Demand response: smart market designs for smart consumers (Preliminary, comments welcome)

Nicolas Astier, and Thomas-Olivier Léautier*

May 16, 2016

Abstract

We study Peak-Time-Rebates (PTR) contracts in day-ahead electricity markets. Such contracts reward customers for reducing their consumption when wholesale prices are high. We start by pointing out a structural flaw of these market designs: embedded arbitrage opportunities. Consumers are allowed to buy their baseline power at a constant (state-independent) price while this power is worth more by construction. Under asymmetric information, this incentivizes strategic consumers to inflate their baseline. We then show that if one were to make a PTR design incentive compatible, it would become equivalent to a variable Critical-Peak-Pricing design (vCPP), in which customers have to *purchase* their peak consumption at the spot price. Under asymmetric information, the relevant economic issue is thus to design vCPP contracts optimally in order to achieve high enrollment rates under voluntary opt-in. This problem has different solutions depending on whether policymakers choose to maintain existing cross-subsidies or not. Such solutions may or may not be implementable depending on the retail industry structure.

*Toulouse School of Economics. Emails: nicolas.astier@ut-capitole.fr and thomas.leautier@tse-fr.eu. We are grateful to Claude Crampes, Richard Green, Erin Mansur, Yannick Perez, Jean Tirole and Frank Wolak, as well as participants of the FAEE Paris workshop (Nov. 2014), the Cologne EWI CIES Summer School (Aug. 2015), the Tenth Conference on The Economics of Energy and Climate Change in Toulouse (Sep. 2015), and the ENTER seminar at the SSE (Feb. 2016) for helpful comments. All remaining errors are ours.

1 Introduction

Electricity being economically non-storable on a large scale, supply must equal demand in real-time in order to avoid unvoluntary curtailments of a fraction of consumers, known as blackouts. The challenge is made harder because demand (and to a lesser extent supply) is variable, partly in a stochastic fashion, and only a fraction of supply is dispatchable (non-dispatchability arising from intermittent generation technologies, startup constraints, ramping constraints, etc...).

These features raise two distinct issues: (i) ensuring reliability of supply (Joskow and Tirole, 2006b), and (ii) achieving allocative efficiency (both in the short and long-run). If prices, supply and demand could be adjusted instantaneously, then a system of prices updated in real-time would solve both issues. This is the logic underlying peak-load pricing (Boiteux, 1949).

Since consumption occurs continuously, it would be too costly to bargain over a different price for every single minute. Consequently, most of supply is allocated through one-hour-long blocks, purchased in advance on a day-ahead "spot" market. As a first approximation, such a market allows to meet reasonably well the efficient allocation goal, while reliability is ensured in real-time by system operators through intraday markets and/or balancing mechanisms.

However, the spot market is for bulk purchases only. In the Western Europe Day Ahead market (EPEX DA) for example, the minimal bid allowed is 100 kWh to be delivered during a single hour, while a single household is only able to consume up to a few kWh during that time. Households thus have to buy their power from retailers, who purchase on the spot market the power they sell. Historically, due to the limited functionalities of cost-effective metering technologies, the tariffs proposed by these retailers have usually been (two-part) flat full-requirements: consumers pay a subscription fee, and can consume as much electricity as they want at any time for a fixed per-kWh price, up to their meter's size. Of course, such tariffs perform poorly regarding allocative efficiency since consumers receive no signal of the real-time opportunity cost of supply.

Today, more sophisticated metering technologies are available, and have been or are about to be rolled out in many countries (Joint Research Center, 2014). More complex tariff structures will then become implementable. As a result, numerous practitioners' and academics' studies have been conducted over the last decade in order to investigate retail consumers' response to different tariffs (see Borenstein (2005) for an example of simulation, Wolak (2010) and Allcott (2011) for examples of field experiments, and Faruqui and Sergici (2010) and Newsham and Bowker (2010) for academic reviews). These tariffs usually fall into one of the following categories:

- **Real-Time Pricing** (RTP): a direct transmission of the spot market price to consumers. A different price is set for each hour and communicated to consumers on a day-ahead basis.
- **Time-of-Use** (TOU): a handful of time periods are defined and a different per-kWh price is set for each period. Periods' span and price are *fixed ex ante*. Such a tariff can thus only accomodate variations that are predictible well in advance.
- **Critical-Peak-Pricing** (CPP), also called "passive demand response": a default constant price is set for all days but a limited number of days per year, chosen *ex post*, during which the per-unit price increases significantly. The 'peak price' is typically fixed at the signature of the contract. Alternatively, peak prices may also be state-dependent and computed *after* the contract is signed, such a design being called *variable* CPP (vCPP).
- **Peak-Time-Rebates** (PTR), also called "active demand response": customers are paid if they decrease their consumption (relative to a counterfactual called *baseline* which has to be computed in some way). In a sense, consumers thus *resell* electricity.

Reviews of dynamic pricing field experiments (Faruqui and Sergici, 2010; Newsham and Bowker, 2010) suggest that PTR may be less effective in reducing peak demand than CPP[1]. Consumers may react more to CPP because they are loss averse, or react less to PTR because this design perfectly

[1]For example Newsham and Bowker (2010) note: '*the data we do have suggests PTR is less effective than CPP*'.

insures them against a bill increase (Fenrick et al., 2014). However, such concerns are likely to be less relevant when 'resale' is handled by a third party, and not directly by consumers. Finally, simplistic methods to establish baselines may also decrease the magnitude of consumers' response due to the asymmetry in provided incentives (customers have no incentive to respond if their baseline is too low), and may reward random shocks in consumption (Ito, 2013), decreasing the cost-effectiveness of PTR programs. This latter point is similar to an issue encountered a couple decades ago for energy efficiency subsidies (Joskow and Marron, 1992).

Nevertheless, PTR programs are very popular both in the US and in Europe[2]. So far, they have triggered two main debates in the literature. First, economists fiercely denounced an important flaw in initial designs. Indeed early implementations of PTR allowed consumers to resell power at the spot price. However, since the underlying default retail contract is *not* a forward purchase, economists pointed out that consumers had first to purchase the power they resell (Chao, 2010; Hogan, 2010; Crampes and Léautier, 2012). This has led to vigorous debates and litigation in the US (see Chen and Kleit (2016) for a summary of the legal debate up to early 2016). Second, since the counterfactual consumption ('what would have happened if the customer would have consumed *as usual*?') is not observed, some methods have been and are being developed to estimate it (Grimm, 2008; Newsham et al., 2011).

Baseline estimation also raises an economic issue due to potential *asymmetric information*. Customers are indeed likely to be better informed than their retailer about their future consumption, at least on some dimensions. Since they know how their baseline is computed, they may try to influence its calculation, as has been observed in Wolak (2007); Chen and Kleit (2016), or in the now famous example of Baltimore's stadium (FERC, 2013). Chao and DePillis (2013) recently formalized this issue for the methods currently used to compute baselines, explaining on these examples why consumers have both the ability and incentives to inflate their baseline. Their observations constitute the initial motivation of the present article, in which we

[2] In France, a specific PTR market design, the so-called NEBEF ('Notification d'Echange de Blocs d'EFacement') market design, in which consumers (or more precisely a third-party acting on their behalf) can resell electricity on the Day-Ahead spot market has been implemented full-scale.

generalize their results.

Two approaches could be contemplated to tackle asymmetric information. The first one is to develop methods to decrease the magnitude of information asymmetry (for example enhanced statistical analysis to compute baselines, or fraud detection algorithms). Since participants learn over time about the mechanism's flaws (Chen and Kleit, 2016), this may be an endless route. The second one is to acknowledge this problem may be never completely solved for some categories of consumers, and design contracts that explicitly take into account asymmetric information, as do Crampes and Léautier (2015) for balancing markets.

This paper chooses the second approach. We start by investigating what a socially optimal Incentive Compatible (IC) PTR contract looks like. We show that the current designs allow consumers to arbitrage between spot prices and the constant state-independent price at which they are allowed to buy baseline electricity, compromising incentive compatibility. Baseline electricity should instead be contracted forward at its (expected) spot price. This modification ensures incentive compatibility, by removing the implicit subsidy given to consumers under PTR contracts. An IC PTR design then boils down to a variable CPP (vCPP) design (assuming consumers are risk-neutral). The latter is much easier to implement, and solves most of the issues mentioned in the literature review. Under asymmetric information, the relevant economic issue is thus to design vCPP contracts optimally in order to achieve high enrollment rates under voluntary opt-in. The solution to this problem crucially depends on whether policymakers decide to maintain cross-subsidies to the historical tariff or not. If cross-subsidies are maintained using public funds, entrant retailers offering DR tariffs will not internalize the social cost of subsidies, implying more imperfect competition may sometimes increase net surplus. Perfect competition may not yield the second-best outcome, contrary to benevolent monopoly retailer pricing, unless appropriate corrective measures are taken. If on the contrary non-switchers receive no subsidies, full-enrollment to RTP is the natural outcome of both perfect competition and benevolent monopoly pricing, although the latter environment may be more easily subject to exogenous constraints preventing to reach such an outcome.

The rest of the paper is organized as follows. Section 2 presents the analytical framework and derives the socially optimal IC PTR contract. Section 3 investigates consumers' opt-in choices when cross-subsidies to non-switchers are either maintained or forbidden. Finally Section 4 concludes.

2 Incentive compatible resale contracts

2.1 Analytical framework

We build on the partial equilibrium model developed by Spulber (1992), and focus on a single class of consumers, defined by common contractable observable characteristics (eg. residential, commercial, etc...). Risk-neutral customers are characterized by a one-dimensional type $\theta \in \left[\underline{\theta}, \overline{\theta}\right]$ (with pdf $g(.)$ and cdf $G(.)$), which is their residual private information (eg. their price-elasticity). Demand varies across months of the year, days of the week, and hours of the day. These states of the world are represented by t. Consumer θ's gross utility from consuming a quantity q of electricity in state t is $U(q, \theta, t)$ (intertemporal substitution is ignored, but could be added to the model at the cost of much more complicated notations). Her marginal utility is $u(q, \theta, t) \equiv \partial_q U(q, \theta, t)$ where $u(q, \theta, t) > 0$ and $\partial_q u(q, \theta, t) < 0$. Individual demand $q(p, \theta, t)$ is implicitly defined by $u(q(p, \theta, t), \theta, t) \equiv p$.

As will be shown below, we do not need to assume a single crossing property. Although we will use tools from the mechanism design literature, we are actually facing a simple asset pricing problem. The one-dimensional private information is thus not really restrictive.

The wholesale price $p(t)$ is assumed to be exogeneous and to represent the social cost of power in state t. The socially optimal level of consumption in state t is $q^*(\theta, t) \equiv q(p(t), \theta, t)$. Finally, we will use the following notations throughout the paper:

- For a given price p, $V(p, \theta, t) \equiv U(q(p, \theta, t), \theta, t) - pq(p, \theta, t)$ is the (variable) consumer's net surplus in state t when facing the price p.
- For a given price p, $W(p, \theta, t) \equiv U(q(p, \theta, t), \theta, t) - p(t)q(p, \theta, t) = V(p, \theta, t) + (p - p(t))q(p, \theta, t)$ is the net social surplus from consumption

when the price is p.

The basic model assumes there is no uncertainty left once the spot price $p(t)$ is known, as in Schweppe et al. (1988) (consumers' utility does not depend on any stochastic variable other than t), that is intraday stochasticity is assumed negligible. This assumption is relaxed in subsection 2.4.

Depending on how the baseline is computed, misreporting may be either free (eg. a household 'reselling' power when spending a scheduled afternoon at the park) or costly (eg. inflating one's baseline by increasing historical consumption (Chao and DePillis, 2013)). The former case involves adverse selection, while the latter involves moral hazard. Although we focus on adverse selection in this paper, moral hazard can be easily incorporated by adding a 'cost of cheating' function to the model.

2.2 "Stand-alone" contract

We first abstract from the current implementations of PTR. Instead, we compute the optimal IC contract when *the only constraint is that consumers are allowed to resell (but not buy) power on the spot market*, and not consuming electricity at all is their only outside option. While not realistic, this case illustrates the underlying economics. By the revelation principle, we focus on direct revelation mechanisms.

Mechanism:

1. The retailer proposes a menu $\{T(.),\, t \to \bar{q}(., t)\}_\theta$ before the state of the world t is known (commitment on a method to establish a maximum allocation).

2. Consumer reports $\hat{\theta}$ and pays $T(\hat{\theta})$ to the retailer (risk-neutrality implies that state-independent transfers can be considered without loss of generality). She gets the right to consume up to $\bar{q}(\hat{\theta}, t)$ in state t.

3. The state of the world t is revealed

4. The customer consumes $q \leq \bar{q}(\hat{\theta}, t)$ and sells back $(\bar{q}(\hat{\theta}, t) - q)$ at the spot price $p(t)$.

