes induced by the optimal linear and two-part tariffs using the TCL model developed in [12], [13]. To that end, we use empirical temperatures and wholesale electricity prices from New York City. In particular, we use hourly data spanning the 2014 Summer (June through August) to estimate \( \hat{\theta}, \Sigma_{\theta}, \Sigma_{\lambda,b} \) using sample mean and covariance estimators. For simplicity, we consider the interaction of the regulated retailer with a single customer (\( M = 1 \)).

We compute the level of social welfare, retailer profit, and consumer surplus achieved by the optimal linear and two-part tariffs given a particular retailer fixed cost \( F \), and we plot them in Pareto fronts. We obtain the renewable supply from a simulated solar PV rooftop system and scale it to roughly match the demand function. We use the same renewable supply to compute the Pareto fronts of both integration regimes.

The six resulting Pareto fronts are plotted in Fig. 4. Regarding linear tariffs (solid lines), the curves confirm that decentralized integrations intensify the decreases in consumer surplus and social welfare (efficiency) that linear tariffs induce relative to centralized integrations. To see this note that the Pareto front achieved in the decentralized integration regime under linear tariffs (solid black) branches off the Pareto front of the corresponding centralized integration regime (solid red) towards the origin as \( F \) increases until it intersects the Pareto front of the corresponding no integration regime (solid blue).

Regarding two-part tariffs (dashed lines), the resulting Pareto fronts dominate those induced by linear tariffs as the former always achieve larger levels of social surplus (and consumer surplus) for any given level of retailer profit regardless the type of integration. Because \( M = 1 \), the magnitude of the connection charge as a function of \( F \) follows roughly the expected retailer profit \( \text{Tr}(\Sigma_{\lambda,b}) \) and \( \text{Tr}(\Sigma_{\lambda,r}) \) turn out to be relatively small), so it is in a quite wide range of 0 to 6 $/day. For two-part tariffs, the resulting retail price \( \pi \) averaged across the 24 hours is 35.44 $/MWh for all \( F \) (which matches the average expected wholesale price). This is in contrast to the average retail prices induced by the optimal linear tariffs which range between 35.44 $/MWh and 112.29 $/MWh (for the no integration regime), a markup of up to 217% relative the wholesale price of electricity. The inefficiencies induced by these price markups (relative to \( \text{SW}^\text{r} = 13.87 \) range between 0% for \( F = 0 \) and 16% for \( F = 4.77 \).

IV. Conclusions

Our results indicate that under optimally designed day-ahead two-part tariffs the integration of renewable resources generally improve social welfare regardless their ownership structure (retailer or consumer-owned). These welfare improvements reflect the net value of the renewables, and they are fully captured by consumers.
These desirable welfare effects are not generally achieved by other tariff structures. For example, under optimally designed day-ahead linear tariffs (i.e., a volumetric tariff without connection charges), uncoordinated integrations of renewables behind-the-meter trigger endogenous price increases and consumption reductions that can cause social welfare and consumer surplus to decrease even below the levels achieved before the integrations. Not surprisingly, this effect intensifies as the size of the integrations increases.

Our results can be extended to retailer and consumer-owned integrations of energy storage systems, and also to renewable-plus-storage systems such as those being offered by several solar companies in the US. We address these issues thoroughly in a forthcoming paper [24].

A limitation of our analysis is that our model ignores income heterogeneity and fairness concerns. Arguably the most critical barrier to retail electricity tariff changes are potential welfare redistribution effects between customers with different income levels (see e.g., [17], [25][27]). Also, when consumer heterogeneity is significant, care needs to be taken when designing two-part tariffs as tradeoffs between efficiency and fairness can emerge as some customers may be better off by choosing not to consume power from the grid at all.

REFERENCES


