Self-Selection in Retail Electricity Contracts

Competition, Regulation, and Welfare Implications

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Abstract.

We develop a model where consumers self-select into different electricity contracts based on heterogeneity in their willingness to pay, which varies over time. We characterize the demand for two contracts: (i) a fixed-price contract and (ii) a real-time pricing contract. We then derive the contract price equilibrium under two market structures that determine which firms set the fixed price: one with competitive retailers and another with a regulated monopoly. Under retail competition, selection effects make the fixed-price contract unprofitable, leading to the first-best outcome. In contrast, a regulated monopoly must account for consumers' outside options, which can result in lower social welfare compared to a setting where real-time pricing is unavailable. Finally, we extend the model to explore cross-subsidies when consumer types are private information and discuss potential extensions to renewable integration and more complex consumer behaviors.

1 Introduction

Economists have long advocated retail electricity contracts replicating wholesale prices as one of the key policies to enhance the functioning of electricity markets. In the context of a market for a non-storable homogeneous good with stochastic demand, transmitting the proper temporal and spatial price signal increases consumer surplus in the short run and welfare in the long run. It reduces the consumption misallocation between different periods (Borenstein, 2005b) and market power (Poletti and Wright, 2020). It avoids having to keep some peak suppliers available who are usually the ones emitting the most (Borenstein and Bushnell, 2021). Building the proper incentives for efficient energy consumption is all the more critical in an energy transition context. On the supply side, decarbonization implies switching from certain but polluting fuel-based producers to uncertain but clean renewable technologies. Therefore, their stochastic nature could threaten the reliability of the electricity system, which makes the transmission of the price signals all the more crucial (Imelda et al., 2024). On the demand side, the electrification of our end-usage is another face of a successful energy transition. Without proper incentives, the use of these new technologies, like storage of electric vehicles, could unnecessarily increase demand during peak hours (Bailey et al., 2024).

Although contracts allowing consumers to meet short-term marginal costs are considered both by policymakers and academics a sure way of reducing the cost of electricity systems, the adoption of these contracts on a voluntary basis in the retail market is a failure. According to recent surveys, 74% of European and 81% of US households are under fixed-price electricity contracts (ACER, 2024; Schittekatte et al., 2024). These relatively high numbers are not due to the absence of technology or contract choices.[1] Most households in the largest electricity markets - 80% of European households and 75% of US households - have a smart meter (Kavulla, 2023; ACER, 2024). Moreover, when both dynamics and fixed contracts are offered, recent studies have shown that the switching decision to dynamics contracts remains relatively low (Fowlie et al., 2021).

To understand such a low adoption rate, we develop in this paper a model in which end-user consumers with varying willingness to pay for electricity can select their contract within a menu in the context of a retail electricity market. We focus on two contracts: a fixed-price (FP) contract and a real-time pricing (RTP) contract that perfectly replicates the wholesale market price.[2] We focus on the consumers' choice for at least two reasons. Economists have advocated that having an energy transition based on well-designed markets can generate significant efficiency (e.g., Fabra

[1]Having the right metering technology has been shown to be crucial in the efficiency of dynamic contracts, notably by providing information to consumers (Jessoe and Rapson, 2014; Bollinger and Hartmann, 2020).

[2]There is a significant diversity of contracts that introduce temporal variation in price. See Cabot and Villavicencio (2024) for a recent literature survey of current industrial practice.

(2022) and Ambec et al. (2023)), and some jurisdictions, such as the European internal market for electricity, emphasized that institutions should be organized to deliver choices for final consumers (European Parliament, 2019). Hence, it is crucial to understand how those choices emerge and potentially deviate from the first-best outcome.[3]

Our paper has several contributions: *i*) We propose a selection model that can rely on a detailed level of consumer characteristics both for short-run consumption decisions and also for long-run appliance and investment decisions.[4] The present model is based on consumers who are characterized by a two-dimensional type describing their profile of willingness to pay over two periods. It allows future research in two different extensions: (a) incorporate additional consumer characteristics that can impact or be related to the willingness to pay and (b) calibrate our model to consumer data and establish links between observable and unobservable data.[5] *ii*) We study how different market structures affect contract choices via contract price equilibrium. By formalizing the demand for contracts, we can derive the best response from private and public firms when making pricing decisions.[6] We notably study two cases: when competitive retailers provide a fixed-price contract and when it is offered by a regulated monopoly. *iii*) Given consumer heterogeneity, we can study the most efficient intervention in the context of private information. Indeed, for a utilitarian social planner, the first best is reached when all consumers face real-time prices. Therefore, given the selection equilibrium, the set of consumer characteristics, and the market structure, our model can provide a characterization of the optimal intervention to foster enrollment in RTP contracts. *iv*) Finally, by studying the equilibrium choices in terms of contracts, we can estimate their impact on the wholesale market. Indeed, the model establishes a direct link between wholesale prices and the demand for contracts, which in turn determines the final demand for electricity as well as its pattern. Therefore, we can shed light on which conditions consumers' contract choices can limit or foster the development of clean production technologies.

In the model, consumers can choose either an RTP contract that perfectly replicates prices on the wholesale market and leads to the first-best outcome or a fixed-price contract. Following Joskow and Tirole (2006), we define the fixed price differently depending on whether it is chosen by

[3]Electricity markets exhibit significantly imperfect information, which can generate adverse selection and moral hazards. Therefore, regulation and market design need to take into account the potential deviation of consumers when facing different choices in terms of contracts. Understanding those deviations would help tailor public intervention.

[4]See, for instance, for a similar spirit, the application to water use (Burlig et al., 2024), or investment in solar panels (Feger et al., 2022).

[5]A two-dimensional type is sufficient to derive the main theoretical solutions. Extending the number of periods will require simulation-based methods but allow the calibration of the model to actual consumption profiles. Other characteristics are related to income or social weight. We also consider ex-ante technological choices that could determine the willingness to pay during the consumption period, such as electric vehicles or batteries.

[6]In this paper, we derive the main results by assuming the set and characteristics of contracts as fixed. For future research, we leave the question of equilibrium in terms of menu characteristics. For instance, this issue relates to the question of representing competition for non-linear tariffs (Stole, 2007), or how insurance companies can offer a menu of the contracts given incomplete information (Rothschild and Stiglitz, 1976; Dosis, 2022).

a set of competitive retailers or by a regulated monopoly. In the first case, competitive forces drive profit to zero, and in the second case, the regulated firm maximizes the surplus of its consumers, given some budget constraints.

We then characterize the demand for each contract given a vector of contract prices. In other words, as a pair of willingness to pay defines each consumer, we are able to describe which set of consumers selects a contract that maximizes its utility, given two outside options, which are respectively not consuming or enrolling in the other contract. Consumers with a relatively higher willingness to pay during off-peak periods tend to select the RTP contract. Meanwhile, consumers with a higher willingness to pay during the on-peak period choose the FP contract. In this model, one crucial element is the comparison between the average price faced by consumers on the RTP contract and the value of the fixed price.

In the next step, we study how different market structures in the retail market lead to specific price equilibrium given the demand for contracts previously defined. In the case where retailers offer the fixed-price contract, we show that an equilibrium cannot exist in which some consumers choose the fixed-price contract. The competitive pressure forcing retailers to have a null profit implies that having consumers in the fixed price contract is never profitable. On the other hand, we find that a regulated monopoly offering a fixed-price contract can lead to a situation where not all consumers switch to the RTP contract. We notably provide a new formulation of the price set by the regulated monopoly, which depends both on the derivatives of the demand for contracts and on the substitution effect between RTP and FP contracts.

With this result in hand, we cannot leave out the case in which having a regulated monopoly and consumers who can select RTP contracts leads to lower welfare compared to the benchmark case where there is only a fixed-price contract. When setting the fixed price, the public firm has to take into account that a specific set of consumers are leaving for the RTP contract. It can incite the monopoly to lower the fixed price below the benchmark case to avoid this leakage. In addition, it allows more consumers to consume during the on-peak period while their willingness to pay is below the wholesale price. Therefore, the welfare gains from having consumers under the RTP contract can be offset by this over-consumption during the peak period. In other words, the regulated monopoly does not internalize the negative externalities generated when maximizing the surplus of its consumers staying in the FP contract. It has significant political implications, as we show that some market structures can lead to low acceptance of RTP contracts, even in the absence of any behavioral bias on the part of consumers.[7]

[7]While having different roots, this issue is similar to the concept of Utility Death Spiral. When some consumers, usually the wealthier, disconnect from the grid, the tariffs to cover investment increases proportionally (Borenstein,

Finally, we discuss multiple extensions to the model. In a first set of results, we show that private information prevents any cross-subsidies between consumers to foster enrollment into the RTP contract. When the consumption profile is not based on their type, consumers under the RTP contract always have the incentive to act as consumers who are indifferent between the two contracts, which constrain transfers to be effectively null. We then discuss the implementation of a more realistic supply side in the model, as well as more detailed consumer decisions.

The paper is structured as follows. Section 2 introduces the model framework. Section 3 describes the demand for the different contracts given consumer type. Section 4 studies how contract prices are set depending on two different market structures, and Section 5 presents the welfare implications. Section 6 discusses some extensions of the model, and Section 7 concludes.

Related Literature

This paper relates to several strands of the literature on real-time pricing and electricity markets. We notably contribute to two main research questions: *i*) how consumers select electricity contracts and *ii*) the consequences of different market structures on welfare.

It has been extensively shown that, in theory, dynamic prices are welfare-improving for electricity markets. Boiteux (1949) has laid the conceptual analysis, which was confirmed by a canonical series of papers (Borenstein and Holland, 2003; Borenstein, 2005b,a). Surprisingly, there have been few papers that extensively study the consequences of having consumers assigned to multiple contracts. Those papers describe the effects of an increase in the share of consumers under RTP contract on long-term investment decisions (Borenstein, 2005b), the comparison between their social gains with the investment cost of smart meters (Leautier, 2014), their interactions with renewable technologies (Ambec and Crampes, 2021) or when consumers are risk-averse (Boom and Schwenen, 2021). However, there are two main caveats that we wish to overcome with this paper: *i*) consumers are considered homogeneous, having the same demand profile up to a constant,[8] and *ii*) the share of consumers under dynamic contract is exogenous. Therefore, our self-selection model provides a micro-founded demand for contracts from heterogeneous consumers, which allows us to understand selection outcomes and their consequences for electricity markets.