Note that we assume neither the maximum allocations nor the transfers are contingent on quantities *actually* consumed later on (the $q(p(t), \theta, .)$s), or more generally on information learnt *ex post*. Otherwise, information learnt *ex post* may remove asymmetric information completely (for example, in the extreme situation where the classic single-crossing assumption holds, there is a one-to-one mapping between θ and $q(p(t), \theta, t)$). In practice though, retailers are likely to face legal restrictions in making the contract explicitly contingent on the realized consumption (notably if resale is handled by a third party), and the single-crossing property is unlikely to hold given the wide variability in individual consumption patterns (θ can thus be thought as the residual uncertainty that cannot be learnt, and remains private information at the time the baseline is set). In our simplified framework, the necessary conditions for a mechanism to be IC and yield a socially optimal allocation are then summarized below:

Proposition 1 *("Stand-alone" contract)*
An IC socially optimal mechanism in which the lowest type gets the surplus she would get under RTP is such that:

1. *For almost all (θ, t), the maximum allocation exceeds the optimal consumption: $\bar{q}(\theta, t) \geq q^*(\theta, t)$*
2. *The transfer is the expected value of the maximum allocation: $T(\theta) = \mathbb{E}_t [p(t)\bar{q}(\theta, t)]$*

Proof. See Appendix A.1. ■

The obtained optimal IC mechanim boils down to the consumers purchasing their maximum allocation forward. The inequality $\bar{q} \geq q^*$ is due to the assumption that consumers can neither consume more than their maximum allocation, nor buy power on the spot market. In states of the world where the spot price is low, customers increasing their consumption would increase net surplus. In this model however, this is not possible if customers already consume their entire allocation. Hence, a high enough allocation is necessary if we want to avoid off-peak underconsumption.

Risk neutrality implies that consumers are indifferent between all contracts that give them a high enough allocation. As shown in Appendix B, some risk-aversion could be added to design a tie-breaking rule.

2.3 Actual PTR implementation

Current PTR implementations face an additional constraint that was ignored so far: consumers still have access to their historical full-requirements contract, assumed to be a two-part tariff with a fixed fee A and a constant per-unit price p^R. Consumers can thus draw any amount of power up to their meter size at a *fixed* price. Hence real-life implementation has two additional features:

1. Any kWh a customer consumes or sells back *has to be purchased at the constant price* p^R.

2. Participation to the PTR program must be voluntary.

We focus for now on the first point, assuming that enrollment to the PTR program is mandatory.

2.3.1 Constrained optimal contract (with mandatory opt-in)

Assuming that consumers have no choice but to opt-in in step 1, we investigate the following constrained mechanism:

Mechanism:

1. The retailer proposes a menu $\{T(.),\, t \to \tilde{q}(.,t)\}_\theta$ before the state of the world t is known (commitment on a method to establish the baseline).

2. Consumer reports $\hat{\theta}$ and pays $T(\hat{\theta})$ to the retailer. She gets allocated a state-dependent baseline $t \to \tilde{q}(\hat{\theta}, t)$.

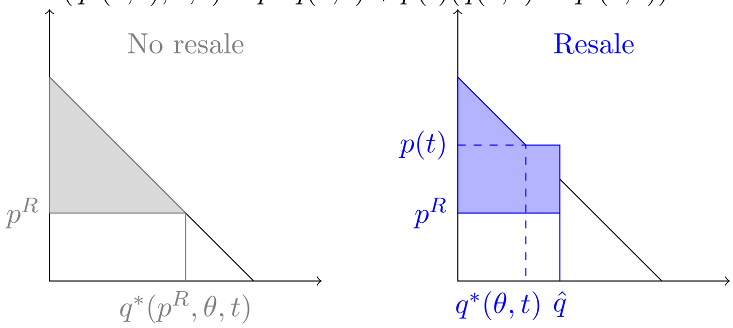
3. The state of the world t is revealed.

4. The customer can consume whatever quantity q she wants (possibly more than her baseline), and resell $(\tilde{q}(\theta,t) - q)^+$ at the spot price $p(t)$.

5. She pays $p^R\tilde{q}(\hat{\theta},t)$ if she resells, $p^R q$ is she does not.

We denote $\hat{q}(\theta, t)$ the threshold baseline quantity such that, in a given state t, a type θ customer is indifferent (in step 4) between consuming as usual or consuming less and selling back the rest of her baseline.
$\hat{q}(\theta, t) \in \left[q^*(\theta,t), q(p^R,\theta,t)\right]$ is uniquely defined by:

$$U(q(p^R,\theta,t),\theta,t) - p^R q(p^R,\theta,t) \equiv$$
$$U(q^*(\theta,t),\theta,t) - p^R \hat{q}(\theta,t) + p(t)(\hat{q}(\theta,t) - q^*(\theta,t))^+$$



On the above drawing, $\hat{q}(\theta,t)$ is the value of $\hat{q}$ such that the grey and blue areas are equal. We can now derive the optimal IC contract:

Proposition 2 *(Constrained IC optimal mechanism)*
An IC (constrained) optimal mechanism is such that (up to a common constant term in transfers):

1. *For almost all* (θ,t), $\tilde{q}(\theta,t) \geq \hat{q}(\theta,t)$ *when* $p(t) > p^R$.
2. $$\begin{aligned} T(\theta) &= \mathbb{E}_t\left[(p(t)-p^R)\tilde{q}(\theta,t)\mathbf{1}_{p(t)>p^R}\right] \\ &= \Pr\left[p(t)>p^R\right] \times \mathbb{E}_t\left[(p(t)-p^R)\tilde{q}(\theta,t)\,|\,p(t)>p^R\right] \end{aligned}$$

Proof. See Appendix A.2. ■

Proposition 2 echoes Proposition 1: in an IC mechanism, consumers have to buy their baseline forward. Socially inefficient underconsumption still occurs off-peak, when $p(t) < p^R$. As observed by Chao and DePillis (2013), making PTR contracts incentive compatible suppose to contract forward on the baseline. By contrast, even the method 'fixed proportion of an aggregate baseline' (computing the baseline by averaging consumption patterns of similar consumers) does not fully solve the problem. Although it removes the moral hazard problem (assuming no third-party helps consumers to coordinate), it remains sensitive to adverse selection, harming the cost-efficiency of PTR demand response programs.

To ensure incentive compatibility, *consumers have to pay a premium for the baseline power they resell because, on average, baseline power is known* *to be worth more than* p^R (as it is sold back *only* if $p(t) > p^R$).

Current implementations set $T(\theta) = 0$, implying they are not IC. Consumers are incentivized to over report as soon as they expect the spot price to be higher than p^R. Loosely speaking, we allow consumers to buy at the average price electricity *known* to be worth the average *peak* price, implicitly subsidizing resale.

In our setting risk neutrality implies that consumers gaming the tariff choose the highest baseline possible. If cheating is more likely to involve moral hazard rather than adverse selection (for example if consumers must overconsume during periods where the baseline is computed), one may introduce a convex cost of lying function[3]. Consumers' reported baseline will then be the inflated level at which the marginal costs and benefits of lying are equal (the higher the expected spot price, the more consumers will cheat). Perhaps not surprisingly, it turns out that preventing cheating essentially boils down to implementing a vCPP tariff:

Corollary 2.1 *(Equivalence IC PTR / vCPP)*
The obtained IC PTR contract is equivalent to a vCPP contract.

Proof.

The following table reports the different cashflows under an IC PTR design, and under a variable Critical-Peak-Pricing (vCPP) design in which all states-of-the-world such that $p(t) > p^R$ are 'event periods', and the 'event period price' is the spot price $p(t)$:

[3]For example EnerNoc (2009) notes: '*A longer baseline window acts to prevent gaming such that the cost of active manipulation to elevate baseline levels outweighs the benefit as the consumer's utility bills would quickly increase due to increased consumption and potentially higher demand charges*'.

	IC PTR	vCPP
Fixed fee	A	A
Baseline subscription	Gets allocated a state-contingent profile $\bar{q}(\theta,t) \geq \hat{q}(\theta,t)$ Pays $\mathbb{E}_t\left[(p(t)-p^R)\bar{q}(\theta,t)\mathbf{1}_{p(t)>p^R}\right]$	None
Non-event days ($p(t) \leq p^R$)	Consumes $q(p^R,\theta,t)$ Pays $p^R q(p^R,\theta,t)$	Consumes $q(p^R,\theta,t)$ Pays $p^R q(p^R,\theta,t)$
Event days ($p(t) > p^R$)	Consumes $q^*(\theta,t)$ Pays $p^R\bar{q}(\theta,t)$ Resells $\bar{q}(\theta,t)-q^*(\theta,t)$ Gets $p(t)(\bar{q}(\theta,t)-q^*(\theta,t))$	Consumes $q^*(\theta,t)$ Pays $p(t)q^*(\theta,t)$
Total expected payment	$A+\mathbb{E}_t\left[p^R q(p^R,\theta,t)\mathbf{1}_{p(t)\leq p^R}\right.$ $\left.p(t)q^*(\theta,t)\mathbf{1}_{p(t)>p^R}\right]$	$A+\mathbb{E}_t\left[p^R q(p^R,\theta,t)\mathbf{1}_{p(t)\leq p^R}\right.$ $\left.p(t)q^*(\theta,t)\mathbf{1}_{p(t)>p^R}\right]$

Thus, if one were to make a PTR design incentive compatible, it would become equivalent to a vCPP design, which is much easier to implement. However, the IC PTR approach may be seen as a better implementation of the allocation reached under vCPP due to some non-rational aspects of consumers' choices, as suggested in Letzler (2010).

■

Making PTR contracts IC, and thus implementing an offer isomorphic to vCPP, raises the question of whether consumers will still voluntarily opt-in such a tariff. We saw that, under asymmetric information, consumers should pay an additional fee in order to prevent cheating. If this transfer is merely added to existing PTR implementations, it will end up deterring adoption:

Corollary 2.2 *(No enrollment into simple IC PTR)*
Under the previous choice of constant for the transfers, if an IC PTR option is just added on top of the existing full-requirements contract, no consumer will voluntarily enroll in the PTR program.

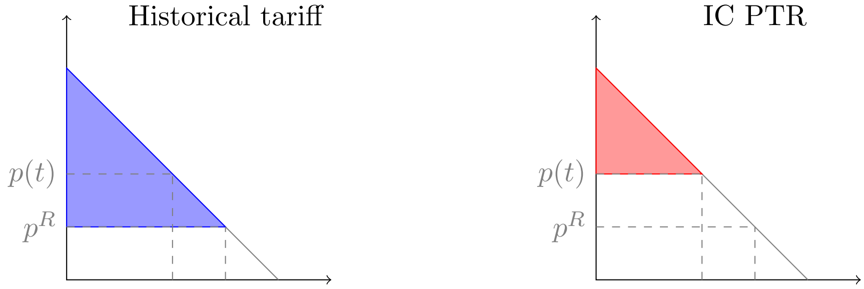
Proof. Under the pre-existing full-requirements contract (FR), type θ consumers get an expected net utility $\mathbb{E}_t\left[V(p^R,\theta,t)\right]-A$. If they enrolled in the IC PTR program, they would instead derive a net utility:

$$\mathbb{E}_t\left[V(p^R,\theta,t)\mathbf{1}_{p(t)\leq p^R}+V(p(t),\theta,t)\mathbf{1}_{p(t)>p^R}\right]-A$$

The difference Δ_{FR-PTR} between the two is then equal to:

$$\Delta_{FR-PTR} = \mathbb{E}_t \left[\left\{ V(p^R, \theta, t) - V(p(t), \theta, t) \right\} \mathbf{1}_{p(t) > p^R} \right] > 0$$

Thus consumers strictly prefer not to enroll in the PTR program. The result is obvious graphically. Indeed, while the off-peak rate is unchanged under IC PTR, on-peak the consumer's surplus is reduced:



On-peak consumer's surplus

■

The previous result is not surprising: an IC PTR contract requires that consumers pay a higher price for their peak electricity, while they pay the same price as before for their off-peak power. No rational consumer will take such a deal. This result may appear discouraging: either policy-makers allow customers to receive subsidies and arbitrage the market, or no one will enroll in PTR programs.

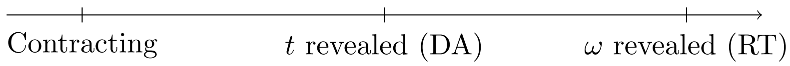
In fact this impossibility result is partly an *artefact* of the arbitrary choice of constant we made regarding the transfer $T(\theta)$. Since an IC PTR design does improve the allocative efficiency compared to the historical tariff, some surplus is created. Hence retailers should be able to get at least some consumers on board by sharing this created surplus with them. This is what we investigate in Section 3. Before, we shortly discuss how our analysis can be extended to intraday stochasticity.

2.4 Intraday stochasticity

In practice, electricity markets are multi-settlement markets since some significant uncertainty often remains regarding demand and supply even after the DA spot price is set[4]. Let ω be a stochastic variable representing the

[4]We are grateful to Frank Wolak for suggesting this extension of our base model.

residual uncertainty between day-ahead (DA) and real-time (RT). The timing of events is thus:



A state of the world is now a pair (t, ω) and one can define:

- Consumer θ's real-time demand: $q^{RT}(p, \theta, t, \omega) = q(p, \theta, t) + \delta q(p, \theta, t, \omega)$
- The real-time social cost of power: $p^{RT}(t, \omega) = p(t) + \delta p(t, \omega)$

While forming the RT social cost of power, all individual demand shocks will tend to compensate each other, meaning we expect $p^{RT}(t, \omega) \simeq p(t)$. In some markets, specific trading mechanisms are in place to make sure this convergence happens (see for example Jha and Wolak (2015) for California). In others, penalties for real-time imbalances are based on the DA spot price (for example in France). Hence we assume for simplicity that the term δp can be neglected.

