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Competitive Effects of an Asymmetric
Universal Service Obligation***

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Skimming the others' cream: competitive effects of an asymmetric universal service obligation*

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Abstract

In a competitive environment, universal service obligations (USOs) appear as constraints imposed on firm behaviour, and are often presented as a burden to the concerned firms. However, we show that USOs might benefit firms by acting as first mover advantages for the incumbent. We build a simple model of two-part tariff competition between two firms, one of which provides an 'essential' good and is subject to a USO requiring ubiquity and uniform pricing, while the other is subject to uniform pricing only, a situation common in energy markets. Surprisingly, the geographic component of the USO incites the incumbent to price more aggressively and induces reduced entry, even though the entrant is able to "cream-skim" the market. We interpret this result as partial appropriation by the incumbent of the surplus brought to the economy by the entrant, and study the conditions under which the strategies at hand might be put to work.

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Abstract

In a competitive environment, universal service obligations (USOs) appear as constraints imposed on firm behaviour, and are often presented as a burden to the concerned firms. However, we show that USOs might benefit firms by acting as first mover advantages for the incumbent. We build a simple model of two-part tariff competition between two firms, one of which provides an 'essential' good and is subject to a USO requiring ubiquity and uniform pricing, while the other is subject to uniform pricing only, a situation common in energy markets. Surprisingly, the geographic component of the USO incites the incumbent to price more aggressively and induces reduced entry, even though the entrant is able to "cream-skim" the market. We interpret this result as partial appropriation by the incumbent of the surplus brought to the economy by the entrant, and study the conditions under which the strategies at hand might be put to work.

Résumé

Dans un environnement concurrentiel, les obligations de service universel (OSU) apparaissent sous la forme de contraintes imposées aux firmes, et représentent souvent un fardeau pour les firmes concernées. Cependant, nous montrons que les OSU peuvent être favorables pour ces dernières en agissant comme un avantage du premier joueur pour l'opérateur en place. Nous construisons un modèle de concurrence en tarif binôme entre deux firmes : l'une fournit un bien essentiel et est soumise à une OSU composée de contraintes d'ubiquité et de tarification uniforme tandis que l'autre n'est soumise qu'à une contrainte de tarification uniforme. Cette situation est fréquemment observée dans les marchés de l'énergie. De façon surprenante, la composante géographique de l'OSU conduit l'opérateur historique à tarifier plus agressivement, ce qui a pour effet de réduire le niveau d'entrée, même si l'entrant est à même d'«écrémer» le marché. Nous interprétons ce résultat comme une appropriation partielle par la firme en place du surplus apporté à l'économie par l'entrant. Nous étudions les conditions sous lesquelles les stratégies mentionnées peuvent être mises en oeuvre.

1. Introduction

For reasons of equity, social cohesion, economic development and economic efficiency, governments have sustained that ideally, everyone should have access to some basic public services such as telephone, electricity, or postal services. This goal has been called universal service, and in order to attain it, governments and regulators have imposed different kinds of restrictions on the providers of these services. However, the exact definition of universal service, and its associated restrictions, generally referred to as universal service obligations (USOs hereafter), is far from being precise. Usually, universal service means the provision of a basic package of services, of at least a minimum quality level, to all consumers, and at affordable prices.¹

USOs traditionally include at least two basic components: ubiquity and non discrimination.² The first addresses full geographic and social coverage, by imposing an obligation to serve every customer asking to be served, within some geographic boundaries defined by the regulator, but usually coinciding with the national territory or regulatory jurisdiction. The second addresses the problem of equity, by impeding providers to discriminate between users (within groups also defined by the regulator) according to characteristics such as cost of service, willingness to pay, solvability, etc. These constraints may be imposed together or independently, and they of course have direct effects in terms of lowering firms profits and creating strategic links between different market segments.

Historically, these restrictions were financed by the incumbent monopolies through cross-subsidies coming from the most profitable services (usually premium services for customers in high-density urban areas) to the more costly ones (usually basic service provision in rural areas to poor customers with low consumption). However, most of these basic services have been recently opened to competition to foster efficiency and cost reduction, while at the same time making the internal funding of the USOs, i.e. through cross-subsidization between profitable and unprofitable categories of consumers, more difficult. In this new context, universal service policies must not only guarantee that the final goal is attained, but they must also explicitly minimize the competitive distortions they introduce. In Europe, for example, the Universal Service Directive states that: “Ensuring universal service (that is to say, the provision of a defined minimum set of services to all end-users at an affordable price) may involve [...] prices that depart from those resulting from normal market conditions. However, compensating undertakings [...] need not result in any distortion of competition, provided that [...] the net cost burden is recovered in a competitively neutral way.”³

The funding of USOs differs considerably across nations and states,⁴ but most of the mechanisms that have been retained so far include the operation of a “universal service fund”, to which all firms operating in the sector must contribute, according to some fixed rule. This means that the USO is financed with resources coming from within the corresponding industry, and does not require resources obtained from other sectors of the economy through taxes.