2012). Here, we show the inverse. Due to consumers switching to another contract, the price decreases, which generates welfare losses.

[8] Our model encompasses consumer heterogeneity with different willingness to pay over two periods. Hence, our paper builds on the growing literature that stresses the importance of considering differences in consumer characteristics when designing and regulating electricity markets. Recent papers primarily focused on the redistributive aspect of dynamic prices for consumers both, in theory, (Blonz, 2022) and empirically, (Leslie et al., 2021; Levinson and Silva, 2022; Cahana et al., 2023). However, they focus on the effect of a single contract. In this paper, we formalize the impact of having different contracts in terms of surplus that have been raised in Borenstein (2013) and Joskow and Wolfram (2012).

Such theoretical results have led to many empirical papers analyzing dynamics contract experiments. They mainly study the consequences of exposing consumers to dynamic prices, which have led to little consensus on a significant change in electricity consumption (Fabra et al., 2021; Han et al., 2023; Enrich et al., 2024; Fu et al., 2024). However, The issue of selection, and especially adverse selection, has remained understudied. Ito et al. (2023) finds that price-elastic consumers in electricity markets who generate more considerable welfare gains are more likely to self-select. On the other hand, Fowlie et al. (2021) finds that customers who should expect to have lower bills on the program without changing their behavior were no more likely to enroll in the program. Their papers and ours are notably inspired by a renewed interest in adverse selection that differentiates between *selection on the level* and *selection on the slope* (Einav et al., 2012, 2021). We propose a theoretical foundation to understand the effect of the selection on the level and its consequences in terms of welfare in the context of the electricity market.[9] Behavioral biases have also been advanced to explain the low uptake dynamic price contracts, such as search friction and brand advantages (Hortaçsu et al., 2017), inattention (Fowlie et al., 2021) or risk aversion (Qiu et al., 2017). While we have not yet represented any bias, we believe that the model we propose could easily adapt them. However, the net welfare effect would remain an empirical question in that case.

Our analysis of different market structures in the retail electricity market is in line with the founding paper of Joskow and Tirole (2006) in which various environment is considered but without consumer self-selecting in contracts. Astier and Léautier (2021) also analyzes the effect of competition and public regulation on consumers with different contracts. However, their modeling assumptions are different, with notably single-type consumers. Our main result on the regulated monopoly price generating lower welfare is also close to the work of Martimort et al. (2020). They show that the public firm is biased against competitive retailers and that prices may be strategically used to promote the government's redistribution objective. More generally, we are contributing to the literature on the coexistence of a public and a private market (see, for instance, Kang (2023)). Issues with private information in the context of electricity pricing remain sparsely studied.[10] Chao and DePillis (2013) shows how the design of a specific dynamic contract might lead to strategic deviation from consumers, and Astier and Léautier (2021) design incentive-compatible contracts. Our results with incomplete information provide notably new insight into the question

[9] In the current version of the model, consumers differ by the level of their willingness to pay, and they have a unit demand per period. Following *Ito* (2014), *selection on the slope* would require some form of price elasticity of demand for a single period. In the extension section, we discuss the possibility of extending our model to include long-term consumer decisions that may also generate some form of adverse selection. It is in the same spirit of the durable good literature that has been discussed in the context of incomplete information in Einav et al. (2021).

[10] Note that both Martimort et al. (2020) and Kang (2023) develop a model in which consumer valuation is private information.

of the cross-subsidies between consumers to increase the adoption of dynamic contracts that have been discussed notably in Joskow and Wolfram (2012) and Borenstein (2013).

2 The model

2.1 The environment

Agents. A unit measure of *consumers* on a retail electricity market wishes to purchase one unit of electricity each period, over two periods $t = 1, 2$. Electricity is produced by identical *firms* operating in a wholesale market. We assume *retailers* operate between the wholesale and the retail electricity market. Retailers purchase electricity from firms on the wholesale market and sell electricity contracts: a commitment to deliver one unit of electricity each period at price $\mathbf{p} = (p_1, p_2)$, on the retail market.

Wholesale market. Firms can produce q units of electricity in period t at a linear cost $C_t(q) = c_t q$. Marginal costs c_t differ across periods, and we assume without loss of generality that $c_1 < c_2$. We denote the off-peak period as period 1 and the on-peak period as period 2.[11] We assume that suppliers in the wholesale market are perfectly competitive. Hence, wholesale prices are determined by the marginal cost of production.

Retail market. In the retail market, we also assume perfect competition for the retailers and that firms do not sustain additional costs beyond the cost of purchasing electricity in the wholesale market. We consider the contract characteristics as given, and retailers can only offer at most two types of contracts: *fixed-price* contracts ($p_1 = p_2$), noted FP, and *real-time pricing* contracts in which prices can vary depending on the period, noted RTP.

Consumers. Consumers are characterized by a two-dimensional type $\mathbf{v} = (v_1, v_2) \in V$, capturing their willingness to pay each period. Types are independent across periods and drawn from a continuous uniform cumulative distribution function $F_t(v)$ with support $\omega_t = [\underline{v}_t, \bar{v}_t]$, and let $\epsilon_t = \bar{v}_t - \underline{v}_t$ denote the range of the support. The corresponding density is denoted by f_t. For analytical tractability, we assume the following affine relationship between period 1 and 2 willingness to pay distribution supports.[12]

[11] In this current version of the model, we assume that the cost variability defines the off-peak/on-peak period. It corresponds to an electricity market with substantial penetration of renewable energy, the availability of which differs exogenously from period to period. For instance, period 2 corresponds to the case where the wind is not blowing or there is no sun. Hence, power plants with higher marginal costs have to be run to satisfy demand. Assuming that the demand level also defines the different periods would be more realistic but requires introducing capacity constraints. We discuss the addition of investment decisions in the Extensions section.

[12] Note that both terms affect the price elasticity of the electricity demand in period 2. An increase in α always increases the elasticity, and the effect of β depends on the value of α. β is the only parameter affecting the range of the range support ϵ_2.

Assumption. $[\underline{v}_2, \bar{v}_2] = [\alpha + \beta\underline{v}_1, \alpha + \beta\bar{v}_1]$ *where* $\alpha, \beta \in \mathbb{R}$.

Type $\mathbf{v}$ consumer surplus from consuming at prices $\mathbf{p}$ is

$$U(\mathbf{v}, \mathbf{p}) = \langle v_1 - p_1 \rangle^+ + \langle v_2 - p_2 \rangle^+$$

Where we implicitly assume zero surpluses if consumers do not consume.

Information We assume that the consumers' willingness to pay is private information.[13] The support and the distribution functions are common knowledge. All the other parameters of the model are also assumed to be common knowledge. There is no uncertainty in this current version of the model.

Timing The extensive form of the game played by the firms and consumers is described below.

- **Stage 1** Consumers draw their types $\mathbf{v}$
- **Stage 2** Each retailer offers a contract.
- **Stage 3** Each consumer selects at most one contract or exits the market
- **Stage 4** Each consumer purchases at most one 1 unit of electricity during period 1 and period 2 at their chosen contract price.

2.2 Consumer contract decision

We now describe the behavior of a consumer who has to select a generic contract k with price $\mathbf{p}^k = (p_1^k, p_2^k)$. Suppose consumers have an outside option contract with price $\mathbf{p}^o = (p_1^o, p_2^o)$.[14] A consumer selects an electricity contract $\mathbf{p}^k$ if its payoff is greater than the outside option,

$$U(\mathbf{v}, \mathbf{p}) \geq U(\mathbf{v}, \mathbf{p}^o)$$

Let $S^k \equiv S^k(\mathbf{p}^k, \mathbf{p}^o) = \{\mathbf{v} \in V : U(\mathbf{v}, \mathbf{p}^k) \geq U(\mathbf{v}, \mathbf{p}^o) > 0\}$ denote the set of consumers selecting contract $\mathbf{p}^k$. Notice that two conditions must be met: *i*) selecting the contract must yield a strictly positive payoff, and *ii*) the consumer must be at least better off than consuming with the outside option contract. Let $S_t^k \equiv S_t^k(\mathbf{p}^k, S^k) = \{\mathbf{v} \in S^k : v_t - p_t^k > 0\}$ denote the set of

[13] For the main results of the paper, this does not change the primary intuitions of considering public information are we are studying a self-selection problem given a set of already defined contracts. In the Extensions section, we discuss the implications of having private information when modifying the type of contracts offered to consumers.

[14] When there is a single contract, the outside option is not to consume that is $p_t^o = 0$. In the next section, it will also be a competing electricity contract. For simplicity, we consider two outside options (not consuming or another contract), but the model could be generalized to more. Equivalently, $\mathbf{p}^o$ can be considered as the best outside option.

consumers subscribing to contract $\mathbf{p}^k$ who consume in period t. Note that we implicitly assume that consumers purchase electricity only if it yields a positive surplus, but this is without loss of generality. We could suppose agents randomize over both options. Note also our assumption $\bar{v}_t > c_t$ for all t ensures S_t is non-empty, i.e., demand for electricity is positive at market price, each period. Moreover, the quantity of electricity sold at a price p is given by the mass of subscribers with willingness to pay greater or equal to p. Therefore, period t electricity demand from contract k subscribers is given by

$$q_t^k \equiv q_t^k(S_t^k) = \int_{S_t^k} f_t(v)dv \tag{1}$$

The demand for a contract is the union of the two sets: $S^k = S_1^k \cup S_2^k$. Therefore, the mass of consumers choosing a contract is given by:

$$\mu_k(S^k) = \iint_{S^k} f(\mathbf{v})d\mathbf{v} \tag{2}$$

The surplus of consumers having selected the contract k is

$$CS^k(\mathbf{p}^k, A) = \sum_{t=1,2} \int_{S_t} (v - p_t^k) f_t(v)dv - A. \tag{3}$$

Where $A \in \mathbb{R}$ denotes transfers or taxes[15].

We illustrate with a simple example how quantities are determined in the model in Figure 1. We assume no outside option besides not consuming. There are four distinct areas given $\mathbf{p}^k = (p_1^k, p_2^k)$: when both willingness to pay is low, consumers do not consume, and we assume he is not choosing the contract (white area). When v_1 is high, but v_2 is low, consumers only consume during period 1 (green area). When v_2 is high, but v_1 is low, consumers only consume during period 2 (blue area). When both willingness to pay are high, consumers consume in the two periods. Note that in this example, there is a difference between the demand for the contract μ_k and the aggregate quantity consumed over the two periods q_1^k and q_2^k. Namely, μ_k corresponds to the sum of the mass in each area, which is lower than the total quantity of electricity consumed.