Similarly as before, let $\hat{q}(\theta, t, \omega)$ be the threshold baseline quantity such that, in a given state (t, ω), a type θ customer is indifferent between consuming as usual or consuming less and selling back the rest of her baseline. This quantity is defined by:

$$U(q^{RT}(p^R, \theta, t, \omega), \theta, t, \omega) - p^R q^{RT}(p^R, \theta, t, \omega) \equiv$$
$$U(q^*(\theta, t, \omega), \theta, t, \omega) - p^R \hat{q}(\theta, t, \omega) + p(t)(\hat{q}(\theta, t, \omega) - q^*(\theta, t, \omega))^+$$

Consistently with current practices, we assume the baseline is computed on a DA basis, and thus cannot be made contingent on ω. We then have:

Proposition 3 *(IC PTR with intraday stochasticity)*
The IC PTR mechanism previously described remains socially optimal provided that:

$$\tilde{q}(\theta, t) \geq \max_{\omega} \hat{q}(\theta, t, \omega)$$

However, even under symmetric information, an additional issue arises under current PTR mechanisms:

Proposition 4 *(current PTR under symmetric information with intraday stochasticity)*
Under symmetric information, the mispricing of the baseline under current PTR mechanisms creates another inefficiency due to intraday stochasticity:

- *Retailers most likely incur a deficit when a non-IC PTR mechanism is implemented (because of the rewards granted to idiosyncratic negative shocks in consumers' demand).*
- *If the baseline is decreased so as to maintain retailers' budget balance, allocative inefficiencies arise (because asymmetric incentives makes consumers inelastic when they incur a big enough idiosyncratric positive demand shock).*

Proof. Propositions 3 and 4 are proved in Appendix A.3. ■

Hence, requiring consumers to contract their baseline at its right price also allows to remove the rewards given to idiosyncratic negative shocks in consumers' demand. However, if consumers' demand is highly volatile on the short-run (w.r.t. ω), the minimum optimal baseline $\max_{\omega} \hat{q}(\theta, t, \omega)$ may end up being pretty high[5]. If one then contracts on a lower baseline in order to decrease the upfront cost, some allocative losses then occur due to the asymmetry in incentives (consumers do not face the spot price if they incur a high positive demand shock). A tariff with symmetric incentives as proposed in Wolak (2011) would then have better allocative properties.

In what follows, we focus on IC PTR contracts, which allows us to ignore these potential complications brought by intraday stochasticity.

[5]However, such a problem may not be significant in practice. First, the baseline level is capped by the size of the consumer's meter. Second, PTR will most likely be called for a limited number of hours per month, at the time of system peak. Finally, there exists tarification systems, such as prepay (EPRI, 2010), that are popular among consumers despite the existence of an upfront fee.

3 IC PTR and opt-in

3.1 Context

Due to political constraints, transition towards dynamic pricing will proceed on an opt-in basis[6]. Consequently, we now investigate under which conditions rational consumers having the outside option of keeping their historical tariff will voluntarily adopt an IC PTR tariff. We focus on first-order incentives to adopt, and leave potential frictions such as consumers' switching costs, risk-aversion or imperfect information for further research.

IC PTR tariffs descrided in Section 2 provide two instruments retailers can use to encourage consumers to switch (Corollary 2.1). First, retailers can set a lower fixed fee B (if $B < A$, consumers receive a fixed subsidy $A - B$ to opt-in the IC PTR contract). Second, they can set a lower off-peak price $\underline{p} < p^R$ for the IC PTR tariff.

For simplicity, we focus on the first instrument and assume from now on that the DR contracts offered by entrants are RTP contracts with a fixed fee B. We denote $\Delta(p^R, A, B, \theta)$ the difference between a type θ consumer's surplus under the IC PTR offer and under the historical tariff. Formally:

$$\Delta(p^R, A, B, \theta) \equiv A - B + \mathbb{E}_t \left[V(p(t), \theta, t) - V(p^R, \theta, t) \right]$$

We will often use the simplified notation $\Delta(\theta)$ instead of $\Delta(p^R, A, B, \theta)$. A type θ consumer then switches to IC PTR if, and only if, $\Delta(\theta) > 0$.

We show in Appendix C that restricting analysis to this class of contracts induces no loss of generality in the context of a local monopoly retailer introducing an IC PTR contract whenever the population of consumers is such that marginal switchers always have a higher off-peak consumption than infra-marginal switchers when facing an IC PTR tariff, that is:

$$\mathbb{E}_t \left[q(\underline{p}, \theta, t) \,|\, p(t) \le \underline{p}, \Delta(\theta) = 0 \right] \ge \mathbb{E}_{\theta t} \left[q(\underline{p}, \theta, t) \,|\, p(t) \le \underline{p},\, \Delta(\theta) > 0 \right] \text{ for all } \underline{p}$$

[6]For example, Alexander (2010) reports that in the US '*national consumer organizations, such as AARP, and the National Association of State Utility Consumer Advocates (NASUCA) have adopted policies that oppose mandatory dynamic pricing, but who support cost-effective demand response programs based on voluntary participation by residential customers*'.

Appendix C also discusses other pricing strategies a local monopoly retailer may use, notably second degree price discrimination. Regarding the case where retail is handled by competitive private companies, restricting contracts to RTP with a fixed fee makes the problem tractable, competition in contracts being beyond the scope of this paper.

Consumers' self-selection into IC PTR will not be random: consumers are more likely to opt-in if they have a high price-elasticity and if most of their consumption happens off-peak. In equilibrium, the parameters of both tariffs must accomodate this selection bias.

However, a massive switch towards more dynamic tariffs would generate significant wealth transfers, and as such is likely to be lobbied against: '*the fear of large redistributions across customers is possibly the largest impediment to further adoption of dynamic pricing*' (Joskow and Wolfram, 2012)[7].

In order to take this '*intense lobbying against the loss of historical cross-subsidies*' scenario into account, we will consider two polar political choices:

1. **Maintained cross-subsidies:** policymakers decide the historical tariff (A, p^R) should remain equal to its value before the introduction of the IC PTR contracts, subsidizing non-switchers if necessary.

2. **No subsidies to non-switchers:** the historical tariff is modified dynamically to account for the selection bias mentioned above, so that the population of consumers staying on the historical tariff covers their supply costs.

For both scenarios, we will study the equilibrium reached under different industry structures: (im)perfect competition and (benevolent) local monopoly. We will illustrate our results with the following example:

- θ and t are uniformly distributed on $[0, 1]$.

- For some fixed positive parameters $(a, b, p_0, \epsilon, \eta)$:

$$q(p, \theta, t) = \frac{(1+\theta)}{b}(p_0 - p + at) \text{ and } p(t) = \epsilon p_0 + \eta\left(t - \frac{1}{2}\right)$$

[7]Borenstein (2007) showed on an example that removing existing cross-subsidies may indeed create some significant wealth transfers.

As explained in Appendix C, we assume that $a > \frac{\eta}{2}$ so that there is no loss of generality in studying a RTP tariff with a fixed fee (instead of a more general $(B, \underline{p})$ tariff) in the local monopoly retailer environment.

3.2 Maintained cross-subsidies to non-switchers

We begin with the first polar case in which the outside option tariff (A, p^R) is frozen at its value before the introduction of optional DR tariffs. Historical cross-subsidies to non-switchers are maintained using public funds. We denote λ the opportunity cost of public funds, arising from the allocative losses induced by inefficient taxation ($\lambda = 0$ means public subsidies are free).

3.2.1 Benchmark: optimal historical tariff

Assuming full-enrollment (which is a good approximation for electricity in developed countries), the historical tariff (A, p^R) can be assumed to solve the following Ramsey-Boiteux problem as in Joskow and Tirole (2006a):

$$\max_{A,p^R} \mathbb{E}_{\theta t}\left[V(p^R,\theta,t)\right] - A$$
$$\text{s.t.}$$
$$\mathbb{E}_{\theta t}\left[(p^R - p(t))q(p^R,\theta,t)\right] - A \geq 0$$

which yields the following formulas:

$$p^R = \frac{\mathbb{E}_{\theta t}\left[p(t)\partial_p q(p^R,\theta,t)\right]}{\mathbb{E}_{\theta t}\left[\partial_p q(p^R,\theta,t)\right]} \text{ and } A = -\mathbb{E}_{\theta t}\left[(p^R - p(t))q(p^R,\theta,t)\right]$$

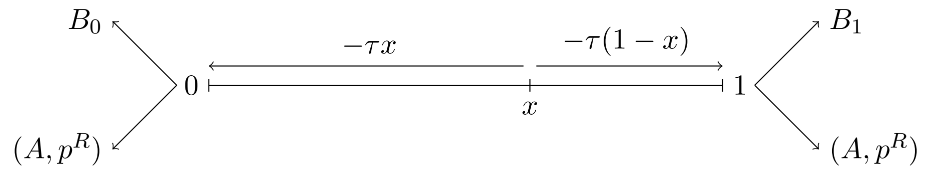
In our illustrative example, we get:

$$p^R = \epsilon p_0 \text{ and } A = \frac{a\eta}{8b}$$

3.2.2 Competitive environment

A model of imperfect competition:

In situations where retail has been liberalized, imperfect competition is likely to prevail (Salies and Waddams Price, 2004). To take this fact into account, we use the modified Hotelling model proposed by Bénabou and Tirole (2016). Consumers now have a bidimensional type (θ, x), where θ is the same parameter as before and x is the location of a consumer on the Hotelling line. To keep things simple, we assume θ and x are *independently* distributed, and x is uniformly distributed on $[0, 1]$. The 'transportation cost' is denoted $\tau \in [0, +\infty[$, and measures *only* the level of differentiation between two entrant retailers located at $x = 0$ and $x = 1$. Consumers are assumed to have to 'go and grab' their outside option (see timing below), offered by the historical retailer (the historical either do not offer two-part RTP, or is one of the two competing retailers but the losses incurred while supplying the historical segment are covered by public subsidies).



Consumers now have to choose among four options, from which they get the following surpluses:

- DR tariff from entrant 0 (DR0): $\mathbb{E}_t [V(p(t), \theta, t)] - B_0 - \tau x$
- DR tariff from entrant 1 (DR1): $\mathbb{E}_t [V(p(t), \theta, t)] - B_1 - \tau(1 - x)$
- Historical tariff at 0 (H0): $\mathbb{E}_t \left[V(p^R, \theta, t)\right] - A - \tau x$
- Historical tariff at 1 (H1): $\mathbb{E}_t \left[V(p^R, \theta, t)\right] - A - \tau(1 - x)$

We assume the following timing:

1. Retailers set (B_0, B_1) simultaneously.
2. Consumers choose their preferred offer i among the two retailers (ignoring outside options). They walk towards the end of the Hotelling line where their preferred DR contract lies.
3. Once they arrived at i, consumers choose between the offer of retailer i and the outside option at i.

Consequently, a consumer (θ, x) chooses[8]:

- DR0 if $x < \frac{1}{2} + \frac{B_1 - B_0}{2\tau}$ and $\Delta(\theta, B_0) > 0$
- H0 if $x < \frac{1}{2} + \frac{B_1 - B_0}{2\tau}$ and $\Delta(\theta, B_0) < 0$.
- DR1 if $x > \frac{1}{2} + \frac{B_1 - B_0}{2\tau}$ and $\Delta(\theta, B_1) > 0$

[8]We ignore tie-breaking rules, assuming no atoms in distributions.

- H1 if $x > \frac{1}{2} + \frac{B_1 - B_0}{2\tau}$ and $\Delta(\theta, B_1) < 0$.

The profit function of retailer 0 is then:

$$\Pi_0(B_0|B_1) = \underbrace{B_0}_{\text{Per cons. profit}} \times \underbrace{\left(\frac{1}{2} + \frac{B_1 - B_0}{2\tau}\right)}_{\text{`x market share'}} \times \underbrace{\mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B_0)>0}\right]}_{\text{`}\theta\text{ market share'}}$$

We further make the assumption that a 'cut-off type' function $\Theta(.)$ can be defined *globally*, such that *for all* (θ, B):

$$\Delta(\theta, B) > 0 \iff \theta \leq \Theta(B)$$

Relaxing this simplification requires significantly more complex notations, without providing much additional economic insight. Indeed, when differentiating the term $\mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B_0)>0}\right]$ w.r.t. B_0, one must then consider *each* $(\hat{\theta}_i, \hat{B}_i)$ such that $\Delta(\hat{\theta}_i, \hat{B}_i) = 0$, and use the implicit function theorem to define *locally* a threshold function $\Theta_i(B)$ such that, in a *neighborhood* of $(\hat{\theta}_i, \hat{B}_i)$:

$$\Delta(\theta, B) = 0 \iff \Theta_i(B) = \theta \text{ where } \Theta_i'(\hat{B}_i) = -\frac{\partial_B \Delta(\hat{\theta}_i, \hat{B}_i)}{\partial_\theta \Delta(\hat{\theta}_i, \hat{B}_i)}.$$

The previous assumption is for example met in our illustrative example since we have:

$$\Delta(\theta, B) = \frac{\eta(a+\eta)}{24b} - B + \frac{\eta - 2a}{24b}\eta\theta$$

which allows to define $\Theta(.)$ as:

$$\Theta(B) = \begin{cases} 0 & \text{if } B > \frac{\eta}{24b}(a+\eta) \\ 1 & \text{if } B < \frac{\eta}{24b}(2\eta - a) \\ \frac{\eta(a+\eta) - 24bB}{\eta(2a-\eta)} & \text{otherwise} \end{cases}$$

Using our simplification, one can rewrite retailer 0's profit function as:

$$\Pi_0(B_0|B_1) = B_0\left(\tfrac{1}{2} + \tfrac{B_1 - B_0}{2\tau}\right) G(\Theta(B_0))$$

where $G(.)$ is the cdf of θ.