For example, in the telecommunications sector, the USO is usually financed to through a universal service fund to which all participants in the telecommunications sector must contribute. Thus, mobile phone operators or international “trunk” carriers pay for the USO imposed on the fixed telephone companies, usually the historic incumbent. However, some network industries that are subject to USOs sell goods or services competing closely, in some segments, with substitutes not constrained by USOs. For example, basic postal services compete not only with private carriers (mainly in and between large cities) but also with telegraph, faxes and e-mail for some applications; and electricity competes with gas, oil, and other forms of energy (mainly for heating applications). This article focuses on the competitive effects from the imposition of USOs under these circumstances. In

¹ What exactly is considered “basic”, “minimum”, and “affordable” varies widely across regulatory jurisdictions.

² An additional “social” component, imposing low tariffs for targeted consumers is sometimes also included in the USOs (see Gasmi, Laffont and Sharkey (1999)).

³ Directive 2002/22/EC of the European Parliament and of the Council of 7 March 2002 on universal service and users' rights relating to electronic communications networks and services (Universal Service Directive).

⁴ See « Rapport GdF » for a more detailed description.

particular, we explore in what way the entry or presence of substitutes not subject to USOs alters the behaviour of the incumbent firm concerned by these obligations and, eventually, if the unconstrained entrants are able to cream-skin the market, whether and in which way they should contribute to the financing of universal service. We also study the effect of asymmetric USOs on entry and determine if there are substitutability or entry thresholds such that USOs cannot be funded without the entrants contributing or through additional taxes.

For our exposition here, we retain the example of the energy sector: gas and electricity are close substitutes in some of their uses, like heating, cooking, or powering machines,⁵ but only the latter is subject to a USO. All our results hold for any other pair of network industries with asymmetric USOs, two-part tariffs and an ‘essential’ service, but for simplicity we confine our discussion to the gas-electricity example.⁶

While electric utilities are forced by law to serve every customer that wants to be served, and this under non discriminatory conditions (regardless of their cost and/or profitability), gas providers can decide whether or not to serve a specific customer (or location).⁷ Hence, in zones where both distribution networks are present, gas and electricity compete effectively with each other, so one might argue that the gas companies should contribute to financing the USO, just like in the telecom example cited above. The intuition behind this argument is that the gas companies take some profitable energy sales away from the electricity companies, thus imposing a heavier burden in the financing of the USO within the electric sector, that should be compensated. But even though intuition tells us that the absence of a USO gives the gas firm a competitive strategic advantage, it turns out that the electricity firm may actually benefit from this asymmetry, as we will later show.

The effects of the non-discrimination component of USOs in competitive environments have been studied, among others, by Choné, Flochel and Perrot (2002), Valletti, Hoernig and Barros (2002), and Anton, Vander Weide and Vettas (2002).⁸ All these authors show that USOs are not competitively neutral, and that uniform pricing creates strategic links between markets that would otherwise be independent. In order to benefit from high prices in its captive segment, the incumbent competes less aggressively in the competitive segment, which benefits the entrant. Hence, equilibrium prices and profits are higher, and so are the associated deadweight losses. Anton, Vander Weide and Vettas (2002) study the effects of these strategic links on competition, prices and the level of subsidies needed. They find that, when there is an uniform pricing constraint, the firm serving high-cost areas weakens competition on the duopoly low-costs areas in order to increase prices and subsidies.⁹ Choné, Flochel and Perrot (2002) also consider the implications of USOs on firms’ strategies and study mainly the welfare effects of alternative allocation and funding mechanisms. They find that ‘pay or play’ dominates under ubiquity but only in the absence of a non-discrimination constraint. In the same direction, Hoernig (2001) finds that the imposition of uniform pricing on entrants might reduce welfare or deter entry. Valletti, Hoernig and Barros (2002) study the effects on coverage and prices : they show that price competition is affected by the relative coverage and that the imposition of a minimum coverage for the incumbent in the presence of uniform pricing raises market prices. They stress that the usual “Net Avoided Costs” approach to USOs is invalid because it focuses only on loss-making areas and does not take into account the global impact USOs have on competition in other areas. As noticed by Panzar (2000), among others, the accurate evaluation of the full costs of USOs requires the specification of an unsubsidised and competitive market scenario. This allows to assess the resource costs of providing facilities (to connect consumers who would otherwise not choose to

⁵ In France, roughly two thirds of all electricity and two thirds of all gas is consumed at the residential level.