2.3 Firms behavior on the retail market

We assume that only retailers offer the RTP contract defined by a price profile $\mathbf{p}^s = (p_1, p_2)$. Due to perfect competition in the wholesale market and in the absence of other costs, retailers' costs

[15]They could be charged either by firms or by a public entity. We remain agnostic so far on its origin.

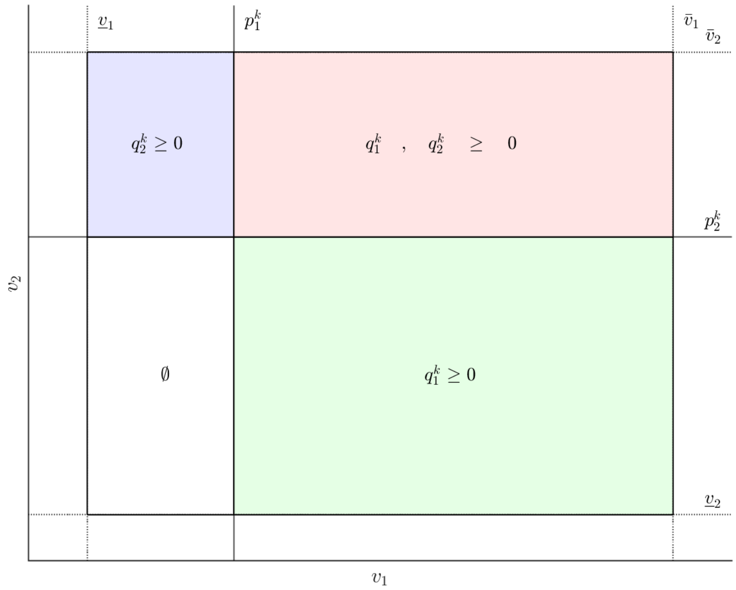

Figure 1: Example of how the quantity is determined in the model given the distribution of types. Here, we assume there is only one outside option, which is not to consume.

are equal to the marginal production costs. Therefore, retailers' profit with RTP contracts can be written as:

$$\pi^s(p_1, p_2) = \sum_{t=\{1,2\}} q_t^s(p_t)(p_t - c_t) \tag{4}$$

With $q_t^s(p_r)$, the quantity of electricity consumed by consumers who chose the RTP contract. Competitive forces drive retailers' profit to zero. Therefore, the equilibrium for the RTP contract is given $p_t = c_t$ (Joskow and Tirole, 2006).

We consider two market structures for the FP contract defined by a price profile $\mathbf{p}^r = (p_r, p_r)$. The contract is offered either by the same competitive retailers or by a regulated monopoly. With private firms, the equilibrium price p_r is pinned down by the zero profit condition, with the profit defined as:

$$\pi^r(p_r) = \sum_{t=\{1,2\}} q_t^r(p_r)(p_r - p_t) \tag{5}$$

With $q_t^r(p_r)$ is the quantity of electricity consumed by consumers who chose the FP contract. Under a regulated monopoly, the objective of the public firm is to maximize the consumer surplus[16] subject to the firm budget constraints by choosing a variable price corresponding to p_r and some lump-sum transfers A. The program can be written as follows:

$$\max_{p_r, A} CS(p_r, A) \qquad \text{s.t.} \quad A + \sum_{t=1,2} \int_{S_t(p_t)} (p_r - p_t) f_t(v) dv \geq 0 \tag{6}$$

2.4 Benchmark case: single contract

This section recalls the benchmark case, in which consumers have only a single contract for electricity, and the only outside option is not to consume it.

In line with the literature, the highest welfare is therefore achieved by setting $p_t = c_t$, which is the outcome for perfectly competitive retailers (Joskow and Tirole, 2006). Thus, if the single contract offered is the RTP contract, it leads to the first-best outcome. Indeed, with constant marginal cost and perfect competition in both markets, social welfare is the sum of consumer valuation from which we remove the production cost. It is formally defined as follows:

$$W(\mathbf{p}) = \sum_{t=1,2} \int_{S_t} (v_t - c_t) f_t(v) dv \tag{7}$$

When only the FP contract is offered, the outcome depends on the market structure. With private firms, the zero profit condition implies

$$p_r = \frac{p_1 q_1^r(p_r) + p_2 q_2^r(p_r)}{q_1^r(p_r) + q_2^r(p_r)} \tag{8}$$

It corresponds to the demand-weighted wholesale cost of retailers purchasing from the wholesale market. When the regulated firm offers the FP contract, then p_r solves:

$$p_r = \frac{p_1 q_1^{r'}(p_r) + p_2 q_2^{r'}(p_r)}{q_1^{r'}(p_r) + q_2^{r'}(p_r)} \tag{9}$$

The fixed price depends on the marginal demand ($q_t^{r'}$) weighted average wholesale cost. When setting p_r, a regulated monopoly trades off consumer surplus and budget balance. A marginal increase in p_r: *i*) decreases the consumer surplus, and *ii*) avoids some of the production cost of supplying consumers.

[16] With a single contract, the monopoly is concerned about the surplus of every consumer in the electricity market. In the next section, with the two contracts, the monopoly maximizes the consumer surplus of only the subscribers of the FP contract.

We conclude this section by providing a welfare ranking between the two market structures in the context of a single contract:

Result 1. *For any values of β and α such that $\bar{v}_1(1-\beta)=\alpha$, the two market structures provide the same welfare. Otherwise, the price implemented by the regulated monopoly dominates the retailers' equilibrium price*

The condition on β and α in the result does not imply that the demand, or its derivative, over the two periods are equal. Still, instead, the share of the demand and its derivative are equal in each period. It leads to p_r being identical in the two environments.

3 Demand for contracts

In that section, we study the case in which consumers can choose between an RTP contract $\mathbf{p}^s=(p_1,p_2)$ and an exogenous fixed price contract $\mathbf{p}^r=(p_r,p_r)$ where $p_r\in[p_1,p_2]$. We are looking to derive the demand for a contract given the contract prices and consumers' willingness to pay.[17] We do so by first describing the set of consumers that are indifferent when choosing the two contracts. Then, we derive the condition on the willingness to pay that determines the demand of consumers for each contract. We conclude by establishing the link between the demand for the contracts and the aggregate consumption during each period and by deriving some comparative statics on this demand with respect to some model parameters.

Type $\mathbf{v}$ consumers choose the RTP contract if and only if $U(\mathbf{v},\mathbf{p}^s)\geq U(\mathbf{v},\mathbf{p}^r)$ which rewrites

$$\langle v_1-c_1\rangle^+ + \langle v_2-c_2\rangle^+ \geq \langle v_1-p_r\rangle^+ + \langle v_2-p_r\rangle^+$$

The characterization of the demand for each contract relies on two ingredients: *i*) the set of consumers indifferent between the two contracts, and *ii*) the relation between the average price of the RTP contracts that we denote $\tilde{p}=(p_1+p_2)\frac{1}{2}$ and the fixed price p_r. Note that for the sake of clarity, we drop the analysis of the consumers who do not consume. In this context, it concerns consumers with low type in both willingness to pay, which are comprised in the set $S_0=[\underline{v}_1,p_1]\times[\underline{v}_2,p_r]$.

Let $S^i(\mathbf{p}^s,\mathbf{p}^r)=\{\mathbf{v}:U(\mathbf{v},\mathbf{p}^s)=U(\mathbf{v},\mathbf{p}^r)>0\}$ denote the set of types who subscribe to an electricity contract, so earn a positive payoff, but are indifferent between both. First, note that the set $S^i(\mathbf{p}^r,\mathbf{p}^r)$ is composed of two different subsets of consumers:

[17] In this model, this is equivalent to determining the mass of consumers that select a contract.

- Consumers who are indifferent between consuming in period 1 under the RTP contract and consuming in period 2 under the FP contract. Let $S^i_a(\mathbf{p}^s, \mathbf{p}^r)$ denote this subset.

- Consumers who are indifferent between consuming in the two periods under a contract k with price profile $\mathbf{p}^k$, and consuming in a single period under the other contract with price p_m with $m \in \{1, r\}$. Let $S^i_b(\mathbf{p}^s, \mathbf{p}^r)$ denote this subset.

This distinction between the two different types of indifferent consumers is crucial for understanding how the demand for contracts is formed. It highlights that, when making contract choices, consumers do not only compare price profiles but also consumption profiles (i.e., consuming during one or two periods under a contract and consuming during one or two periods under the other contract). The following Lemma describes how the relation between the fixed price p_r and the average real-time price $\tilde{p}$ pinned down the second type of indifferent consumer (S^i_b).

Lemma 1. *Given a set of contract price $\boldsymbol{p}^s = (p_1, p_2)$ and $\boldsymbol{p}^r = (p_r, p_r)$,*

- *When $p_r < \tilde{p}$, the consumer indifferent between consuming during the two periods in the FP contract or consuming during period 1 with the RTP contract determines the set $S^i_b(\boldsymbol{p}^s, \boldsymbol{p}^r)$.*
- *When $p_r > \tilde{p}$, the consumer indifferent between consuming during the two periods in the RTP contract or consuming during period 2 with the FP contract determines the set $S^i_b(\boldsymbol{p}^s, \boldsymbol{p}^r)$.*
- *When $p_r = \tilde{p}$, the two previous indifferent consumers determine the set $S^i_b(\boldsymbol{p}^s, \boldsymbol{p}^r)$.*

Proof. See Appendix. □

Then, given the definition of each set, one can notice that S^i_a is described by a linear function expressing a type v_i with respect to another. We define $\phi_j(v_i)$ this functions with $i, j \in \{1, 2\}$. The set S^i_b is described by a unique willingness to pay. It depends on which contracts are chosen for consumption over two periods or during a unique period. We define the willingness to pay v^Δ_1 when the consumer is indifferent between consuming during two periods with the RTP contract and the willingness to pay v^Δ_2 when the consumer is indifferent between consuming during two periods with the FP contract.[18]

With the previous result and notation in hand, the following Lemma formally establishes the characteristics of the consumers that choose the FP and RTP contracts. In other words, the demand for a contract is given by the mass of consumers who satisfy the conditions described in the Lemma.