Proposition 5 *(Equilibrium Fixed-Fee)*
When a symmetric equilibrium exists, the equilibrium fixed fee B^* set by entrant retailers is such that (for an interior solution):

$$B^* = \tau(1 - \eta_\theta(B^*))$$

where $\eta_\theta(B) = -\frac{B\Theta'(B)g(\Theta(B))}{G(\Theta(B))}$ *the elasticity of the demand* $G(\Theta(.))$ *on the 'θ market' (i.e. choice between historical tariff vs. RTP).*

Proof. The first-order condition (for an interior solution) writes down:

$$\left(\frac{1}{2} + \frac{B_1 - B_0}{2\tau}\right) G(\Theta(B_0)) + B_0 \left(\frac{1}{2} + \frac{B_1 - B_0}{2\tau}\right) \Theta'(B_0) g(\Theta(B_0)) - \frac{B_0}{2\tau} G(\Theta(B_0)) = 0$$

Which can be rewritten:

$$(\tau + B_1 - 2B_0) - (\tau + B_1 - B_0)\,\eta_\theta(B_0) = 0$$

At a symmetric equilibrium, $B_0 = B_1 = B^*$ which yields the above formula.

If one denotes $B_1 \mapsto r_0(B_1)$ the reaction function of retailer 0 we get at a symmetric equilibrium:

$$r_0'(B^*) = \frac{1 - \eta_\theta(B^*)}{1 - \eta_\theta(B^*) + 1 + \tau\eta_\theta'(B^*)}$$

For a reasonable behavior of demand elasticity (namely $\eta_\theta < 1$ and $\eta_\theta' > -\frac{1}{\tau}$), we have $0 < r_0'(B^*) < 1$, which ensures stability. ■

When the 'θ demand' is inelastic ($\eta_\theta = 0$), we retrieve the classic Hotelling model's outcome when the market is fully covered: $B^* = \tau$ [9].

In our illustrative example, we obtain for an interior solution[10]:

$$B^*(\tau) = \frac{\eta(a+\eta)}{48b} + \tau - \sqrt{\left(\frac{\eta(a+\eta)}{48b}\right)^2 + \tau^2}$$

As expected, we get $B^* = 0$ when $\tau = 0$. When $\tau >> 1$, one can write:

[9] More generally, the formula of Proposition 5 is an application of a more familiar-looking expression:

$$\frac{p^* - c}{p^*} = \frac{1}{\eta_x(p^*, p^*) + \eta_\theta(p^*)}$$

where p_i denotes the price charged by competitor i, c his marginal cost, and his profit function is given by $\Pi(p_i, p_{-i}) = (p_i - c) D_x(p_i, p_{-i}) D_\theta(p_i)$ where $D_x(.)$ arises from the distribution of x (which need not be uniform) and the transportation cost function (which need not be linear). In our application, $c = 0$, $p = B$ and $\eta_x(p^*, p^*) = \frac{B^*}{\tau}$.

[10] Corner solutions may also arise when there is full-enrollment in θ. $B^*(\tau)$ is then the minimum of the standard Hotelling solution ($B^* = \tau$) or of the standard monopoly pricing ($B^*(\infty) = \frac{\eta(2\eta - a)}{24b}$). The more general solution is thus:

$$B^*(\tau) = \max\left(\frac{\eta(a+\eta)}{48b} + \tau - \sqrt{\left(\frac{\eta(a+\eta)}{48b}\right)^2 + \tau^2}, \min\left(\tau, \frac{\eta(2\eta - a)}{24b}\right)\right)$$

$$B^*(\tau) \simeq \frac{\eta(a+\eta)}{48b}\left(1 - \frac{\eta(a+\eta)}{96b\tau}\right)$$

Hence, $B^*(.)$ increases with τ up to a limit value of $\frac{\eta(a+\eta)}{48b}$ which corresponds to the monopoly fixed fee (under partial enrollment).

Imperfect competition and net surplus:

When DR tariffs are handled by private retailers under imperfect competition, two market imperfections coexist: (i) *market power*, since entrant retailers have incentives to ration output suboptimally; and (ii) the *cost of public funds' externality*, since entrant retailers do not internalize the cost of public funds needed to maintain cross-subsidies.

In our partial equilibrium framework, the net surplus for a given RTP contract with a fixed fee B offered by entrant retailers will be the sum of three terms:

1. Consumers' surplus:

$$V(B) = \mathbb{E}_{\theta t}\left[V(p(t), \theta, t)\mathbf{1}_{\Delta(\theta,B)>0}\right] + \mathbb{E}_{\theta t}\left[V(p^R, \theta, t)\mathbf{1}_{\Delta(\theta,B)<0}\right]$$
$$-B\mathbb{E}_{\theta}\left[\mathbf{1}_{\Delta(\theta,B)>0}\right] - A\mathbb{E}_{\theta}\left[\mathbf{1}_{\Delta(\theta,B)<0}\right]$$

2. Retailer's profit on the historical tariff (valued at $(1+\lambda)$):

$$\Pi_h(B) = \mathbb{E}_{\theta t}\left[(p^R - p(t))q(p^R, \theta, t)\mathbf{1}_{\Delta(\theta,B)<0}\right] + A\mathbb{E}_{\theta}\left[\mathbf{1}_{\Delta(\theta,B)<0}\right]$$

3. Retailers' profit on the DR tariff:

$$\Pi_{DR}(B) = B\mathbb{E}_{\theta}\left[\mathbf{1}_{\Delta(\theta,B)>0}\right]$$

From what preceeds, we can define a function $\tau \mapsto B^*(\tau)$ giving the equilibrium fixed fee as a function of the level of competition, which we assume to be differentiable. We can then express the net surplus as a function of the degree of competition τ:

$$W(\tau) =$$
$$\int_{\underline{\theta}}^{\Theta(B^*(\tau))} \mathbb{E}_t\left[W(p(t), \theta, t)\right] g(\theta)d\theta + \int_{\Theta(B^*(\tau))}^{\bar{\theta}} \mathbb{E}_t\left[W(p^R, \theta, t)\right] g(\theta)d\theta +$$
$$\lambda A \int_{\Theta(B^*(\tau))}^{\bar{\theta}} g(\theta)d\theta + \lambda \int_{\Theta(B^*(\tau))}^{\bar{\theta}} \mathbb{E}_t\left[(p^R - p(t))q(p^R, \theta, t)\right] g(\theta)d\theta$$

Proposition 6 *(Imperfect competition and net surplus)*
The sign of $W'(\tau)$ *is given by the sign of:*

$$(1+\lambda)\left(A+\mathbb{E}_t\left[(p^R-p(t))q(p^R,\Theta(B^*(\tau)),t)\right]\right)-B^*(\tau)$$

The first term is $(1+\lambda)$ *times the cross-subsidy paid by the marginal consumer (indifferent between switching or not) under the historical tariff. Hence more imperfect competition may increase welfare only when marginal switchers are among the ones who used to cross-subsidize other consumers (ie. if this first-term is positive).*

Proof. If we denote $\alpha(\tau) = -(B^*)'(\tau)\Theta'(B^*(\tau))g(\Theta(B^*(\tau)))$, which we expect to be positive ($(B^*)' = \frac{1-\eta_\theta(B^*)}{1+\tau\eta'_\theta(B^*)} > 0$ if the symmetric equilibrium is stable, and $\Theta' < 0$), and by using the fact that by definition $\Delta(\Theta(B^*(\tau)), B^*(\tau)) = 0$, we get by differentiating $W(.)$ w.r.t. τ:

$$W'(\tau) = \alpha(\tau)\left[(1+\lambda)\left(A+\mathbb{E}_t\left[(p^R-p(t))q(p^R,\Theta(B^*(\tau)),t)\right]\right)-B^*(\tau)\right]$$

■

This result pretty intuitive: if by contrast marginal switchers were initially subsidized, a decrease in the intensity of competition would both increase allocative inefficiencies (less consumers switch to RTP) *and* the pressure on public funds (consumers' discouraged to switch are costly to the historical supplier). The result is particularly stark if one starts from perfect competition $\tau = 0$. In this case we get:

$$W'(0) = \alpha(0)(1+\lambda)\left(A+\mathbb{E}_t\left[(p^R-p(t))q(p^R,\Theta(0),t)\right]\right)$$

meaning more imperfect competition decrease welfare if, and only if, the historical retailers used to earn some positive profit on marginal switchers. This formula for $\tau = 0$ remains true even in situations where more complex DR tariffs $(B, \underline{p})$ are allowed. Intuitively, as τ goes to zero, Bertrand competition forces $(B, \underline{p})$ tariffs to boil down to RTP anyway.

In our illustrative example, we get:

$$\alpha(\tau) = \tfrac{24b}{\eta(2a-\eta)}\left(1-\frac{\tau}{\sqrt{\left(\frac{\eta(a+\eta)}{48b}\right)^2+\tau^2}}\right) > 0$$

and:

$$W'(\tau) = \frac{\alpha(\tau)}{2a-\eta}\left[(\eta + 2a\lambda)B^*(\tau) - (1+\lambda)\frac{a\eta^2}{8b}\right]$$

The sign of W' is thus given by the sign of $(\eta+2a\lambda)B^*(\tau)-(1+\lambda)\frac{a\eta^2}{8b}$ where $B^*(.)$ is increasing in τ. In particular, since $B^*(0) = 0$, we have $W'(0) < 0$. Besides, as we showed before:

$$\lim_{\tau \to +\infty} B^*(\tau) = \frac{\eta(a+\eta)}{48b}$$

Consequently, we see that two different situations can arise:

1. Either $(\eta+2a\lambda)(a+\eta) < 6(1+\lambda)a\eta$, in which case $W'(.)$ remains always negative: more imperfect competition always decreases net surplus.

2. Or $(\eta + 2a\lambda)(a + \eta) > 6(1 + \lambda)a\eta$, in which case $W'(.)$ is negative at first, and then positive: welfare reaches a *minimum* at the level of competition τ_m such that:

$$B^*(\tau_m) = (1+\lambda)\frac{a\eta^2}{8b(\eta+2a\lambda)}$$

3.2.3 Benevolent monopoly and first-best benchmark

Because private profits yield no returns[11] while public profits yield a return equal to the opportunity cost of subsidies λ, the first-best outcome will be achieved when DR is handled by the historical retailer (if benevolent). To see that, let $B_e^* \geq 0$ be the obtained equilibrium DR contract offered by private entrant retailers. Net surplus is equal to:

$$W_e(B_e^*) = \mathbb{E}_{\theta t}\left[W(p(t),\theta,t)\mathbf{1}_{\Delta(\theta,B_e^*)>0}\right] + \mathbb{E}_{\theta t}\left[W(p^R,\theta,t)\mathbf{1}_{\Delta(\theta,B_e^*)<0}\right] + \lambda A \mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B_e^*)<0}\right] + \lambda\mathbb{E}_\theta\left[(p^R - p(t))q(p^R,\theta,t)\mathbf{1}_{\Delta(\theta,B_e^*)<0}\right]$$

Now, if a benevolent monopoly retailer handles the DR tariff, he can choose to set B_e^* as a fixed fee. Because his profits are weighted by $(1+\lambda)$ the obtained net surplus is then:

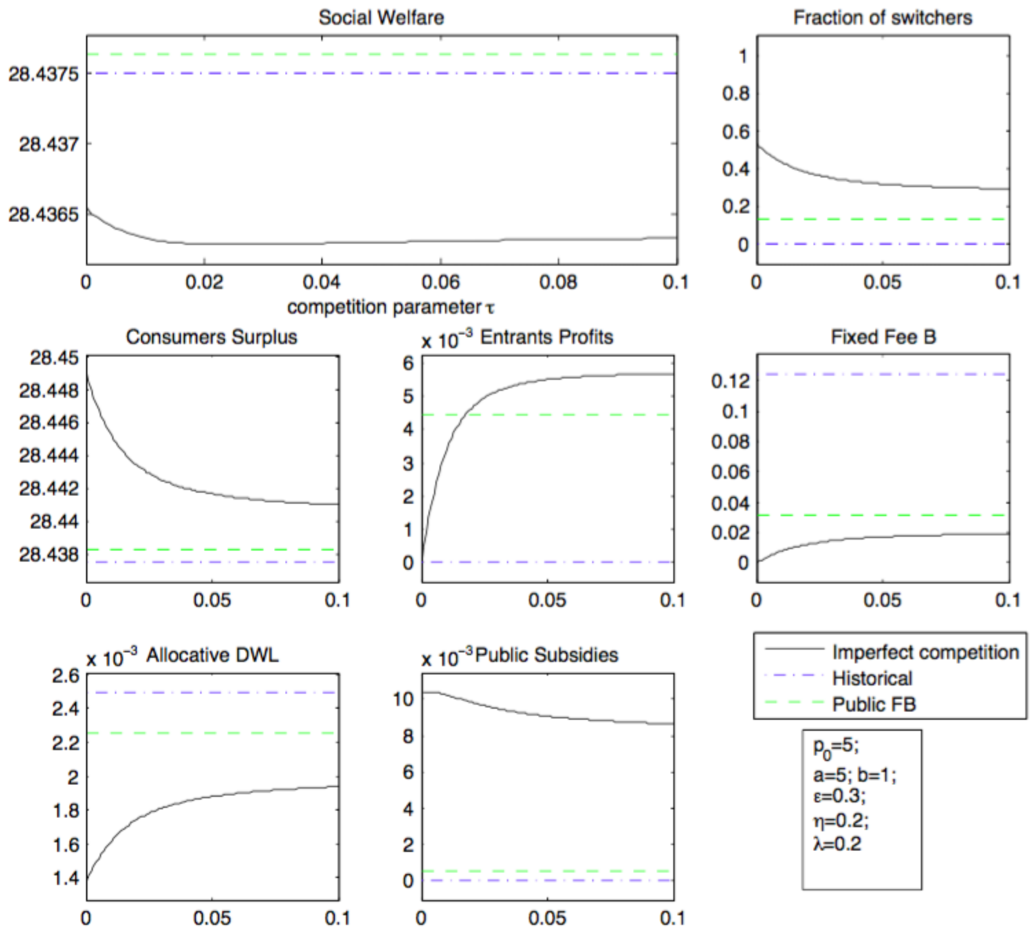
$$W_h(B_e^*) = W_e(B_e^*) + \lambda B_e^* \mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B_e^*)>0}\right]$$

which is higher than the net surplus achieved under imperfect competition ($B_e^* \geq 0$). Hence a benevolent monopoly retailer can always perform weakly

[11] Adding a tax Φ on entrants' profit would not change the following argument, it would just add a term $\Phi\lambda B_e^*\mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B_e^*)>0}\right]$ in the formula of W_e, meaning $W_h = W_e + (1-\Phi)\lambda B_e^*\mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B_e^*)>0}\right]$.

better than a combination of a historical retailer and private entrant retailers: *perfect competition fails to reach the second-best outcome* (unless there is full enrollment to RTP in equilibrium). However, as described in the next subsection, perfect competition can yield the second-best outcome once entrant retailers are forced by appropriate instruments to internalize the cost of public funds.