⁶ For a broader perspective, just think of the electricity firm as the firm subject to a USO, and of the gas firm as the competing firm. The ‘essential’ service in this case is “light”.

⁷ Once the gas provider chooses to serve a region he is then usually subject to constraints, at least regarding the continuity of service and generally including non discrimination.

⁸ These articles, in turn, complete the literature on cross-market price restrictions initiated by Leontief (1940)’s analysis of multi-market monopoly and extended to competitive entry by Armstrong and Vickers (1993).

⁹ See DeGraba (1987) for another view on how cross-market price restrictions affect competition, without focusing on entry.

subscribe) as well as the reduction in net revenues, both resulting from the pricing policies used to implement the USOs. Our article fits into this stream but concentrates on the role of an ‘essential’ good and two-part tariff competition.

Captive sales of an essential good provide firms with an excellent opportunity to leverage their market power from one market to another. Whinston (1990) provides a good literature survey on the ‘leverage theory’ of tied good sales, and builds a model with linear pricing and fixed proportions consumption where strategic foreclosure arises in one market as a consequence of monopoly power in another.¹⁰ The basic intuition behind the leverage theory resembles that of predation:¹¹ firms subsidize more aggressive behaviour in the competitive market with profits coming from the monopolized market. Hence, firms traditionally face a trade-off in the competitive market between raising their market shares and eroding their margins, with eviction as a limiting case.

The preceding discussion shows that the incumbent faces the following antagonistic incentives: on the one hand, to compete less aggressively, in order not to spill eroded margins over to the monopoly segment (due to the non discrimination constraint); and on the other hand, to be more aggressive in order to leverage market power from the ‘essential’ good to the competitive segment. The interplay of these two effects depend crucially on the nature of prices: under linear pricing, lower prices translate into higher market shares, lower margins, and more aggressive behaviour. However, under more general pricing assumptions, this equivalence no longer holds.¹² We restrict our analysis to two-part tariff competition not only because it is the situation prevailing in most of the network industries inspiring our study, but also because the strategy space is rich enough to illustrate all important effects while at the same time allowing for simple, intuitive interpretations.¹³

The remainder of this article is structured as follows. In section 2 we introduce the model, and in section 3 we expose the unregulated and regulated monopolies as benchmark cases. In section 4 we present duopoly competition subject to a USO and describe the unregulated equilibrium and the underlying strategic effects. We complete the analysis by comparing the results to the regulated outcomes in section 5, before proceeding to discuss some extensions and other possible applications of our results. We conclude in section 7 with policy implications.

2. The model

We consider two representative firms, g and e , selling respectively gas and electricity at two-part tariffs $\{t_g, p_g\}$ and $\{t_e, p_e\}$ (where t_i is the fixed fee and p_i is the per-unit charge) to a continuum of energy consumers differentiated only by their location q on the segment $[0, \bar{q}]$. Each q in the interval corresponds to a “local market” (a village, town, city, etc.), and $\bar{q}$ is the size of the country (or the regulatory jurisdiction). Each market has the same number of customers (i.e. the same size: at each location there is a mass 1 of identical representative consumers), the same wealth and utility functions, but different fixed costs of service: a firm deciding to serve a certain location q must incur the fixed cost associated to that location, denoted as $f_g(q)$ for gas and $f_e(q)$ for electricity. We assume that the locations are ordered by increasing fixed costs of service and that the order is the same for both firms, and we normalize fixed costs at the central location to zero (i.e. $f_g(q)$ and $f_e(q)$ are continuously increasing functions with $f_g(0)=f_e(0)=0$).¹⁴

¹⁰ In his model, this will happen only if (i) the monopolist can commit to bundle two independent products or (ii) the monopolized good is not essential for all uses of the other good. We present here another mechanism through which leveraging may take place.

¹¹ See for example Spector (2001).

¹² See Wilson (1993) for an in-depth analysis of non-linear pricing.

¹³ Choné, Flochel and Perrot (2002) use general non-linear pricing in their assessment of USOs effects on firms’ strategies and competition but do not consider the presence of an essential good.