[18]Formally when solving $U(\mathbf{v}, \mathbf{p}^s) = U(\mathbf{v}, \mathbf{p}^r)$ under the linear utility function assumption gives: $\phi_1(v_2) = p_1 - p_r + v_2$, $\phi_2(v_1) = p_1 - p_r + v_2$, $v^\Delta_1 = p^s_1 + p^s_2 - p_r$ and $v^\Delta_2 = 2p_r - p_1$.

Lemma 2. *Given a set of contract price* $\boldsymbol{p}^s = (p_1, p_2)$ *and* $\boldsymbol{p}^r = (p_r, p_r)$*,*

- *When* $p_r < \tilde{p}$*, a consumer having a type* v_2 *lower than* $\min(\phi_2(v_1), v_2^\Delta)$ *chooses the RTP contract. Otherwise, it chooses the FP contract.*
- *When* $p_r > \tilde{p}$*, consumers having a type* v_1 *lower than* $\min(\phi_1(v_2), v_1^\Delta)$ *choose the FP contract. Otherwise, it chooses the RTP contract.*
- *When* $p_r = \tilde{p}$*, the two previous conditions holds except that a consumer with* $[v_1^\Delta, \bar{v}_1] \times [v_2^\Delta, \bar{v}_2]$ *is now indifferent between the two contracts.*

Proof. See Appendix. □

The two different cases in which $p_r > \tilde{p}$ and $p_r < \tilde{p}$ imply that those high types of consumers always favor a specific contract. When $p_r > \tilde{p}$, then high v_1-type consumers prefer the RTP contract because the average wholesale price is lower than the fixed price p_r. It is only when v_1 is sufficiently low that a consumer finds it profitable to switch to the FP contract and stop consuming in period 1, that is when $v_1 < v_1^\Delta$. The same reasoning apply with v_2 and v_2^Δ when $p_r < \tilde{p}$: high v_2-type consumers prefer the RTP contract. The condition on p_r and $\tilde{p}$ determines the behavior of the consumer having high-type in both valuations. For instance, $p_r = p_r$ corresponds to the case where the aggregate demand is identical between the two periods. Any consumer with sufficiently high willingness to pay in both periods is indifferent between the two contracts as $2p_r = p_1 + p_2$.

The following corollary relates the demand for contracts and the aggregate quantity consumed over the different periods. The key insight is that, depending on the relative value of p_r with respect to $\tilde{p}$, there exists a mass of consumers (who have the highest willingness to pay in both periods) that oscillate between the two contracts.

Corollary 1. *When* $p_r < \tilde{p}$ *(resp.* $p_r > \tilde{p}$ *), some consumers that choose the FP contract (resp. RTP contract) consume in both periods, while consumers under the RTP contracts (resp. FP contract) consume only during period 1 (resp. period 2).*

Proof. See Appendix. □

Formally, it implies that $S_2^s \subseteq S_1^s$ and $S^r = S_2^r$ when $p_r > \tilde{p}$, and that $S_1^r \subseteq S_2^r$ and $S^s = S_1^s$ when $p_r < \tilde{p}$. Morever $\mu_s = \max\{q_1^s, q_2^s\}$ and $\mu_r = \max\{q_1^r, q_2^r\}$.

We illustrate in Figure 2 the different zones corresponding to the choice of consumers with respect to the contract type. When $p_r < \tilde{p}$, a consumer with the highest valuation always prefers contracts with fixed prices. When $p_r > \tilde{p}$, they choose the RTP contract. The case $p_r = \tilde{p}$ is similar.

Still, it corresponds to an indifferent case where utility is the same under the two contracts for any consumer in the $[v_1^{\Delta}\ ,\ \bar{v}_1] \times [v_2^{\Delta}\ ,\ \bar{v}_2]$ upper right rectangle.

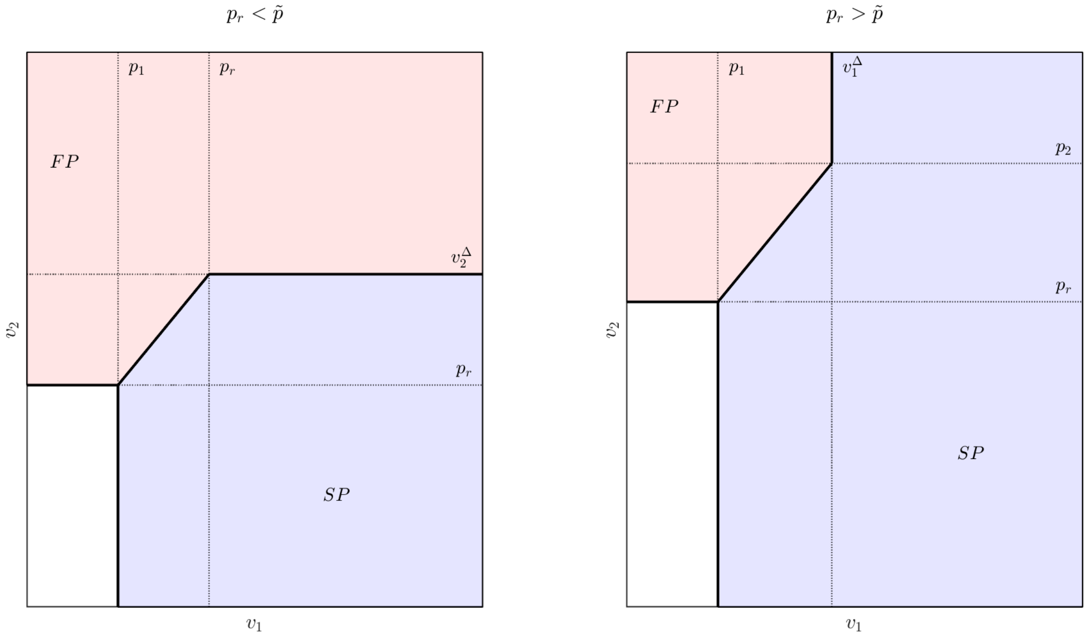

Figure 2: Demand zone for the two contracts, depending on the consumer valuation. Note that the function ϕ is represented by the segment between p_r and v_2^{Δ} when $p_r < \tilde{p}$ and between p_r and p_2 when $p_r > \tilde{p}$.

We conclude this section by studying how the demand system for the contracts changes with respect to the set of prices $\{p_1, p_2, p_r\}$ and to the demand parameters $\{\alpha, \beta\}$. We denote by μ_s and μ_r those demands for, respectively, the RTP and FP contracts. Note following Corollary 1 that the mass of consumers choosing the FP contract is given by the quantity of electricity consumed during the on-peak period and the mass of consumers selecting the RTP contract is given by the quantity of electricity consumed in period 1. We rewrite the wholesale prices as follows: $p_1 = \tilde{p} - d$ and $p_2 = \tilde{p} + d$ to capture the effect of the average price on the demand for contracts as well as the distance between the two prices. Note that under this framework, this boils down to capturing the same changes in the marginal cost.

Lemma 3. *Given $\boldsymbol{p}^s$ and $\boldsymbol{p}^r$.*

- *The demand for RTP contracts (μ_s) increases in the FP price (p_r) and in the variation of the price (d) and decreases in the average price ($\tilde{p}$) and the demand factors (β,α).*
- *The demand for FP contracts (μ_r) decreases in the FP price (p_r) and in the variation of the price (d) and increases in the average price ($\tilde{p}$) and the demand factors (β,α).*

Proof. See Appendix.

□

The effect of p_r on the demand of the two contracts is straightforward. Increasing p_r decreases the mass of consumers in FP and increases the mass of consumers in RTP as it makes the respective contracts relatively less and more attractive. The opposite effect of the average and variation of the prices are less intuitive. Increasing d implies that p_1 decreases and p_2 increases. When $p_r < \tilde{p}$, it has three effects: i) it makes consumers switch from no consumption to consuming in period 1 under RTP contract; ii) increases $\phi_2(v_1)$ meaning consuming in period 1 under the RTP contract is more attractive than consuming in period 2 under the FP contract (indifferent consumers belonging to the set S_a^i), iii) increases v_2^{Δ}, meaning consuming only in period 1 under the RTP contract is more attractive than consuming in both periods under the FP contract (indifferent consumers belonging to the set S_b^i). When $p_r > \tilde{p}$, v_1^{Δ} does not depend on d, so only the effects i) and ii) are present. The effect of the demand parameters can be ambiguous. For instance, an increase of β raises both $\underline{v}_2$ and $\bar{v}_2$ but also changes the mass distribution via f_2. We find clear-cut signs for each demand, which are rather intuitive. An increase in the demand parameters is a similar increase in the demand for period 2. As relatively high v_2 types primarily choose FP contracts, this, in turn, increases μ_r, which also decreases μ_s.

This change in the demand for the RTP contract is illustrated in the first plot of Figure 3. The effect i) is shown via the grey area, and the effect ii) is shown via the green area. For an increase in d, both effects are positive for the demand for RTP contracts. Note that as we consider p_r as fixed, only the second effect (i.e., the green area) is relevant for a change in the demand for the FP contract. When $\tilde{p}$ increases, both p_1 and p_2 increases, which has the reverse effect on both μ_s and μ_r. It is illustrated in the second plot of Figure 3. When p_1 increases, it makes consumers with low valuations in both periods under the RTP contract stop consuming in period 1. It is shown by the grey area. It also renders the consumption during period 1 under the RTP contract less attractive compared to the choice of consuming only during period 2 under the FP contract (indifferent consumers belonging to the set S_a^i). Finally, it also renders the consumption during the 2 periods under the RTP contract less attractive compared to the choice of consuming only during period 2 under the FP contract (indifferent consumers belonging to the set S_b^i). The green area represents the two last effects.