As an illustration, the following graphs represent the metrics of interest as the intensity of competition varies for given parameters' values of our example.



3.2.4 From third-best to second-best

A natural instrument to make entrant retailers internalize the cost of public funds would be to have them face the externality they create. More precisely, when a consumer θ switches to a DR tariff, an entrant retailer would be taxed/subsidized an amount:

$$\lambda \times \left(A + \mathbb{E}_t \left[(p^R - p(t))q(p^R, \theta, t)\right]\right)$$

In pratice, such a policy sounds hard to implement given the difficulty to assess λ and the fact that $q(p^R, \theta, t)$ is no more observed once a consumer has switched and faces the spot price $p(t)$ instead of the historical rate p^R. Calibrating a tax on entrant retailers' gross profit so as to limit switching to its socially optimal level faces the same difficulties.

In order to avoid endless debates about the value of λ, and/or for various reasons political economy reasons (Laffont and Tirole, 1993), the industry may be exogenously constrained to be budget balanced. Interestingly, our model of imperfect competition then offers a very simple instrument to retrieve the second-best outcome under perfect competition: *entrants just have to be required to also propose the historical* (A, p^R) *to their consumers*, while receiving no compensatory subsidy.

This claim is discussed in Appendix D rather than here, because its underlying assumptions sound very strong. In particular, (i) consumers must have no switching costs (so that do not tend to disproportionately stick to their historical retailer) ; (ii) demand side relevant parameters are not correlated (θ and x are independent: a given consumer's preference for a given retailer is not correlated with her demand characteristics) ; and (iii) supply side relevant parameters are not correlated (the transportation cost and locations of retailers are exogenous: in particular, entrant retailers do not target their commercial efforts towards more profitable consumers only).

3.3 No subsidies to non-switchers

We now turn to the case where cross-subsidies to non-switchers are not maintained. The difference with what preceeds is then that the outside option tariff (A, p^R) is *no more exogenous*, it must be updated to make sure that the revenue made of the population non-switchers is high enough to cover its supply costs.

3.3.1 Competitive environment

Perfect competition among retailers:

In a perfectly competitive environment, Bertrand competition between retailers will drive the IC PTR contract toward RTP (ie. $\underline{p} = B = 0$) , which generates the highest surplus from trade. Imagine instead that a fraction of the consumers of a given retailer are not under RTP. A concurrent retailer could then propose a RTP contract to these consumers, and redistribute the allocative efficiency gains in order to make a better offer to the whole customer base of the first retailer.

As a consequence, $\underline{p}$ and B are constrained by competitive forces to be equal to zero. The main question is thus to characterize the values of A and p^R. For a given (A, p^R), we define:

- $V^0(\theta) \equiv \mathbb{E}_t \left[V(p^R, \theta, t)\right] - A$
- $V^{RTP}(\theta) \equiv \mathbb{E}_t \left[V(p(t), \theta, t)\right]$
- $W^0(\theta) \equiv \mathbb{E}_t \left[W(p^R, \theta, t)\right]$
- $W^{RTP}(\theta) \equiv \mathbb{E}_t \left[W(p(t), \theta, t)\right]$

Proposition 7 *(Full-enrollment to RTP)*
If the historical tariff is not subsidized, which can be written formally:

$$\mathbb{E}_\theta \left[\left\{W^0(\theta) - V^0(\theta)\right\} \mathbf{1}_{V^0(\theta) \geq V^{RTP}(\theta)}\right] \geq 0$$

then almost all consumers switch to RTP in equilibrium.

Proof. Using $V^{RTP}(\theta) = W^{RTP}(\theta)$, the no cross-subsidies condition can be rewritten:

$$\mathbb{E}_\theta \left[\left\{\underbrace{W^0(\theta) - W^{RTP}(\theta)}_{\leq 0} + \underbrace{V^{RTP}(\theta) - V^0(\theta)}_{\leq 0}\right\} \mathbf{1}_{V^0(\theta) \geq V^{RTP}(\theta)}\right] \geq 0$$

Consequently, either the historical option is isomorphic to RTP or only a zero measure of consumers sticks to it. ■

The intuition behind this result is as follows. Under RTP, consumers get the entire net surplus from trade (Bertrand competition implying zero profits for retailers). This net surplus is the maximal surplus than can be created through trade (efficient pricing). Hence if a consumer does not switch, it means the historical tariff gives her a surplus higher than the highest achievable social surplus created through trade. As a consequence, the retailer is losing money on this consumer. Since only such subsidized consumers have incentives to stay on the historical tariff, there is no one left to cross-subsidize them and the historical tariff cannot be balanced. In practice, the likely outcome is a progressive increase of the historical tariff until all consumers have switched to RTP[12]. This intuition is robust to endogenizing wholesale prices, as long as consumers have no switching costs, which may slowly become more and more realistic in a smart grid environment.

Imperfect competition among retailers:
When competition is not perfect, the fact that retailers extract part of consumers' surplus should, on the one hand, prevent full-enrollment to the DR tariff, and on the other hand, decrease the social surplus from the DR segment due to distortions in pricing. Intuitively, one thus expects that the more imperfect the competition, the lower the opt-in rates and the lower the net surplus.

However, the situation is more complicated that one may think at first because the outside option tariff (A, p^R) will vary with the level of competition. Indeed, (A, p^R) is chosen so as to cover the supply costs of the population of non-switchers, which will change with the level of competition. Besides, competitors' pricing strategy will also depend on whether they endogenize the fact that their choice of DR tariff affects the outside

[12] The spirit of this result is very similar to the unraveling result in the quality disclosure literature. As such, on top of the potential failures we explore in this paper, many further insights may be extrapolated this literature, one of the most important being perhaps: '*[u]nraveling requires consumers to play their part*' (Dranove and Jin, 2010). Consumers could be also helped by third-parties as suggested in Kamenica et al. (2011).

option tariff (A, p^R) or not[13]. Given these technical difficulties, and the little additional insight we expect to get from modelling this situation, we chose to discuss it only in Appendix E.

3.3.2 Local monopoly retailer

Unconstrained benevolent monopoly:

A benevolent local monopoly retailer can of course replicate the outcome of perfect competition: launch a RTP tariff and let the unravelling dynamics induce all consumers to switch.

Benevolent monopoly and tariff rigidities:

However, when electricity retail is handled by a local monopoly, the IC PTR contract is no more constrained by competitive forces to be isomorphic to RTP. The monopoly may then opt for a more gradual approach (or be required to do so), implementing instead an IC PTR tariff first.

Unlike the RTP case, full-enrollment may no more be the unique equilibrium outcome because of cross-subsidies *within* switching consumers[14]. To understand why, note that the no cross-subsidies between tariffs condition writes down:

$$\begin{cases} \mathbb{E}_{\theta t}\left[A + (p^R - p(t))q(p^R, \theta, t)|\Delta(\theta) \leq 0\right] \geq 0 & \text{(Historical tariff)} \\ \mathbb{E}_{\theta t}\left[B + (\underline{p} - p(t))q(\underline{p}, \theta, t)\mathbf{1}_{p(t)\leq \underline{p}}|\Delta(\theta) > 0\right] \geq 0 & \text{(IC PTR tariff)} \end{cases}$$

while consumers' switching decision is driven by:

$$\Delta(\theta) \equiv A - B + \mathbb{E}_t\left[V(\underline{p}, \theta, t)\mathbf{1}_{p(t)\leq \underline{p}} + V(p(t), \theta, t)\mathbf{1}_{p(t)>\underline{p}} - V(p^R, \theta, t)\right]$$

Notice that in the budget balance formula of the IC PTR contract above, the cost of supplying a given switching consumer off-peak is $\mathbb{E}_t\left[p(t)q(\underline{p}, \theta, t)\mathbf{1}_{p(t)\leq \underline{p}}\right]$. This cost depends on the covariance between $p(t)$ and $q(\underline{p}, \theta, t)$, conditionnaly on being *off-peak* (ie. $p(t) \leq \underline{p}$). However this covariance term plays no

[13]Note in particular that the (modified) Hotelling model we use later on is not well-suited to account for this aspect of imperfect competition. Indeed, this strategic effect will increase with the concentration in the retail industry (for example measure by the HHI) which is another dimension of imperfect competition, not included in an Hotelling model (in which competitors have a 50% market share whatever the level of competition is).

[14]Which correspond to what Borenstein (2007) calls *within* period cross-subsidy in the context of TOU tariffs.

role in the self-selection of consumers (see the formula for $\Delta(\theta)$). As a consequence, a disproportionate amount of 'costly-to-supply' consumers may enroll first, maintaining the IC PTR tariff at a high level and preventing further adoption.

To illustrate this point, consider the simple case in which the historical tariff is linear ($A = 0$) and consumers are price inelatic ($\eta(\theta) = 0$ for all θ). We denote $q(\theta, t)$ the quantity consumed by a type θ consumer in state t (independent of the price charged). We further assume there are only three states of the world $\{0, 1, 2\}$ (with frequency $\frac{1}{3}$ each) and two types of consumers $\{\theta_1, \theta_2\}$ (with frequency $\frac{1}{2}$). The values of $p(.)$, $q(\theta_1, .)$ and $q(\theta_2, .)$ are given in the following table:

State t	Spot price $p(t)$	Type-θ_1 demand $q(\theta_1, t)$	Type-θ_2 demand $q(\theta_2, t)$
0	$p(0) = 0$	$q(\theta_1, 0) = 0$	$q(\theta_2, 0) = 1$
1	$p(1) = 1$	$q(\theta_1, 1) = 2$	$q(\theta_2, 1) = 0$
2	$p(2) = 4$	$q(\theta_1, 2) = 0$	$q(\theta_2, 2) = 1$

When both types of consumers are on the historical tariff, a linear tariff with $p^R = 1.5$ ensures retailer's budget balance. One can check that an IC PTR contract $(B, \underline{p}) = (0, 1)$ initially attracts type θ_1 consumers, but not type θ_2 ones. The historical tariff must then increase to $p^R = 2$ in order to ensure budget balance. We then have $\Delta(\theta_1) = 2 > 0$ and $\Delta(\theta_2) = -1 < 0$ so type θ_2 consumers stay on the historical tariff despite the increase of p^R.

More generally, any rigidity in the tariff design may create some adverse selection. As a consequence a coordination failure may arise, in the sense that an iterative approach regularly updating tariffs to ensure budget balance may not converge to a full-enrollment situation, even when it is socially optimal.

4 Conclusion

This paper studies Peak-Time-Rebates (PTR) contracts, which give consumers the right to resell into the market the power they have purchased from their retailers. Resale occurs only when the state-dependent wholesale price exceeds the fixed contract price. Then, resale profit is the price spread times the difference between the baseline consumption that would have occured and the consumption that actually occured. By construction, baseline consumption is a consumer's private information. Thus, there exists an incentive and an opportunity to overstate baseline consumption. This article determines socially optimal contracts, taking asymmetric information into account. It first proves that the all Incentive Compatible contracts require consumers to purchase their baseline forward at the expected spot price (Propositions 1 and 2). However, consumers having access to a standard retail contract will not voluntarily enroll in a simple Incentive Compatible PTR (Corollary 2.2).

Enrollment depends on industry structure and subsidy level. If (i) competition among retailers is perfect and (ii) no subsidies are maintained for non-switchers, retailers offer a Real Time Pricing contract (a specific form of PTR), and all consumers enroll. Full enrollment is not guaranteed if any of these conditions is not met.