¹⁴ Alternatively one might assume that fixed costs are the same but willingness to pay or density decreases, without changing the results. What matters is that profitability decreases with q for both firms.

In this context it is fairly simple to see that a company that finds it profitable to be present at location q_0 will also serve all locations such that $q < q_0$, because they have lower locational fixed costs.¹⁵ We thus define the total fixed costs for each company as a function of the respective level of entry q_i :

$$F_i(q_i) = \int_0^{q_i} f_i(q) dq \quad (1)$$

While the gas firm is able to choose any level of entry q_g , the imposition of a USO on the electricity company means that it serves all locations up to $\bar{q}$ in a non discriminatory manner, so consumers will be able to choose between gas and electricity in locations below q_g , but will face an electricity monopolist between q_g and $\bar{q}$, as shown in Figure 1.

Figure 1. Market structure

Consumers value two basic needs: “light”, indexed by L and representing all uses for which gas is not an effective alternative to electricity (like lighting or powering radios and TV sets); and “heat”, indexed by H and corresponding to uses for which both kinds of energy are substitutes. Thus, even consumers buying all their “heat” from the gas company value buying “light” from the electricity company. Consumers are characterized by their indirect utility functions for each of the two goods, which are assumed to be continuous, decreasing, convex and twice differentiable: $v_L(p_e)$ for light; and $v_d(p_e, p_g)$ or $v_m(p_e)$ for heat depending on whether both products are available or not.¹⁶ We can thus compute optimal consumption of each good:

- light is always sold by the electricity company only: $q_L(p_e) = -\frac{\partial v_L(p_e)}{\partial p_e}$,
- all heat will be electric in the monopoly region: $q_e^m(p_e) = -\frac{\partial v_m(p_e)}{\partial p_e}$,
- in the duopoly region, heat demand will be divided between gas and electricity according to:
 $q_e^d(p_e, p_g) = -\frac{\partial v_d(p_e, p_g)}{\partial p_e}$, and $q_g^d(p_e, p_g) = -\frac{\partial v_d(p_e, p_g)}{\partial p_g}$.

¹⁵ This is of course related to the non discrimination constraint and to the fact that consumption decisions do not depend on location. We follow Valletti, Hoernig, and Barros (2002) by assuming that firms start building their networks from location 0 and do not leave gaps between served locations. Also notice that density hypotheses on q do not alter our results due to the independence of consumption decisions on location.

¹⁶ Notice that this specification is equivalent to one in which consumers have a utility function depending on the consumptions of the two goods (“heat” and “light”) that is additively separable.

Our only assumptions on these functions are that $v_d(p_e, p_g) \geq v_m(p_e), \forall p_e, \forall p_g$, i.e. that given electricity prices, consumers are always better off if they are also able to buy gas at some price p_g , and that $q_e^d(p_e, p_g) \leq q_e^m(p_e), \forall p_e, \forall p_g$, i.e. that given electricity prices consumers will not buy more electricity when they are also able to buy gas.

Firms play a two-stage game in which the gas firm first chooses its entry level q_g , and then both firms compete in two-part tariffs $\{t_i, p_i\}$, where t_i denotes the fixed charge of firm i and p_i its per-unit price, subject to constraints of non discrimination neither across locations nor across goods. This captures the fact that the electricity firm can observe the extension of the gas network (or entry level) before setting its tariffs competitively. The non discrimination constraint across goods means that the electricity company cannot know if the electricity it is selling is used as “heat” or “light”, so it is unable to price discriminate according to its use. Marginal production costs for gas and electricity are assumed to be constant and equal to c_g and c_e , with $c_g < c_e$.¹⁷

3. Benchmarks

Useful benchmarks are given by the allocations that would be chosen by an unregulated monopolist and by a benevolent social planner regulating a single electricity firm.