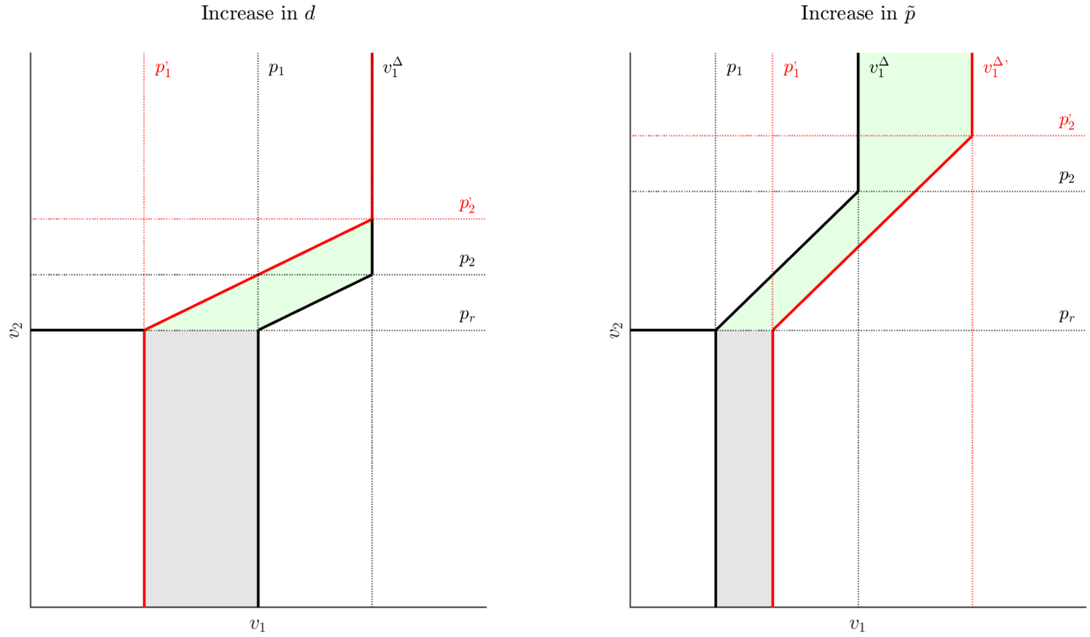

Figure 3: Effects of a change in the wholesale price variation (d) and average value ($\tilde{p}$) on the demand for contracts. Black segments represent the initial state. The red segments and the values with $'$ illustrate the change in the parameters. Net changes in the demand for each contract are decomposed between the two outside options. Grey areas show the switch between one contract and the no-consumption option. Green areas show the switch between the RTP and the FP contracts.

4 Price equilibrium

In that section, we use the previous demand system to determine the price equilibrium in the retail market. As discussed in the framework, the equilibrium depends on the retail market structure. The fixed price p_r could be determined either by private firms subject to competition or by a regulated monopoly maximizing its consumer surplus subject to budget constraint. Note the equilibrium price of the RTP contracts is identical in both market structures, with the contract prices equal to the wholesale price (see Joskow and Tirole (2006)). We start with the private firm case and then move to the regulated monopoly case.

4.1 Private Firms

Due to competitive forces, firms set the price p_r so that the profit is null only for consumers staying in FP contracts. From Lemma 2 and Corollary 1, the profit is equal to

$$\pi^r(p_r) = \begin{cases} q_1^r(p_r, p_1, p_2)(p_r - p_1) + q_2^r(p_r, p_1, p_2)(p_r - p_2) & \text{if} \quad p_r < \tilde{p} \\ q_2^r(p_r, p_1, p_2)(p_r - p_2) & \text{if} \quad p_r > \tilde{p} \end{cases}$$

With $q_t^r(p_r)$ being the quantity of electricity consumed in period t under FP contracts. Besides having to satisfy the null profit condition and consider the demand for each contract, an equilibrium p_r should be coherent with the demand functions it generates. Namely it has to belong to either $p_r \in [p_1, \tilde{p}]$ or $p_r \in [\tilde{p}, p_2]$ depending on the case considered. We state in the following Lemma that a positive mass of consumers cannot exist while strictly preferring the FP contract to the RTP contract when private firms offer them.

Lemma 4. *With private firms, there is no equilibrium, with consumers having a strict preference for the fixed-price contract.*

Proof. See Appendix. □

The proof relies on the two cases depending on the value of p_r with respect to $\tilde{p}$. When $p_r > \tilde{p}$, consumers choosing FP contracts consume only during the peak period (recall from Corollary 1 that $S^r = S_2^r$). Therefore, competition between retailers drives the price of the FP contracts up to p_2, which implies that there are no consumers with a strict preference for FP contracts.[19] In the case of $p_r < \tilde{p}$, we show that the average cost of retailers is always above the average price, as consumers that choose the FP contracts always consume more during the peak period than during the off-peak period (recall from Corollary 1 that $S_1^r \subseteq S_2^r$). It contradicts the condition that $p_r < \tilde{p}$ and implies the non-existence of such equilibrium.

4.2 Regulated monopoly

Now, we turn to the case in which a regulated monopoly offers the FP contract. The main assumption is that the public firm chooses the price p_r (and the corresponding transfers) to maximize the surplus of consumers selecting the FP contracts. Following the Equation 6 and from Lemma 2, we can drop the choice of A and look only for the value of p_r that maximizes the following equations:

$$O(p_r) = \begin{cases} \displaystyle\sum_{t=1,2} \int_{S_t^r(p_r)} f_t(v)(v - p_t)dv \qquad \text{if} \qquad p_r < \tilde{p} \\ \displaystyle\int_{S_2^r(p_r)} f_2(v)(v - p_2)dv \qquad \text{if} \qquad p_r > \tilde{p} \end{cases}$$

The following two lemmas describe how the public firm chooses the optimal prices. Those two solutions are not mutually exclusive, which implies multiple local maxima to the regulated monopoly problems. The absence of closed-form solutions prevents us from having a clear ranking in terms of surplus. The following Lemma describes the first possible price.

[19] This result mirrors what Astier and Léautier (2021) have described in a different set-up: they show the impossibility of having a set of consumers under fixed-price contracts such that cross-subsidies are realized only between consumers staying on the historical flat rate.

Lemma 5. *With a regulated monopoly, there exist some consumers who strictly prefer the fixed-price contract for some $\beta \in [\underline{\beta}, \beta^{pu}]$ in which $p_r > \tilde{p}$. The price set by the monopoly solves the following:*

$$p_r = \frac{q_2^{r'}(p_r)\, p_2 + \Omega(p_r)}{q_2^{r'}(p_r)} = p_2 + \frac{\Omega(p_r)}{q_2^{r'}(p_r)}$$

Where $q_2^{r'}(p_r)$ is the variation of the quantity with respect to p_r, and $\Omega(p_r)$ is the surplus of consumers consuming in period 2 in RTP if they had chosen the FP contract.

Proof. See Appendix.

□

The following Lemma describes the second possible price.

Lemma 6. *With a regulated monopoly, there exist some consumers who strictly prefer the fixed-price contract in which $p_r < \tilde{p}$. The price set by the monopoly solves the following:*

$$p_r = \underbrace{\frac{q_1^{r'}(p_r)\, p_1 + q_2^{r'}(p_r)\, p_2}{q_1^{r'}(p_r) + q_2^{r'}(p_r)}}_{\textit{weighted average price}} + \underbrace{\frac{\Omega(p_r)}{q_1^{r'}(p_r) + q_2^{r'}(p_r)}}_{\textit{foregone CS}}$$

Where $q'_{fp,t}(p_r)$ is the variation of the quantity of electricity consumed under the FP contract with respect to p_r in period t, and $\Omega(p_r)$ is the forgone surplus of consumers which either stop consuming or switch to the RTP contracts due to an increase in p_r.

Proof. See Appendix.

□

The two lemmas extend the canonical result from Joskow and Tirole (2006) to account for the multidimensionality of the consumers' type and the coexistence of another outside option, which, in this context, is the RTP contract offered by the firm. In Joskow and Tirole (2006), the price is given by Equation 9 and fixed such that it is equal to the wholesale cost weighted by the derivatives of the aggregate demand. In our framework, similar intuition explains in part the price fixed by the regulated monopoly. In the case when we look for p_r such that $p_r > \tilde{p}$, consumers that choose the FP contract only consume during the second period. It explains that the weighted average is equal to 1. In the case $p_r < \tilde{p}$, p_r is indeed given in part by a weighted average. After calculation and simplification, the derivatives are equal to:

$$
q_1^{r'} = \begin{cases}
-\overbrace{\int_{\underline{v}_1}^{p_1} f_1 f_2 dv_1}^{\Delta S_0} \; -\overbrace{\int_{p_r}^{p_2} f_1 f_2 dv_2}^{\Delta S_a^i} \; -\overbrace{\int_{p_2}^{\bar{v}_2} f_1 f_2 dv_2}^{\Delta S_b^i} & \text{if} \quad p_r > \tilde{p} \\
\underbrace{-\int_{v_2^{\Delta}}^{\bar{v}_2} f_1 f_2 dv_2}_{\Delta S_0} \; \underbrace{-2\frac{\partial v_2^{\Delta}}{\partial p_r}\int_{p_r}^{\bar{v}_1} f_1 f_2 dv_1}_{\Delta S_b^i} & \text{if} \quad p_r < \tilde{p}
\end{cases}
$$

and

$$
q_2^{r'} = -\overbrace{\int_{\underline{v}_1}^{p_1} f_1 f_2 dv_1}^{\Delta S_0} \; -\overbrace{\int_{p_r}^{v_2^{\Delta}} f_1 f_2 dv_2}^{\Delta S_a^i} \; -\overbrace{\frac{\partial v_2^{\Delta}}{\partial p_r}\int_{p_r}^{\bar{v}_1} f_1 f_2 dv_1}^{\Delta S_b^i}
$$

In this expression, we illustrate the change in electricity consumption for an increase in p_r. All the derivatives are strictly harmful, as shown in Lemma 3, and the ΔS represents the change in consumption of consumers under the FP contract. ΔS_0 are consumers who stop consuming electricity due to an increase in p_r. ΔS_a^i are consumers who stop consuming electricity during period 2, switch to the RTP contract, and start consuming during period 1. ΔS_b^i are consumers who stop consuming electricity during either period 2 or the two periods, switch to the RTP contract, and start consuming during period 1 or the two periods depending on the equilibrium. The derivatives differ from the ones of the aggregate demand as they must accommodate the set of marginal consumers, which is not defined by a linear relation between v_1 and v_2, as shown in Lemma 2.