Appendices

A Proofs

A.1 Proof of Proposition 1

Once state t is realized, a type θ consumer that has reported being type $\hat{\theta}$ and consumes q gets a gross utility:

$$U(\theta, \hat{\theta}, t, q) = \begin{cases} U(q, \theta, t) + (\bar{q}(\hat{\theta}, t) - q)p(t) & \text{if } \bar{q}(\hat{\theta}, t) > q \\ U(\bar{q}(\hat{\theta}, t), \theta, t) & \text{otherwise} \end{cases}$$

She consumes $q^*(\theta, t)$ (socially optimal quantity) if $q^*(\theta, t) < \bar{q}(\hat{\theta}, t)$; otherwise, she consumes $\bar{q}(\hat{\theta}, t)$ (since $\partial_q u < 0$). Hence she derives a gross utility:

$$U(\theta, \hat{\theta}, t) = \begin{cases} U(q^*(\theta, t), \theta, t) + (\bar{q}(\hat{\theta}, t) - q^*(\theta, t))p(t) & \text{if } \bar{q}(\hat{\theta}, t) > q^*(\theta, t) \\ U(\bar{q}(\hat{\theta}, t), \theta, t) & \text{otherwise} \end{cases}$$

Expected gross utility is then:

$$\begin{aligned} U(\theta, \hat{\theta}) \quad = \quad & \mathbb{E}_t \Big[\Big\{ U(q^*(\theta, t), \theta, t) + (\bar{q}(\hat{\theta}, t) - q^*(\theta, t))p(t) \Big\} \mathbf{1}_{\bar{q}(\hat{\theta}, t) > q^*(\theta, t)} \\ & + U(\bar{q}(\hat{\theta}, t), \theta, t) \mathbf{1}_{\bar{q}(\hat{\theta}, t) \leq q^*(\theta, t)} \Big] \end{aligned}$$

1. **Step 1: optimal allocation**

   $p(t)$ has been assumed to be the social marginal cost of supply in state t. In addition, we assume that electricity sold back by consumers is worth no more than the one sold on the spot market. Hence, selling back electricity is just a financial transfer irrelevant for the social planner. The social planner problem will then be:

   $$\begin{aligned} \max_{\bar{q}(.,.)} \mathbb{E}_{\theta,t} \big[& \{ U(q^*(\theta, t), \theta, t) - p(t) q^*(\theta, t) \} \mathbf{1}_{\bar{q}(\theta, t) > q^*(\theta, t)} \\ & + \{ U(\bar{q}(\theta, t), \theta, t) - p(t) \bar{q}(\theta, t) \} \mathbf{1}_{\bar{q}(\theta, t) \leq q^*(\theta, t)} \big] \end{aligned}$$

   Euler-Lagrange necessary condition yields:

   $$\mathbb{E}_{\theta,t} \left[\{ u(\bar{q}(\theta, t), \theta, t) - p(t) \} \mathbf{1}_{\bar{q}(\theta, t) \leq q^*(\theta, t)} \right] = 0$$

   As $u(., \theta, t)$ decreases, a necessary condition is thus that the set $\{ t \,|\, \bar{q}(\theta, t) < q^*(\theta, t) \}$ is of zero measure.

2. **Step 2: information rents (local necessary conditions)**
Inserting the optimal allocation into consumers expected gross utility we get:

$$U(\theta,\hat{\theta}) = \mathbb{E}_t\left[U(q^*(\theta,t),\theta,t) + (\bar{q}(\hat{\theta},t) - q^*(\theta,t))p(t)\right]$$

If we note $\tilde{U}(\theta)$ the information rents, we have by the envelope theorem:

$$\tilde{U}'(\theta) = \mathbb{E}_t\left[\partial_\theta U(q^*(\theta,t),\theta,t)\right]$$

Using:

$$\partial_\theta U(q^*(\theta,t),\theta,t) = \tfrac{dU(q^*(\theta,t),\theta,t)}{d\theta} - p(t)\partial_\theta q^*(\theta,t)$$

we get:

$$\tilde{U}(\theta) = \tilde{U}(\underline{\theta}) + \\ \mathbb{E}_t\left[U(q^*(\theta,t),\theta,t) - p(t)q^*(\theta,t) - \{U(q^*(\underline{\theta},t),\underline{\theta},t) - p(t)q^*(\underline{\theta},t)\}\right]$$

3. **Step 3: choice of reference type's rent**
We assume the lowest type is getting the surplus she would get under RTP, which translates into:

$$\tilde{U}(\underline{\theta}) = \mathbb{E}_t\left[U(q^*(\underline{\theta},t),\theta,t) - p(t)q^*(\underline{\theta},t)\right]$$

which yields:

$$\tilde{U}(\theta) = \mathbb{E}_t\left[U(q^*(\theta,t),\theta,t) - p(t)q^*(\theta,t)\right]$$

4. **Step 4: obtained necessary condition for IC transfers**
Finally we recover the expression of transfers:

$$\begin{aligned} T(\theta) &= U(\theta,\theta) - \tilde{U}(\theta) \\ &= \mathbb{E}_t\left[p(t)\bar{q}(\theta,t)\right] \end{aligned}$$

Standard analysis shows that the obtained necessary condition for optimal IC transfers is also sufficient.

A.2 Proof of Proposition 2

1. **Step 1: consumer's choice on whether to resell**:
Once t is realized, a type θ consumer having reported being $\hat{\theta}$ gets:

$$\max \left\{ \underbrace{\max_q U(q,\theta,t) - p^R q}_{\text{if does not resale}} ; \underbrace{\max_q U(q,\theta,t) - p^R \tilde{q}(\hat{\theta},t) + p(t)(\tilde{q}(\hat{\theta},t) - q)^+}_{\text{if resales}} \right\}$$

She thus chooses:

$$\begin{cases} q = q(p^R,\theta,t) & \text{if } p(t) \leq p^R \text{ or } \tilde{q}(\hat{\theta},t) \leq \hat{q}(\theta,t) \\ q = q^*(\theta,t) & \text{otherwise} \end{cases}$$

2. **Step 2: Optimal allocation** The social planner objective is:

$$\begin{aligned} \max_{\tilde{q}(.,.)} \quad & \mathbb{E}_{\theta,t} \Big[\left\{ U(q(p^R,\theta,t),\theta,t) - p(t)q(p^R,\theta,t) \right\} \mathbf{1}_{p(t)\leq p^R} \\ & + \left\{ U(q(p^R,\theta,t),\theta,t) - p(t)q(p^R,\theta,t) \right\} \mathbf{1}_{p(t)>p^R} \mathbf{1}_{\tilde{q}(\theta,t)\leq\hat{q}(\theta,t)} \\ & + \left\{ U(q^*(\theta,t),\theta,t) - p(t)q^*(\theta,t) \right\} \mathbf{1}_{p(t)>p^R} \mathbf{1}_{\tilde{q}(\theta,t)>\hat{q}(\theta,t)} \Big] \end{aligned}$$

Since:

$$U(q(p^R,\theta,t),\theta,t) - p(t)q(p^R,\theta,t) < U(q^*(\theta,t),\theta,t) - p(t)q^*(\theta,t)$$

A social planner chooses $\tilde{q}(\theta,t) \geq \hat{q}(\theta,t)$ for almost all (θ,t).

3. **Step 3: information rents (local necessary conditions)**
Plugging the allocation that the social planner wants to implement we have:

$$\begin{aligned} U(\theta,\hat{\theta}) = \mathbb{E}_t \Big[& \left\{ U(q(p^R,\theta,t),\theta,t) - p^R q(p^R,\theta,t) \right\} \mathbf{1}_{p(t)\leq p^R} \\ + & \left\{ U(q^*(\theta,t),\theta,t) - p^R \tilde{q}(\hat{\theta},t) + p(t)\left(\tilde{q}(\hat{\theta},t) - q^*(\theta,t) \right) \right\} \mathbf{1}_{p(t)>p^R} \Big] \end{aligned}$$

Using the envelope theorem, information rents $\tilde{U}(\theta)$ satisfy:

$$\tilde{U}'(\theta) = \mathbb{E}_t \left[\partial_\theta U(q(p^R,\theta,t),\theta,t)\mathbf{1}_{p(t)\leq p^R} + \partial_\theta U(q^*(\theta,t),\theta,t)\mathbf{1}_{p(t)>p^R} \right]$$

Thus:

$$\tilde{U}(\theta) = \tilde{U}(\underline{\theta}) + \mathbb{E}_t \Big[\big\{ U(q(p^R,\theta,t),\theta,t) - p^R q(p^R,\theta,t) \big\} \mathbf{1}_{p(t)\leq p^R} + \{ U(q^*(\theta,t),\theta,t) - p(t) q^*(\theta,t) \} \mathbf{1}_{p(t)>p^R} \Big] - \mathbb{E}_t \Big[\big\{ U(q(p^R,\underline{\theta},t),\underline{\theta},t) - p^R q(p^R,\underline{\theta},t) \big\} \mathbf{1}_{p(t)\leq p^R} + \{ U(q^*(\underline{\theta},t),\underline{\theta},t) - p(t) q^*(\underline{\theta},t) \} \mathbf{1}_{p(t)>p^R} \Big]$$

4. **Step 4: choice of reference type's rent**
   For simplicity we set:

$$\tilde{U}(\underline{\theta}) = \mathbb{E}_t \Big[\big\{ U(q(p^R,\underline{\theta},t),\underline{\theta},t) - p^R q(p^R,\underline{\theta},t) \big\} \mathbf{1}_{p(t)\leq p^R} + \{ U(q^*(\underline{\theta},t),\underline{\theta},t) - p(t) q^*(\underline{\theta},t) \} \mathbf{1}_{p(t)>p^R} \Big]$$

   This choice corresponds to the case where the lowest type gets her expected surplus from variable CPP. We then have:

$$\tilde{U}(\theta) = \mathbb{E}_t \Big[\big\{ U(q(p^R,\theta,t),\theta,t) - p^R q(p^R,\theta,t) \big\} \mathbf{1}_{p(t)\leq p^R} + \{ U(q^*(\theta,t),\theta,t) - p(t) q^*(\theta,t) \} \mathbf{1}_{p(t)>p^R} \Big]$$

5. **Step 5: obtained necessary condition for IC transfers**
   Finally we recover the IC transfers:

$$\begin{aligned} T(\theta) &= U(\theta,\theta) - \tilde{U}(\theta) \\ &= \mathbb{E}_t \Big[(p(t) - p^R) \tilde{q}(\theta,t) \mathbf{1}_{p(t)>p^R} \Big] \end{aligned}$$

Again, obtained necessary conditions are actually sufficient.

A.3 Proof of Proposition 3 and 4

Proposition 3 follows the same logic as proposition 2.

For proposition 4, a given retailer's historical profit is:

$$\Pi_0 = A + \mathbb{E}_{\theta t \omega} \left[(p^R - p(t)) q^{RT}(p^R,\theta,t,\omega) \right]$$

When a non-IC PTR mechanism with a baseline $\bar{q}(\theta,t)$ purchased at p^R is implemented, our retailer's profit becomes:

$$\Pi_{PTR} = A + \mathbb{E}_{\theta t \omega} \Big[(p^R - p(t)) q^{RT}(p^R,\theta,t,\omega) \mathbf{1}_{p(t)\leq p^R} \Big] + \mathbb{E}_{\theta t \omega} \Big[\{ p^R \tilde{q}(\theta,t) - p(t) \left(\tilde{q}(\theta,t) - q^*(\theta,t,\omega) \right) - p(t) q^*(\theta,t,\omega) \} \mathbf{1}_{p(t)>p^R} \Big]$$

Substracting the two, the change in retailers' profit due to the implementation of PTR is then:

$$
\begin{aligned}
\Delta\Pi &= \Pi_{PTR} - \Pi_0 \\
&= \mathbb{E}_{\theta t}\left[\left(p^R - p(t)\right)\left(\tilde{q}(\theta,t) - \mathbb{E}_\omega\left[q^{RT}(p^R,\theta,t,\omega)\right]\right)\mathbf{1}_{p(t)>p^R}\right] \\
&= \mathbb{E}_{\theta t}\left[\left(p^R - p(t)\right)\left(\max_\omega \hat{q}(\theta,t,\omega) - \mathbb{E}_\omega\left[q^{RT}(p^R,\theta,t,\omega)\right]\right)\mathbf{1}_{p(t)>p^R}\right]
\end{aligned}
$$

Thus, as soon as $\max_\omega \hat{q}(\theta,t,\omega) > \mathbb{E}_\omega\left[q^{RT}(p^R,\theta,t,\omega)\right]$ which is by far the most likely situation, retailer's profit decreases.

To avoid this loss, one may decrease the baseline (for example set $\tilde{q}(\theta,t) = \mathbb{E}_\omega\left[q^{RT}(p^R,\theta,t,\omega)\right]$ although such a choice could be optimized). However, there exists then some realizations of ω such that $\tilde{q}(\theta,t) < \hat{q}(\theta,t,\omega)$. By definition, a consumer chooses not to resell in such situations, creating some allocative inefficiencies.

B Risk-aversion and optimal state-independent baseline

Let $V(\theta,t)$ be type θ consumer payoff in state t, and denote $\bar{V}(\theta)$ (resp. $\sigma^2(\theta)$) the average (resp. the variance) of $V(\theta,t)$. Risk-aversion can be modeled through a concave function u which is such that the *ex ante* consumer's payoff is:

$$V(\theta) = \mathbb{E}_t\left[u\left(V(\theta,t)\right)\right]$$

Assuming uncertainty is not too large so that a second-order Taylor development can be used we have:

$$
\begin{aligned}
V(\theta) &= u\left(\bar{V}(\theta)\right) + u'(\bar{V}(\theta))\mathbb{E}_t\left[V(\theta,t) - \bar{V}(\theta)\right] + \tfrac{u''(\bar{V}(\theta)}{2}\mathbb{E}_t\left[\left(V(\theta,t) - \bar{V}(\theta)\right)^2\right] + o\left(\mathbb{E}_t\left[\left(V(\theta,t) - \bar{V}(\theta)\right)^2\right]\right) \\
V(\theta) &= u\left(\bar{V}(\theta)\right) + \tfrac{u''(\bar{V}(\theta))}{2}\sigma^2(\theta) + o\left(\sigma^2(\theta)\right)
\end{aligned}
$$

Since $u'' < 0$, a risk-averse consumer will choose, as a first approximation, the baseline that minimizes the variance of her payoffs. For the optimal mechanism in the unconstrained case we have:

$$\sigma^2(\bar{q}) =$$

$$\mathbb{E}_t\left[\left(\underbrace{U(q^*(\theta,t),\theta,t) + (\bar{q} - q^*(\theta,t))p(t) - \mathbb{E}_t\left[p(t)\right]\bar{q}}_{\text{Payoff in state } t} - \underbrace{\mathbb{E}_t\left[U(q^*(\theta,t),\theta,t) - p(t)q^*(\theta,t)\right]}_{\text{Expected payoff}}\right)^2\right]$$

Minimizing w.r.t. $\bar{q}$ then allows to pin down a single optimal baseline for each type:

$$\bar{q}^*(\theta) = \max\left(-\mathrm{Cov}_t\left(\frac{p(t)}{\mathrm{Var}_t(p(t))}, U(q^*(\theta,t),\theta,t) - p(t)q^*(\theta,t)\right), \sup_t q^*(\theta,t)\right)$$

C RTP tariffs' simplification

In the most general setting, the entrant retailers or the local monopoly should be allowed to use any pricing instrument they find suitable. In the imperfect competition environment, one should refer to the literature on competition in contracts; while in the local monopoly environment, one should refer to the mechanism design literature. For simplicity, we will focus on the local monopoly environment, where the electricity retail industry is required to be budget balanced. As explained in Laffont and Tirole (1993), allowing external subsidies through public funds instead of requiring budget balance would yield similar formulas provided one replace the (endogenous) Lagrange multiplier of the budget constraint μ by the (exogenous) cost of public funds λ.

IC PTR tariffs (pooling):

The IC PTR tariffs of the type $(B, \underline{p})$ we discuss in section 3 would be, in the vocabulary of mechanism design, a pooling contract: every consumer is offered the same contract.

In the local monopoly constrained to budget balance situation, fundings to boost opt-in can only come from the savings the monopoly makes on switching consumers. As a consequence, money is scarce and has an (endogenous) opportunity cost: the monopoly retailer faces a Ramsey-Boiteux problem.

More precisely, the optimization problem faced by the local monopoly is to maximize the created social surplus given his budget constraint[15]:

$$\max_{B,\underline{p}} \mathbb{E}_{\theta,t}\left[\left\{\left(W(p(t),\theta,t)-W(p^R,\theta,t)\right)\mathbf{1}_{p(t)>\underline{p}}\right.\right.$$
$$\left.\left.+\left(W(\underline{p},\theta,t)-W(p^R,\theta,t)\right)\mathbf{1}_{p(t)\leq\underline{p}}\right\}\mathbf{1}_{\Delta(\theta,B,\underline{p})>0}\right]$$
$$\text{s.t}$$
$$\mathbb{E}_{\theta,t}\left[\left\{(\underline{p}-p(t))q(\underline{p},\theta,t)\mathbf{1}_{p(t)\leq\underline{p}}-(p^R-p(t))q(p^R,\theta,t)\right\}\mathbf{1}_{\Delta(\theta,B,\underline{p})>0}\right]$$
$$+(B-A)\mathbb{E}_{\theta}\left[\mathbf{1}_{\Delta(\theta,B,\underline{p})>0}\right]\geq 0$$

In order to avoid unecessarily complex mathematical notations, we make the following technical assumption:

Assumption 1 *(Negligible covariance term)*
Marginal types who end up being indifferent between the historical tariff and the optimal IC PTR tariff have the same average off-peak consumption, which we denote $\mathbb{E}_t\left[q(\underline{p},\theta^*,t)\,|\,p(t)\leq\underline{p}\right]$

This assumption just aims at getting simple formulas and could be relaxed at the cost of adding a covariance term at the frontier of marginal consumers.

Proposition 8 *(Ramsey-Boiteux pricing)*
Under the previous assumptions, if one denotes μ *the Lagrange multiplier of the budget constraint, first-order conditions yield:*

$$\underline{p} = \frac{\mathbb{E}_{\theta t}\left[p(t)\partial_p q(\underline{p},\theta,t)\,|\,p(t)\leq\underline{p},\Delta(\theta)>0\right]}{\mathbb{E}_{\theta t}\left[\partial_p q(\underline{p},\theta,t)\,|\,p(t)\leq\underline{p},\Delta(\theta)>0\right]} + \frac{\mu}{1+\mu}\frac{\mathbb{E}_t\left[q(\underline{p},\theta^*,t)\,|\,p(t)\leq\underline{p}\right]-\mathbb{E}_{\theta t}\left[q(\underline{p},\theta,t)\,|\,p(t)\leq\underline{p},\Delta(\theta)>0\right]}{\mathbb{E}_{\theta t}\left[\partial_p q(\underline{p},\theta,t)\,|\,p(t)\leq\underline{p},\Delta(\theta)>0\right]}$$

In particular, $\underline{p}=0$ *if the average off-peak consumption of marginal consumers is higher than the average off-peak consumption of all switching consumers* (which unfortunately sounds like an unlikely situation, since the higher a given consumer's off-peak consumption, the most likely she switches early).

In order to understand when such a situation arises, we denote:

[15] The budget constraint being defined as the fact that the monopoly must make at least as much profit as he used to do when all consumers were on the historical tariff.

- $DWL(\theta) = \mathbb{E}_t\left[W(p(t),\theta,t) - W(p^R,\theta,t)\right]$ the allocative deadweight loss due to a type-θ consumer who sticks to the historical tariff.
- $CSub(\theta) = A + \mathbb{E}_t\left[(p^R - p(t))q(p^R,\theta,t)\right]$ the cross-subsidy initially paid/received by a type-θ consumer (bill minus actual supply costs).

When the DR contract is RTP plus a fixed fee, one may write[16]:

$$\Delta(\theta, B) = -B + \underbrace{DWL(\theta)}_{\text{Allocative gains}} + \underbrace{CSub(\theta)}_{\text{Cross-subsidies removal}}$$

Hence, consumers' decision to switch is driven by the two potential sources of benefits they face: the allocative gains from facing spot prices and the removal of the cross-subsidies' burden. The way the sum of these two incentives to switch vary across consumers takes a relatively simple form:

$$\partial_\theta \Delta(\theta, B) = \mathbb{E}_t\left[\partial_\theta U(p(t),\theta,t) - \partial_\theta U(p^R,\theta,t)\right]$$

If $\partial_\theta \Delta < 0$ (resp. > 0) low θ (resp. high θ) consumers switch first. Then, if for all (p,t) $\partial_\theta q > 0$ (resp. < 0), marginal swichers end up having higher (resp. lower) consumption levels than inframarginal switchers. A sufficient condition for our study of RTP (instead of more general $(B, \underline{p})$ contracts) to induce no loss of generality is thus:

$$\text{For all } (p,t)\text{: } \partial_\theta q(p,\theta,t) \times \mathbb{E}_t\left[\partial_\theta U(p(t),\theta,t) - \partial_\theta U(p^R,\theta,t)\right] < 0$$

Intuitively, consumers with higher consumption levels are likely to generate greater deadweight losses in the benchmarck situation. Hence, if say $\partial_\theta q > 0$, one expects $DWL' > 0$. Since $\partial_\theta \Delta = DWL' + CSub'$, a necessary condition for $\partial_\theta q \times \partial_\theta \Delta < 0$ is to have $CSub' < 0$. Hence, optimal DR contracts will boil down to RTP if (1) low-consumption customers were initially cross-subsidizing high-consumption customers and (2) variations in cross-subsidies paid/received are significantly higher than variations in allocative inefficiencies.

In our illustrative example, the previous discussion is captured by parameters η and a. Indeed:

[16]Of course, in a more general setting, this boils down to changes in consumers' surplus equals change in social surplus minus change in producer surplus.

- η measures the dispersion in spot prices. The higher it is, the higher is the DWL in the historical benchmark ($DWL(\theta) = \frac{\eta^2(1+\theta)}{24b}$). As a consequence, allocative gains are expected to matter more for high η.

- a affects the level of cross-subsidies ($CSub(\theta) = \frac{a\eta(1-2\theta)}{24b}$) but not the allocative deadweight loss. Consumers such that $\theta < \frac{1}{2}$ subsidize consumers such that $\theta > \frac{1}{2}$, and the higher a the more so. The condition $\partial_\theta q \times \partial_\theta \Delta < 0$ boils down to:

$$(p_0 - p + at)(\eta - 2a) < 0$$

  When a is high enough (namely $a > \frac{\eta}{2}$), the removal of cross-subsidies dominates in consumers' decision to switch. Since low-consumption customers were initially paying for the cross-subsidies, RTP can be studied without loss of generality.

Other instruments (pooling):

On top of $(B, \underline{p})$, a local monopoly could use additional instruments in the design of demand response tariffs such as:

1. A threshold spot price $\hat{p} > p^R$: when the spot price turns out to be higher than $\hat{p}$ a 'critical event' is called, as proposed in Chao and DePillis (2013).

2. Peak prices faced by consumers $p^*(t)$ could be different from *actual* spot prices $p(t)$.

One can then rewrite the above Ramsey-Boiteux problem and get:

$$p^*(t) = p(t) + \frac{\mu}{1+\mu}\frac{q(p^*(t),\theta^*,t) - \mathbb{E}_\theta[q(p^*(t),\theta,t) \mid \Delta(\theta) > 0]}{\mathbb{E}_\theta[\partial_p q(p^*(t),\theta,t) \mid \Delta(\theta) > 0]}$$

Contrary to what happens in traditionnal Ramsey-Boiteux pricing, the optimal peak prices will most likely be set *below* the social cost $p(t)$. This reflects the fact that decreasing $p^*(t)$ from its socially optimal value $p(t)$ is a less costly tool for attracting consumers than decreasing B (since there are no first-order welfare losses). Going back to IC PTR contracts, it means that baseline power should be purchased and sold back at a discount compared to its social value. By contrast, in current implementations, power is on the contrary often sold back at a premium!

Second-degree price discrimination (screening):

Finally, a local monopoly may find it socially optimal to offer its consumers a menu of DR tariffs in order to screen their outside option: '*if high users are more responsive than low users, different tariffs might be targeted at each customer segment in order to maximize demand response and/or minimize implementation costs*' (Faruqui and George, 2005). However, the task of screening optimally consumers is a difficult one since it is subject to countervailing incentives (Jullien, 2000). If one assumes a sorting condition $\partial^2_{\theta q} U > 0$, consumers have indeed incentives to:

1. Overstate their type to claim having a high outside option.
2. Understate their type to get lower peak prices.
3. Understate their type to get a lower off-peak price.
4. Understate their type to be asked to face less peak events.

Designing optimal vCPP tariffs in the context of a regulated monopoly willing to maintain historical cross-subsidies is thus extremely challenging. Handling it would require simplifications backed by empirical observations on data that are usually not publicly available to academic researchers. In the absence of such data, we let this work to utilities' own researchers.

D From third-best to second-best when a local monopoly would be constrained to budget balance

Local monopoly benchmark:

The program faced by a benevolent local monopoly constrained to budget balance is:

$$\max_B \mathbb{E}_{\theta t}\left[W(p(t),\theta,t)\mathbf{1}_{\Delta(\theta,B)>0}\right] + \mathbb{E}_{\theta t}\left[W(p^R,\theta,t)\mathbf{1}_{\Delta(\theta,B)<0}\right]$$
$$\text{s.t.}$$
$$B\mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B)>0}\right] + A\mathbb{E}_\theta\left[\mathbf{1}_{\Delta(\theta,B)<0}\right] + \mathbb{E}_{\theta t}\left[(p^R - p(t))q(p^R,\theta,t)\mathbf{1}_{\Delta(\theta,B)<0}\right] \geq 0$$

Under our simplifying assumptions, one may write the Lagrangian:

$$\mathcal{L}(B,\mu) = \int_{\underline{\theta}}^{\Theta(B)} \mathbb{E}_t\left[W(p(t),\theta,t)\right] g(\theta)d\theta + \int_{\Theta(B)}^{\bar{\theta}} \mathbb{E}_t\left[W(p^R,\theta,t)\right] g(\theta)d\theta +$$
$$\mu\left(BG(\Theta(B)) + A(1-G(\Theta(B))) + \int_{\Theta(B)}^{\bar{\theta}} \mathbb{E}_t\left[(p^R - p(t))q(p^R,\theta,t)\right] g(\theta)d\theta\right)$$

Using the fact that $\Delta(\Theta(B),B) = 0$, we have for an interior solution[17]:

$$\partial_B\mathcal{L} = \underbrace{g(\Theta(B))\Theta'(B)(1+\mu)\left(B - A - \mathbb{E}_t\left[(p^R - p(t))q(p^R,\Theta(B),t)\right]\right)}_{\leq 0} + \underbrace{\mu G(\Theta(B))}_{\geq 0}$$

When $\mu = 0$ (no budget constraint), we see that we get $\partial_B\mathcal{L} \leq 0$ for all B so that the retailer decreases B until full-enrollment is reached (implying $\Theta'(B) = 0$). When μ goes to infinity, $1+\mu$ can be replaced by μ and we retrieve the private monopoly pricing formula.

In our example, one can get two possible outcomes:

- **Full-enrollment ($a < 2\eta$):** when a is small enough, the budget constraint is not binding. Then any $B^* \in \left[0, \frac{\eta(2\eta-a)}{24b}\right]$ ensures both full-enrollment and budget balance.
- **Partial-enrollment ($a > 2\eta$):** when the budget constraint becomes binding, only partial enrollment is achievable. A benevolent monopoly then sets:

  $$B^* = \frac{a\eta(a-2\eta)}{24b(a-\eta)}$$

  A fraction $\Theta(B^*) = \frac{\eta}{a-\eta}$ of consumers ends up choosing the DR tariff.

Competitive environment:

We now consider the problem of entrant retailers under imperfect competition constrained to offer the frozen historical tariff to their consumers.