In the canonical setting, an increase in the price lowers the consumer surplus, and this decrease in surplus is equal in magnitude to the avoided production cost. In this framework, the regulated monopoly must also take into account consumers who switch to the RTP contracts. The following expressions capture this effect:

$$
\Omega(p_r) = \begin{cases}
\overbrace{\int_{p_r}^{\bar{v}_2} f_2 f_2 (v_2 - p_r) dv_2}^{\Delta S_b^i} & \text{if} \quad p_r > \tilde{p} \\
\underbrace{\frac{\partial v_2^{\Delta}}{\partial p_r}\int_{p_r}^{\bar{v}_1} f_1 f_2 (v_1 - p_r) dv_1}_{\Delta S_a^i} + \underbrace{\int_{p_r}^{v_2^{\Delta}} f_1 f_2 (v_2 - p_r) dv_2}_{\Delta S_b^i} & \text{if} \quad p_r < \tilde{p}
\end{cases}
$$

The equilibrium fixed price set by the regulated monopoly can be either greater or smaller than the fixed price set by the monopoly when consumers face only an FP contract. The key mechanism to understand the possibility of having a lower p_r when consumers face contract choice is the following. With the existence of the outside option of the RTP, the regulated monopoly faces the risk of losing consumers that are significantly contributing to its surplus, notably those with a relatively high value of v_1. The public firm's only choice is to decrease the fixed price p_r contract to make the FP more attractive and avoid consumer leakage. This ranking is especially relevant in the first analysis of the next section as we show that having a lower p_r may lead to lower welfare compared to the single FP contract environment. We perform some comparative statics in the second analysis of the next section to formally study how the equilibrium price and the demand for contracts are related to the model parameters.

5 Welfare analysis

5.1 Welfare ranking between multiple contracts and single contract

In that section, we answer the following question: Is giving the option between the two contracts necessarily welfare improving compared to the benchmark case in which every consumer is under the FP contract fixed by the regulated monopoly?[20] We state in this section that the welfare at the price equilibrium can be lower than when consumers only face the FP contract.

The intuition behind this result comes from the following observation: When consumers can choose between the two contracts, then the price p_r fixed by the regulated firm may be lower than under the benchmark case when consumers only face the FP contract. We first confirm in the following Lemma that it is only when the equilibrium price is below the benchmark price that it may generate lower welfare.

Lemma 7. *While welfare does not always strictly increase with p_r, welfare with consumer choice is always higher whenever p_r is higher than under a full FP economy.*

Proof. See Appendix. □

While the welfare for a given p_r is always superior when a consumer chooses between the two contracts, the welfare function is not strictly increasing in p_r. It could imply that a higher value

[20] As shown by Result 1, the welfare in the benchmark case with only the FP contract is higher when fixed by the regulated monopoly, so we focus on this case.

p_r may theoretically lead to lower welfare compared to the benchmark case. The Lemma rules out this case.

We turn now to the welfare changes of having: *i*) a set of consumers choosing the RTP contract and *ii*) a fixed price p_r lower compared to the benchmark case. While the effect *i*) is always positive, the effect *ii*) is ambiguous for the welfare. The key idea is that if the equilibrium price is sufficiently low, then the ambiguous effect of having a low p_r becomes negative and outweighs the positive impact of having consumers switch to the RTP contract. In the following Result, we summarize the allocation inefficiencies that having some consumers in FP contracts generates.

Result 2. *Consumers who stay under FP contracts create three types of inefficiencies: i) they consume in period 2 while they should not, ii) they consume in period 2 instead of period 1, and iii) they do not consume in period 1 while they should.*

The first and second type of inefficiency is well known in the literature. It relates to the case when, with a fixed price, consumers over-consume when the production cost is high (on-peak - period 2) and under-consume when the production cost is low (off-peak - period 1). The second one relates to an (inefficient) inter-temporal choice made by the consumer due to price differentials. Note that not every consumer under the FP contract generates inefficiencies. Indeed, some consume only during the second period under both contracts, while others consume during the two periods under both contracts.

Therefore, the comparison between the two cases (equilibrium with contract choice and only FP contract) boils down to studying the difference between the two deadweight losses generated by each environment. We illustrate in Figure 4 the net change of welfare depending on consumer types. Note that analysis depends on the value of p_r in the contract choice case compared to $\tilde{p}$. The red line stands for the p_r sets under the benchmark case with only the FP contract. The rest of the black lines correspond to the contract demand limits, as shown in Figure 2. The white areas correspond to the case in which consumers still do not consume or do not generate any welfare losses/gains with or without switching contracts.[21] The blue areas show the set of consumers who, by switching to the RTP contract, generate a net gain in terms of welfare, either by starting to consume or by changing their consumption period. The green area, which only exists when $p_r < \tilde{p}$, indicates the consumer who starts consuming in period 1 due to the decrease of the fixed price. It happens when $v_1 > p_1$; hence it is a positive welfare gain. Finally, the red areas are the negative welfare change due to having a lower p_r. When $p_r > \tilde{p}$, the effect only captures the consequences of having consumers who were not consuming in period 2 start consuming because of a lower price.

[21] The key idea is that if they have the same consumption pattern with a different contract, it does not change the aggregate welfare.

It is also present when $p_r < \tilde{p}$ but with a higher magnitude. Indeed, when the set of indifferent consumers characterized by the type v_2^{Δ} is lower than the p_r fixed under the benchmark case, then more consumer starts consuming during period 2 when $v_2 < p_2$, which is a welfare loss.

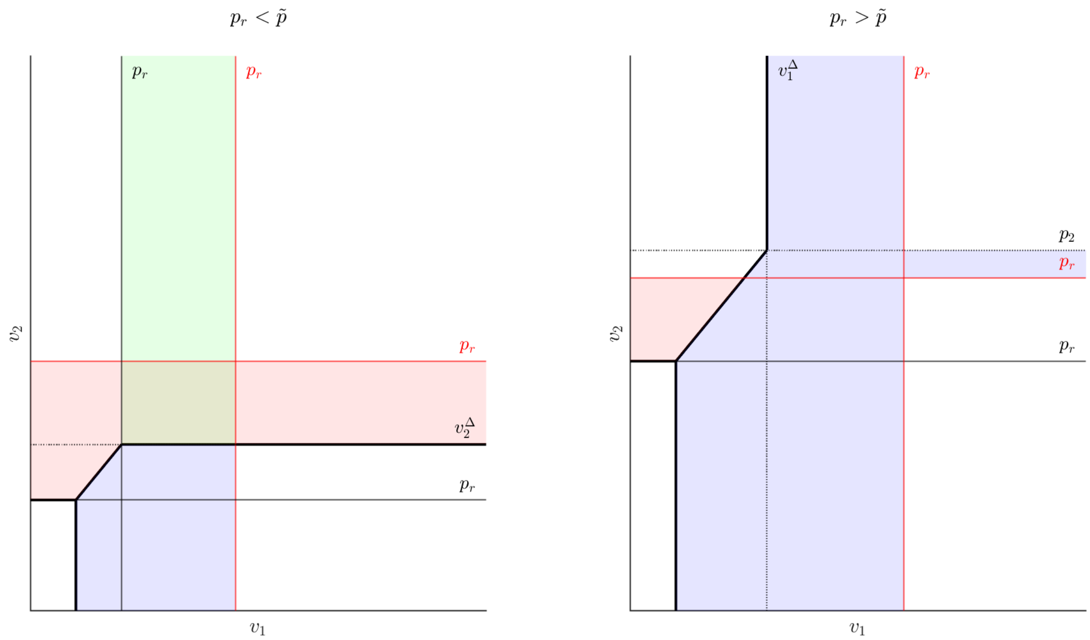

Figure 4: Deadweight loss when $p_r > \tilde{p}$. Consumers in $DW1$ should not consume in period 2. Consumers in $DW2$ should consume in period 1 but not in period 2. Consumers in $DW3$ should consume in period 1.

We conclude with the following Lemma, which formally proves that the negative effect of a lower p_r is exacerbated when the p_r set when consumers face different contracts decreases.

Lemma 8. *When consumers face different contracts, a lower value of p_r implies that both the welfare gains from the consumer switch to the RTP contract and the net effect from the other consumer decreases.*

Proof. See Appendix. □

This result can be shown in Figure 4 and from the results of Lemma 3. A decrease of p_r makes the RTP contract less attractive. Hence, fewer consumers switch to the contract, which explains a lower efficiency gain. When $p_r > \tilde{p}$, the red area expands south and east, which always implies an increase in its size, hence a lower welfare. When $p_r < \tilde{p}$, the result is a priori ambiguous as both the green area and the red area expand. The Lemma shows that the overall welfare effect is convex in p_r and is always negative at the lower bound when $p_r = p_1$. As the welfare effect is always positive when the price p^r is higher than with the benchmark case, then a lower value of p_r implies a decrease in this effect.

5.2 Comparative Statics

We now study the effect of four model parameters on the equilibrium price fixed by the regulated monopoly. : *i*) the wholesale price parameters, namely the variation (d) and the level ($\tilde{p}$) and *ii*) the demand parameters (β,α). We summarize the results in the following Lemma.

Lemma 9. *The price set by the regulated monopoly is:*

- *Decreasing in the demand factors (β,α).*
- *Increasing in the variation of the price (d) and the average price ($\tilde{p}$) when $p_r > \tilde{p}$.*
- *Decreasing in the average price ($\tilde{p}$) when $p_r < \tilde{p}$. The variation of the price (d) has an ambiguous effect on p_r. The effect is negative when β is low.*

Proof. See Appendix.

□

Due to the concavity of the objective function, the main intuition of the results stems from the analysis of the cross derivative of the objective function with respect to the parameter. Recall that an increase in p_r has three effects: consumers either *i*) stop consuming or *ii*) choose the RTP contracts, and *iii*) it reduces the cost associated with the purchase of electricity in the wholesale market. The first-order condition that leads to Lemma 5 and 6 can be represented as follows:

$$\frac{\partial O(p_r)}{\partial p_r} = \overbrace{(q_1^{r'} + q_2^{r'})p_r}^{i)\text{ No conso. effect}} \quad - \quad \overbrace{\Omega(p_r)}^{ii)\text{ RTP effect}} \quad - \quad \overbrace{(q_1^{r'} p_1 + q_2^{r'} p_2)}^{iii)\text{ Cost effect}}$$

Therefore, each parameter's sign depends on its effect on the three components of the marginal objective function.