In our illustrative example, one can check that, for an interior solution, entrant retailers' equilibrium pricing would then be:

[17] Note that by denoting $c = A + \mathbb{E}_t\left[(p^R - p(t))q(p^R,\Theta(B),t)\right]$ (the opportunity cost of losing a consumer on the historical tariff) and $\eta(B) = -\frac{g(\Theta(B))\Theta'(B)}{BG(\Theta(B))}$ (the elasticity of 'demand') we retrieve the classic Ramsey-Boiteux formula:

$$\frac{B-c}{B} = \frac{\mu}{1+\mu}\frac{1}{\eta(B)}$$

$$B(\tau) = \tau + \tfrac{\eta}{24b}\left(a + \tfrac{\eta^2}{2(\eta-a)}\right) - \sqrt{\tau^2 + \tfrac{\eta^4}{576b^2(\eta-a)^2}\left(\tfrac{\eta}{2} - a\right)^2}$$

which indeed converges to the optimal outcome (with partial enrollment) as τ goes to zero.

The general proof remains to be written.

E Imperfect competition in the 'no cross-subsidies to non-switchers' case

For simplicity, we assume as in section 4.3 that competitors offer two-part RTP contracts, that is they pass-through variable costs and compete on the fixed fee B. Let τ be a parameter representing the level of competition ($\tau = 0$ meaning perfect competition among entrants, and $\tau = +\infty$ meaning entrants have (locally) perfect monopolies). Finally, in order to simplify notations, we assume that the population of consumers is such that for every equilibrium fixed fee $B(\tau)$ offered by entrant retailers, and a given outside option (A, p^R), there exists a threshold type $\hat{\theta}(\tau)$ such that all $\theta \leq \hat{\theta}(\tau)$ switch to the DR tariff, while all $\theta > \hat{\theta}(\tau)$ (see section 4.3 for a discussion of when these conditions are met).

Outside option (A, p^R):

We assume the historical monopoly retailer takes the population of non-switchers as given (he does not endogenize entrant retailers' response to his change in tariffs), that is he takes $\hat{\theta}(\tau)$ as exogenous. As shown in Joskow and Tirole (2006a), he will then set:

$$p^R = \max_p \int_{\hat{\theta}(\tau)}^{\bar{\theta}} \mathbb{E}_t\left[W(p,\theta,t)\right] g(\theta)d\theta$$

and

$$A = -\int_{\hat{\theta}(\tau)}^{\bar{\theta}} \mathbb{E}_t\left[(p^R - p(t))q(p^R,\theta,t)\right] g(\theta)d\theta$$

In particular, the first-order condition for p^R implies:

$$\int_{\hat{\theta}(\tau)}^{\bar{\theta}} \mathbb{E}_t\left[\partial_p W(p^R,\theta,t)\right] g(\theta)d\theta = 0$$

Entrant retailers:

Similarly, entrant retailers are assumed to take (A, p^R) as given. The threshold type $\hat{\theta}(\tau)$ will then be given by the indifference condition:

$$\mathbb{E}_t\left[V(p(t),\hat{\theta},t)\right] - B(\tau) = \mathbb{E}_t\left[V(p^R,\hat{\theta},t)\right] - A$$

Using the implicit function theorem:

$$\theta'(\tau) = \frac{B'(\tau)}{\mathbb{E}_t\left[\partial_\theta V(p(t),\hat{\theta},t) - \partial_\theta V(p^R,\hat{\theta},t)\right]}$$

We expect most models of imperfect competition to deliver $B'(\tau) > 0$. Besides, as explained in section 4.3, our simplifications regarding consumers' switching behavior imply that the denominator is negative. We then get:

$$\hat{\theta}'(\tau) < 0$$

Welfare and imperfect competition:

The aggregate social welfare for a given level of competition can now be written as:

$$W(\tau) = \int_{\underline{\theta}}^{\hat{\theta}(\tau)} \mathbb{E}_t\left[W^{RTP}(\theta,t)\right] g(\theta)d\theta + \int_{\hat{\theta}(\tau)}^{\bar{\theta}} \mathbb{E}_t\left[W(p^R(\tau),\theta,t)\right] g(\theta)d\theta$$

Differentiation w.r.t. τ then yields:

$$W'(\tau) = (p^R)'(\tau)\int_{\hat{\theta}(\tau)}^{\bar{\theta}} \mathbb{E}_t\left[\partial_p W(p^R(\tau),\theta,t)\right] g(\theta)d\theta + \hat{\theta}'(\tau)\left(\mathbb{E}_t\left[W^{RTP}(\hat{\theta}(\tau),t) - W(p^R(\tau),\hat{\theta}(\tau),t)\right]\right) g(\hat{\theta}(\tau))$$

The first-term is equal to zero due to the first-order condition regarding p^R. Besides, by definition $W^{RTP}(\hat{\theta}(\tau),t) > W(p^R(\tau),\hat{\theta}(\tau),t)$, so we get as expected:

$$W'(\tau) \leq 0$$

Remark: if instead of two-part RTP, entrant retailers were offering other types of DR contracts, the first-term of the social welfare formula would be of the form:

$$\int_{\underline{\theta}}^{\hat{\theta}(\tau)} \mathbb{E}_t\left[W^{IP}(\theta,t,\tau)\right] g(\theta)d\theta$$

meaning it would add a term:

$$\int_{\underline{\theta}}^{\hat{\theta}(\tau)} \mathbb{E}_t\left[\partial_\tau W^{IP}(\theta,t,\tau)\right] g(\theta)d\theta$$

to the derivative of welfare. However, since more market power most likely means more price distortions, we expect to have $\partial_\tau W^{IP}(\theta, t, \tau) < 0$. This effect would thus add to the welfare decreasing impact of imperfect competition. However, the sign of the second term of the derivative of welfare would become ambiguous ($W^{IP}(\hat{\theta}(\tau), t, \tau) >$ or $< W(p^R(\tau), \hat{\theta}(\tau), t)$? Or equivalently, is the entrant retailers profit on marginal consumers higher than the profit the historical was making with the tariff (A, p^R)?), so we leave this more general setting for further research.

References

Barbara R. Alexander. Dynamic Pricing? Not So Fast! A Residential Consumer Perspective. *The Electricity Journal*, 23(6):39–49, July 2010. ISSN 10406190. doi: 10.1016/j.tej.2010.05.014. URL `http://linkinghub.elsevier.com/retrieve/pii/S1040619010001417`.

Hunt Allcott. Rethinking real-time electricity pricing. *Resource and Energy Economics*, 33(4):820–842, November 2011. ISSN 09287655. doi: 10.1016/j.reseneeco.2011.06.003. URL `http://linkinghub.elsevier.com/retrieve/pii/S092876551100042X`.

Christophe Aubin, Denis Fougère, Emmanuel Husson, and Marc Ivaldi. Real-Time Pricing of Electricity for Residential Customers: Economic Analysis of an Experiment. *Journal of Applied Econometrics*, 10:171–191, 1995.

Roland Bénabou and Jean Tirole. Bonus Culture: Competitive Pay, Screening, and Multitasking. *Journal of Political Economy*, 124(2):305–370, April 2016. URL `https://ideas.repec.org/p/iza/izadps/dp7321.html`.

Marcel Boiteux. La Tarification des Demandes en Pointe: Application de la Théorie de la Vente au Coût Marginal. *Revue Générale de l'Electricité*, LVIII(8), 1949.

Severin Borenstein. The Long-Run Efficiency of Real-Time Electricity Pricing. *The Energy Journal*, 26(3):93–116, 2005.

Severin Borenstein. Wealth Transfers Among Large Customers from Implementing Real-Time Retail Electricity Pricing. *The Energy Journal*, 28(2):131–149, 2007.

Severin Borenstein. Effective and Equitable Adoption of Opt-In Residential Dynamic Electricity Pricing. *Review of Industrial Organization*, 42(2):127–160, 2013.

Severin Borenstein and Stephen Holland. On the efficiency of competitive electricity markets with time-invariant retail prices. *The RAND Journal of Economics*, 36(3):469–493, 2005.

Hung-po Chao. Price-Responsive Demand Management for a Smart Grid World. *The Electricity Journal*, 23(1):7–20, 2010.

Hung-po Chao and Mario DePillis. Incentive effects of paying demand response in wholesale electricity markets. *Journal of Regulatory Economics*, 43:265–283, 2013. ISSN 0922-680X. doi: 10.1007/s11149-012-9208-1. URL `http://link.springer.com/10.1007/s11149-012-9208-1$\backslash$nhttp://link.springer.com/article/10.1007/s11149-012-9208-1`.

Xu Chen and Andrew N Kleit. Money for Nothing? Why FERC Order 745 Should have Died. *The Energy Journal*, 37(2):201–222, 2016.

Claude Crampes and Thomas-Olivier Léautier. Distributed Load-Shedding in the Balancing of Electricity Markets. 2012.

Claude Crampes and Thomas-Olivier Léautier. Demand response in adjustment markets for electricity. *Journal of Regulatory Economics*, pages 1–33, 2015.

David Dranove and Ginger Zhe Jin. Quality Disclosure and Certification: Theory and Practice. *Journal of Economic Literature*, 48(4):935–963, 2010. ISSN 0022-0515. doi: 10.1257/jel.48.4.935.

EnerNoc. The Demand Response Baseline, 2009.

EPRI. Paying Upfront: A Review of Salt River Project's M- Power Prepaid Program. Technical report, 2010.

Ahmad Faruqui and Stephen George. Quantifying Customer Response to Dynamic Pricing. *The Electricity Journal*, 18(4):53–63, 2005.

Ahmad Faruqui and Sanem Sergici. Household response to dynamic pricing of electricity: a survey of 15 experiments. *Journal of Regulatory Economics*, 38(2):193–225, August 2010. ISSN 0922-680X. doi: 10.1007/s11149-010-9127-y. URL `http://link.springer.com/10.1007/s11149-010-9127-y`.

Steve A Fenrick, Lullit Getachew, Chris Ivanov, and Jeff Smith. Demand Impact of a Critical Peak Pricing Program: Opt-in and Opt-out Options, Green Attitudes and Other Customer Characteristics. *The Energy Journal*, 35(3):1–24, 2014.

FERC, June 2013. URL http://www.ferc.gov/enforcement/civil-penalties/actions/143FERC61218.pdf.

Clifford Grimm. Evaluating Baselines for Demand Response Programs. In *AEIC Load Research Workshop, San Antonio, Texas, February 25-27*, 2008.

William W Hogan. Demand Response Pricing in Organized Wholesale Markets, 2010.

Koichiro Ito. Asymmetric Incentives in Subsidies: Evidence from a Large-Scale Electricity Rebate Program Koichiro Ito September 2013 Asymmetric Incentives in Subsidies : Evidence from a Large-Scale Electricity Rebate Program Koichiro Ito. 2013.

Akshaya Jha and Frank A Wolak. Testing for market efficiency with transaction costs: An application to financial trading in wholesale electricity markets. September 2015.

Joint Research Center. Smart grid projects outlook 2014. Technical report, European Commission, 2014.

Paul Joskow and Donald Marron. What Does a Negawatt Really Cost ? Evidence from Utility Conservation Programs. *The Energy Journal*, 13 (4):41–71, 1992.

Paul Joskow and Jean Tirole. Retail Electricity Competition. *Rand*, pages 1–25, 2006a.

Paul Joskow and Jean Tirole. Reliability and competitive electricity markets. *Rand*, pages 1–38, 2006b.

Paul Joskow and Catherine D Wolfram. Dynamic Pricing of Electricity. *American Economic Review*, 102(3):381–385, May 2012. ISSN 0002-8282. doi: 10.1257/aer.102.3.381. URL http://pubs.aeaweb.org/doi/abs/10.1257/aer.102.3.381.

Bruno Jullien. Participation Constraints in Adverse Selection Models. *Journal of Economic Theory*, 93:1–47, 2000.

Emir Kamenica, Sendhil Mullainathan, and Richard Thaler. Helping consumers know themselves. *American Economic Review*, 101:417–422, 2011. ISSN 00028282. doi: 10.1257/aer.101.3.417.

Jean-Jacques Laffont and Jean Tirole. *A Theory of Incentives in Procurement and Regulation*. MIT Press, 1993.

Robert Letzler. Using Incentive Preserving Rebates to Increase Acceptance of Critical Peak Electricity Pricing. 2010.

Guy R. Newsham and Brent G. Bowker. The effect of utility time-varying pricing and load control strategies on residential summer peak electricity use: A review. *Energy Policy*, 38(7):3289–3296, July 2010. ISSN 03014215. doi: 10.1016/j.enpol.2010.01.027. URL `http://linkinghub.elsevier.com/retrieve/pii/S0301421510000510`.

Guy R. Newsham, Benjamin J. Birt, and Ian H. Rowlands. A comparison of four methods to evaluate the effect of a utility residential air-conditioner load control program on peak electricity use. *Energy Policy*, 39(10):6376–6389, October 2011. ISSN 03014215. doi: 10.1016/j.enpol.2011.07.038. URL `http://linkinghub.elsevier.com/retrieve/pii/S0301421511005702`.

Evens Salies and Catherine Waddams Price. Charges, Costs and Market Power: the Deregulated UK Electricity Retail Market. *The Energy Journal*, 25(3):19–35, 2004.

F.C. Schweppe, M.C. Caramanis, R.D. Tabors, and R.E. Bohn. *Spot Pricing of Electricity*. Power Electronics and Power Systems. Springer US, 1988. ISBN 9780898382600. URL `https://books.google.fr/books?id=Sg5zRPWrZ\_gC`.

Daniel F. Spulber. Optimal nonlinear pricing and contingent contracts. *International Economic Review*, 33(4):747–772, 1992.

Frank A Wolak. Residential customer response to real-time pricing: The anaheim critical peak pricing experiment. 2007.

Frank A Wolak. An Experimental Comparison of Critical Peak and Hourly Pricing: The PowerCentsDC Program. 2010.

Frank A Wolak. Managing Demand-Side Economic and Political Constraints on Electricity Industry Restructuring Processes. 2011.