For instance, let's study the effect of the price variation (d) when $p_r < \tilde{p}$. These comparative statics notably illustrate why p_r might be lower when consumers face multiple contracts compared to the benchmark case. The following equation captures the impact of d on p_r:

$$\frac{\partial^2 O(p_r)}{\partial p_r \partial d} = \overbrace{\frac{\partial q_1^{r'}}{\partial d} p_r}^{+} \quad - \quad \overbrace{\frac{\partial \Omega(p_r)}{\partial d}}^{+} \quad - \quad \overbrace{\frac{\partial q_1^{r'}}{\partial d} p_1}^{-} \quad + \quad \overbrace{q_1^{r'} - q_2^{r'}}^{+/-}$$

Similarly to the results in Lemma 3, the effect of p_r on $\Omega(p_r)$ is positive. As an increase in the variation makes the RTP contract more attractive, it also increases the value of the foregone surplus $\Omega(p_r)$. It is the second term in the above equation. On the other hand, it reduces the welfare loss associated with consumers leaving the retail market: a positive cross derivative implies that the quantity is less reduced when d is relatively high. It is the first term in the equation. This effect has to be compensated partly by the change in the cost effect, which is captured by the third term. Recall that $p_r \geq p_1$, hence the net effect between the first and third term is positive. Finally, the last term is ambiguous and notably depends on the size of the intervals ϵ_t relative to the prices p_1 and p_r.

Therefore, the effect of d is ambiguous on the equilibrium price because it makes the RTP contract more attractive, which tends to decrease p_r. Still, it reduces the welfare loss of having more consumers with a low v_2 type (i.e., $v_2 < p_2$), which tends to increase p_r. Interestingly, the effect of d is negative for low values of β. It confirms the intuition: as β is low, the RTP contract is more attractive, and there are more low v_2 type consumers. It reinforces the cost associated with consumers leaving for the RTP contract and the welfare loss with gaining more low v_2 type. Hence, p_r should be decreasing when d increases and when β is low.

We conclude this section by linking the study of the parameter's effects on p_r and contract demands μ_s and μ_r. While the model can give some clear-cut answers on some parameters, there remains some ambiguous effect of the parameters, which also makes the analysis an empirical question.

Corollary 2. *At the price equilibrium,*

- *The demand for RTP contracts (μ_s) increases in d when $p_r > \tilde{p}$, and only when β is sufficiently high when $p_r < \tilde{p}$. It always decreases in β, α. The effect of $\tilde{p}$ is ambiguous when $p_r > \tilde{p}$, but it increases in $\tilde{p}$ otherwise.*
- *The demand for FP contracts (μ_r) decreases in d when $p_r > \tilde{p}$, and only when β is sufficiently high when $p_r < \tilde{p}$. It always increases in β, α. The effect of $\tilde{p}$ is ambiguous when $p_r > \tilde{p}$, but it decreases in $\tilde{p}$ otherwise.*

Proof. See Appendix.

□

6 Extensions and Discussion

In this section, we present and discuss potential extensions of the model in two main directions: *i*) increasing the set consumers' characteristics, which would allow the demand for contracts to incorporate more realistic features, and *ii*) providing a richer set of mechanisms in the model, which would deepen the welfare implications of having consumers self-selecting in electricity contracts.

We have three extensions in mind: *a*) Assuming a set of consumer characteristics partly or fully private information, what could be the optimal intervention to increase the enrollment in dynamic contracts? *b*) How do we represent the short-term and long-term decisions of end-user consumers, and how do they affect contract choices? *c*) How does a market-based penetration of renewable interact with consumers' contract choices?

6.1 Cross-subsidies with incomplete information

The previous results showed that when consumers face different contracts, some market structures do not lead to every consumer switching to the RTP contract. While every marginal increase in the RTP uptake is welfare improving, it shows that there is a difference between the social value and the private value of adopting a specific contract. In this section, we wish to study if it is possible to implement a vector of individual lump sum transfer such that consumers preferring FP contracts now switch to RTP contracts, and consumers preferring RTP contracts remain in RTP contracts. The key assumption in this section is that the consumer's type (i.e., v_1 and v_2) is private information. For now, we remain agnostic on the market structure as we conduct this analysis with contract prices considered as given and on the practical implementation of such contracts.

From the environment perspective, those lump-sum transfers can be defined in the electricity contracts, which are now not only a pair of unitary prices $\mathbf{p}^k = \{p_1^k, p_2^k\}$ but a pair of monetary transfers such that $\mathbf{T}^k = \{\mathbf{p}^k, \mathbf{t}^k\}$ associated to an allocation profile $\mathbf{q}^k(\mathbf{v})$ that dictates how consumers consume electricity in each period.[22] Note that $\mathbf{t}^k$ does not need to be positive. In terms of timing, we assume that consumers pay (or receive) $\mathbf{t}^k$ when choosing the electricity contract. As there is no uncertainty in the model, this is without loss of generality. We also rely on the Revelation Principle, such that now the choice of contracts can be seen as a Direct Mechanism in which consumers are allocated a contract $(\mathbf{T}^k(\mathbf{v}), \mathbf{q}^k(\mathbf{v}))$ given their type report $\mathbf{v}$.

So far, we will be characterizing the set of transfer $\mathbf{t}^k(\mathbf{v})$ that allows consumers to enroll entirely in the RTP contracts, given the unitary prices $\mathbf{p}^s$, $\mathbf{p}^r$. We decomposed the problem in two steps, that is, determining *i*) the transfer of consumers under the FP contract $\mathbf{t}^r(\mathbf{v})$, *ii*) the transfer of consumers under the RTP contract $\mathbf{t}^s(\mathbf{v})$. As we are looking to encourage consumers to switch from the FP contracts to the RTP contract, this question boils down to finding the subsidies paid by the RTP consumers ($\mathbf{t}^s(\mathbf{v}) > 0$) to the FP consumers ($\mathbf{t}^r(\mathbf{v}) < 0$).

We start by observing that under complete information, it is always possible to implement the first-best allocation with appropriate lump-sum transfers.

[22] Leaving aside the lump sum question, there are effectively six contracts. For instance, three RTP contracts allow consumers to consume either in the first period only, in the second period only, or in both periods.

Claim 1. *Efficiency gains are not sufficient for complete switching. However, under full information, some transfers can always be implemented from any consumer choosing RTP to a consumer initially choosing FP, such that all consumers choose or stay in RTP contracts.*

In the context of incomplete information, we need to define the set of participation (IR) and incentive (IC) constraints. For every consumer who has chosen the fixed-price contract, the transfer and consumption under the RTP contract should make them at least better off than those under the fixed-price contract. The same idea applies to consumers who are already selecting the RTP contract. In that case, their dedicated transfers should not make them switch to FP contracts. They should also select the contract that leads to the right amount of consumption, given their type. We define those conditions as the IR^k and IC^k constraints:

$$U(\mathbf{v}, \mathbf{p}^r) \leq U(\mathbf{v}, \mathbf{p}^s(\mathbf{v})) + \mathbf{t}^k(\mathbf{v}) \qquad (IR^k)$$

$$\mathbf{v} \in \arg\max_{\tilde{\mathbf{v}}} \quad U(\mathbf{v}, \mathbf{p}^s(\tilde{\mathbf{v}})) - \mathbf{t}^k(\tilde{\mathbf{v}}) \qquad (IC^k)$$

A T^k contract is implementable if it satisfies the two conditions. The set of contract (T^s, T^r) is implementable if it satisfies a budget constraint, as we do not allow for public funds. We describe first the main results with respect to the T^r contract below in which $t^r(\mathbf{v}) \geq 0$. We show that due to the IC^r conditions, some consumers have to receive some information rents to select the right consumption profile. It constrains the total subsidy to be potentially higher than the welfare gains generated from having all consumers switch to RTP contracts. In other words, if we assume that only RTP consumers subsidize FP consumers, and compared to the complete information benchmark, implementable transfers that lead to full adoption of the RTP contract might not always exist.

Claim 2. *i) IR^r only contracts are not IC^r. ii) A contract with $\boldsymbol{t}^r(\boldsymbol{v}) = p_2 - p_r$ minimizes the total subsidies and is implementable.*

We turn now to the contract for consumers under the RTP contract, which boils down to characterizing an implementable T^s contract in which $t^s(\mathbf{v}) \geq 0$. The result is quite sharp as we find that given the model framework, every consumer has an incentive to deviate from the truth, which forbids any subsidies from being taken from those consumers. We believe this result holds for at least one reason: as we do not make the consumption pattern depending on the types, every RTP consumer has an incentive to act like the indifferent consumer who earns the same utility under both contracts, who pinned down the transfer to 0.

Claim 3. *The only T^s contract that is implementable implies a transfer such that $t^s(\boldsymbol{v}) = 0$.*

It effectively implies that the incentive constraints lead to no implementable transfers in which the RTP consumers pay the subsidies. One potential modification could partly reverse this result: conditioning the unit price (or the quantity allocation) in the contract to the consumer's type. It could create a utility wedge for some indifferent consumers. However, it may come at the expense of allocative efficiencies.

6.2 Consumers long-term decisions

The motivation for extending consumer decisions is based on multiple observations. There is a growing literature that stresses the importance of considering the short-term and long-term price elasticity of electricity demand. A recent study by Buchsbaum (2023) shows, for instance, that consumers are sixteen times as responsive to prices in the long run compared to the short run, with elasticity estimates of -2.25 and -0.14, respectively. It is crucial notably when considering the redistributive effects of dynamic price contracts (Cahana et al., 2023). One of the reasons for such differences could be explained by considering how the consumer responds in the long run when exposed to higher prices. It could relate to the question of the extensive and intensive margins associated with the consumption of durable goods where utilization and appliance choices are modeled jointly.[23]

Therefore, the key idea of this extension is to study how appliance choices (i.e., long-term decisions) affect the willingness to pay for electricity (i.e., a proxy for short-term decisions)[24], which in turn ultimately conditions the choice of contracts. As investment decisions are also made based on future electricity prices, having different electricity contracts may also affect how consumers choose the set of appliances. To do so, we propose the following extension to the model. It is notably inspired by the adoption model from Feger et al. (2022), who studied how tariffs may be designed to foster the adoption of solar panels by households, considering budget balance and equity.

Assume that there exists a technology I available to consumers, such that its investment cost is noted as r. A consumer decides whether to invest in a technology $\mathbb{I} = \{0, 1\}$. If it does, he sustains a disutility of $\theta(\mathbf{v})r$ where $\theta(\mathbf{v})$ is a parameter that measures the consumer's sensitivity to installation costs and can be correlated with its willingness to pay.[25] His willingness to pay

[23]See, for instance, the recent paper on crop choices by Burlig et al. (2024) on how water price changes the use of water in the short run but also the type of crops in the long run. Other papers relate to electrics vehicles adoption (Bushnell et al., 2022) or credit markets (Karlan and Zinman, 2019)

[24]There are multiple factors affecting short-term electricity consumption. One can think that the choice of appliance defines some capacity constraints or their energy efficiency level. We believe that for the sake of simplicity, establishing a link between the distribution of the consumer's willingness to pay and appliance choice is sufficient to capture the primary intuitions.

[25]See Feger et al. (2022) for a discussion on this parameter. It can be considered as a measure of some consumption preference or characteristics such as income

in period t will be drawn from a new distribution $f_t^I(v)$ such that $f_t^I = f_t(v|\lambda)$, where lambda measures the change of the initial distribution due to the technology.[26] In that case, the utility from investing and given the choice of contract k is $U(\mathbf{v}, \mathbf{p}^k) - \theta(\mathbf{v})r$ and from not investing is still $U(\mathbf{v}, \mathbf{p}^k)$. We define the technology adoption decision for a given contract as follows:

$$\nu(\mathbf{v}, \mathbf{p}^k, r) = \max_{\mathbb{I}} \quad (\mathbb{I} = 1)(U(\mathbf{v}, \mathbf{p}^k) - \theta(\mathbf{v})r) + (\mathbb{I} = 0)U(\mathbf{v}, \mathbf{p}^k)$$

Therefore, the demand for an RTP contract is the set of consumers whose willingness to pay satisfies the condition: $\nu(\mathbf{v}, \mathbf{p}^s, r) > \nu(\mathbf{v}, \mathbf{p}^r, r)$.

Introducing this technological choice sheds light on a new rationale for understanding self-selection into specific contracts in electricity markets. It will necessitate a deeper analysis and some precisions on the concrete form of how the investment shapes the distribution f_t^I. Indeed, self-consumption from solar panels, electric vehicles, heat pumps, or batteries does not have the same effect on consumption decisions. For instance, if it disproportionally increases the willingness to pay during the second period, our model predicts an increase in the selection of FP contracts. Note that this modeling approach allows introducing another characteristic of consumers captured by the term $\theta(\mathbf{v})$, which can be estimated through consumer data as in Feger et al. (2022).

6.3 Renewable technologies

The constant marginal cost assumption in this model is somewhat reductive. One of the key aspects of an electricity market is its complex supply side. Different technologies coexist to satisfy electricity demand, and a pair of marginal and fixed costs define them. Leaving aside technological constraints, a well-functioning electricity market relies on a merit order that ranks available generation based on ascending marginal cost. It implies that a realistic supply function on the wholesale market should then exhibit a convex, or at least, an increasing form.

Such mathematical properties of the marginal cost do not change the primary intuitions of the main result of this paper.[27] However, we believe that studying jointly the demand for contracts and a more complex supply side does shed light on the implications of the former for electricity markets. Indeed, allowing consumers to self-select in contracts also implies a change in consumption pattern, both in terms of aggregate quantity in a single period and across different periods. If aggregate quantities are changed, then so does the price equilibrium in the wholesale market. In turn, this

[26] For instance, it can induce some specific correlations between the distribution f_1, f_2, or one could interpret f_t^I to be a mean preserving spread, increasing or decreasing the willingness to pay during on-peak periods.

[27] Namely, the foundation of the demand for contracts and the existence of externalities not internalized by the regulated entity.

affects the demand for contracts by changing p_1, p_2, and p_r. Therefore, considering the feedback loop with the wholesale market might change the selection level of the different contracts in the wholesale market.[28] For instance, if we assume that it reduces the volatility of the wholesale price[29], then given our result in Corollary 2, it might reinforce the demand for the RTP contract.

More importantly, considering a more realistic wholesale price opens the door to studying the long-term effect of contract choices. Indeed, following the peak-load pricing theory, investment decisions are based on the expectation of the future inframarginal rent made on the wholesale market. This rent, which is the difference between a producer's marginal cost and the clearing price, should cover the investment cost. The long-term equilibrium is reached when the marginal investment cost equals the marginal inframarginal rent.

One of the challenges of the energy transition is that the new carbon-free technologies exhibit significant specificity: renewable technologies have variable availability and a null marginal cost with high investment costs, while batteries rely on the temporal price differential.[30] Therefore, an efficient penetration of those technologies in a market-based environment requires specific price signals. Namely, prices that are relatively high to cover renewable investment costs and sufficient variation between the different prices so that batteries capture enough revenue from price arbitrage. Again, if we assume that *i*) contract self-selection leads to a specific consumption pattern and that *ii*) new production technologies also modify the wholesale market marginal cost, then the joint representation of contract self-selection and wholesale equilibrium would shed light on how relying on consumer choice can foster or deter the penetration of such clean technologies.

7 Conclusion

This paper builds a theoretical framework to study how end-user consumers in the retail electricity market self-select into a menu of contracts. We describe the demand for two contracts: *i*), a fixed price (FP) contract corresponding to the historical tariffs, and a real-time pricing (RTP) contract replicating the wholesale prices of electricity. Although these two contrasts coexist in most retail markets around the world, they also serve as high and low-efficiency limits. Indeed, electricity market theory predicts that the more a contract transmits the price signal from the wholesale market to end consumers, the higher the welfare. A fixed contract gives no signal, while an RTP contract transmits the full signal. In the context of an energy transition based on voluntary

[28] It requires an additional market clearing constraint that the set of price $\{p_1, p_2\}$ needs to satisfy $c(q_t) = p_t$, as we assumed perfect competition in the wholesale market. We could also assume steps with capacity constraints as supply functions.

[29] As studied, for instance, in the framework of Boom and Schwenen (2021) and Ambec and Crampes (2021).

[30] See Butters et al. (2021) for a comprehensive equilibrium analysis of renewable technologies and battery storage.

consumer choice, it is therefore crucial to understand how consumers formulate their choices when faced with a variety of contracts.

To do so, we propose to model a set of consumers characterized by a willingness to pay for electricity that differs both between different periods and between consumers themselves. First, we describe how, given a given set of contract prices, consumers make their choice of contract. It boils down to defining a specific set of indifferent consumers based on their willingness to pay that, in the end, describes the demand for each contract. Second, we use this demand for each contract to understand the firms' incentives to set contract prices. We assume that RTP contracts are always offered by competitive retailers, which implies a strict transmission of wholesale prices to consumers choosing this contract. On the other hand, we study two market structures for the pricing of the FP contract. The first framework assumes that retailers also set the price of the FP contract. The second framework assumes that a regulated monopoly sets the price. We show that in the competitive environment, firms do not have the incentive to offer a fixed-price contract. Indeed, consumers who self-select into this contract always consume more during on-peak periods, that is when the price on the wholesale market is high. Therefore, competitive forces lead to the first-best outcome. Conversely, we show that the regulated monopoly that maximizes its consumer surplus under budget constraints may keep some consumers under the fixed-price contract.

In a welfare analysis, we compare the outcomes of a regulated monopoly when the consumers can and cannot select an RTP contract. Importantly, we show that the pricing decisions made by the regulated monopoly when consumers can choose an RTP contract may lead to lower welfare. The primary rationale stems from the fact that consumers who switch to RTP contracts are particularly valuable in terms of surplus for the regulated monopoly. In order to stop the exit of such consumers, the monopoly has an incentive to set a low fixed price. However, this allows some consumers with a significantly low willingness to pay to enter the market, which generates significant welfare losses. In some cases, those losses can outweigh the gains from consumers switching to the RTP contract. We conclude the welfare analysis with some comparative statics that we believe are important in the context of electricity markets: *i*) some price parameters that define the wholesale price dispersion across the different periods as well as the average price, and *ii*) some demand parameters that dictate how the aggregate demand vary between the different periods. We find that an increase in the wholesale price dispersion increases the demand for the RTP contract, but an increase in the average price decreases it. Similarly, when the willingness to pay during the on-peak period is relatively higher compared to the off-peak period, then the demand for the RTP contract also decreases.

We conclude this paper by discussing multiple extensions. First, we provide an initial set of results that study how contracts can be modified in order to increase the self-selection of the RTP contract. We do so by assuming that consumers' types are private information and that contracts can be modified only by adding a lump-sum transfer. This analysis boils down to the issue of how consumers under RTP contracts can cross-subsidized FP consumers. Due to the simplified assumption in our model, we find sharp results such that no subsidy can originate from RTP consumers as they can always imitate consumers who are indifferent between the two contracts while still providing efficient consumption. Then, we discuss two potential extensions that could help shed light on how consumer choices affect electricity markets: *i*) the modeling of appliance choices from consumers and *ii*) the addition of a wholesale market module, including renewable technologies and batteries.

Beyond those extensions, we believe that this model and the associated results should, above all, be understood as upper and lower bounds for the effects of contract choice on electricity markets. First, it's worth noting that there's a vast choice of dynamic-price contract designs. A recent body of literature studies the analysis of the gains generated by approximating RTP contracts while maintaining simplicity in their implementation (Hinchberger et al., 2024). It also raises the question of whether companies choose to offer specific contract designs rather than others, notably in retail markets with friction and market power (Fabra and Reguant, 2020). Second, the hypothesis of a regulated monopoly choosing only to maximize its own consumers' surplus is somewhat reductive. In reality, the government and regulators who oversee the setting of regulated prices may also choose to maximize aggregate surplus. However, it seems equally unrealistic that setting these prices would be fully efficient. For example, redistribution objectives or political constraints can distort this choice and generate effects similar to those shown in this paper (Martimort et al., 2020). Finally, we are aware that consumers might face a considerable amount of behavioral bias when selecting electricity contrast (Fowlie et al., 2021; Gibbard and Remmy, 2024). However, we believe that the foundation of the demand contract, even with rational consumers and in the context of private information, has still been understudied. Therefore, we see this paper as the first step in shedding light on consumers' choices in the context of contracts in the retail electricity market and as a basis for developing more complex modeling approaches.

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