3.1 Unregulated Electricity Monopolist

The unregulated electricity monopolist maximizes its profits subject to the participation constraint of consumers:

$$\begin{aligned} \max \quad & \Pi_e^m(p_e, t_e, q_e) = q_e \cdot [(p_e - c_e)q_e^m(p_e) + (p_e - c_e)q_L(p_e) + t_e] - F_e(q_e) \\ \text{s.t.} \quad & S(p_e, t_e) = v_m(p_e) + v_L(p_e) - t_e \geq 0 \end{aligned} \quad (2)$$

The solution is:

$$\begin{cases} p_e^m = c_e \\ t_e^m = v_m(c_e) + v_L(c_e) \\ q_e^m \text{ such that } F_e'(q_e^m) = v_m(c_e) + v_L(c_e) \end{cases} \quad (3)$$

We recognize in this solution the standard result of full extraction of consumer surplus by a monopolist via two-part tariffs, with the added flavour of the choice of the level of entry. As the monopoly becomes residual claimant of all consumer surplus, its maximisation problem coincides with social objectives: the electricity monopolist will cease to serve locations when the fixed cost of entry exceeds the gains in global welfare. In other words, entry of the unregulated electricity monopoly occurs at the socially optimal level. The larger the consumer surplus at marginal cost, the larger q_e^m , so for the universal service constraint to be binding (which means the market would not be spontaneously served by the unregulated monopolist), we need the following condition to hold:

¹⁷ Real data on costs is unreliable and difficult to find, but prices may be a good reference. For example, January 2003 prices of 100 kWh to small final consumers in France were € 5.94 for gas and € 12.55 for electricity, according to the French Ministry of Finance. Similar price differences exist in most energy markets, and are partly explained by the fact that gas is an important input for electricity generation. We do not explore vertical issues here but assume that the cost of producing electricity is inherently higher than the cost of gas.

$$q_e^m < \bar{q} \quad (4)$$

Keeping this unregulated behaviour in mind, we now explore the regulated outcome with a single firm and two part tariffs.

3.2 Regulation of a single electricity monopolist

We now turn to the problem faced by the regulator, which consists in maximising the global welfare function subject to the participation constraints of the consumers and of the firm.¹⁸ We assume that the global welfare function is a weighted sum of firm profits and consumer surplus, where the respective weights $\mathbf{a}_p$ and $\mathbf{a}_s$ represent the redistributive preferences of the regulator:

$$\begin{aligned} \max \quad & W_m(p_e, t_e, \mathbf{q}_e) = \mathbf{a}_p \cdot \Pi_e^m(p_e, t_e, \mathbf{q}_e) + \mathbf{a}_s \cdot \mathbf{q}_e \cdot S(p_e, t_e) \\ \text{s.t.} \quad & S(p_e, t_e) \geq 0; \quad \Pi_e^m(p_e, t_e, \mathbf{q}_e) \geq 0 \end{aligned} \quad (5)$$

For any level of service $\mathbf{q}_e$ and price p_e , the participation constraints of consumers and the firm impose respectively upper and lower bounds on the fixed part of the tariff: it must be low enough for net consumer surplus to be non negative, and high enough for the firm to recover its fixed costs. Thus, we can rewrite both participation constraints so that they define an interval for t_e :¹⁹

$$\frac{F_e(\mathbf{q}_e)}{\mathbf{q}_e} - [(p_e - c_e)(q_e^m(p_e) + q_L(p_e))] \leq t_e \leq v_m(p_e) + v_L(p_e) \quad (6)$$

By observing that the welfare function defined in (5) is linear in t_e with coefficient $(\mathbf{a}_p - \mathbf{a}_s)$, we find that whenever $\mathbf{a}_p \neq \mathbf{a}_s$ the regulator will always set the fixed part either to its minimum or maximum value, depending of which component of global welfare she values the most. This means that if $\mathbf{a}_p > \mathbf{a}_s$, the regulator will set consumer surplus to zero by taking $t_e^{Rm} = v_m(p_e) + v_L(p_e)$ and give the whole surplus to the firm, or if $\mathbf{a}_p < \mathbf{a}_s$, the regulator will set firm profits to zero by taking $t_e^{Rm} = \frac{F_e(\mathbf{q}_e)}{\mathbf{q}_e} - [(p_e - c_e)(q_e^m(p_e) + q_L(p_e))]$ and give the whole surplus to consumers. Finally, if $\mathbf{a}_p = \mathbf{a}_s$, any value of t_e in the interval defined by (6) yields the same outcome in terms of global welfare. The complete solution of (5) is:

$$\begin{cases} p_e^{Rm} = c_e \\ t_e^{Rm} = \begin{cases} \frac{F_e(\mathbf{q}_e)}{\mathbf{q}_e} & \text{if } \mathbf{a}_p < \mathbf{a}_s \\ v_m(c_e) + v_L(c_e) & \text{if } \mathbf{a}_p > \mathbf{a}_s \\ \left[\frac{F_e(\mathbf{q}_e)}{\mathbf{q}_e}; v_m(c_e) + v_L(c_e) \right] & \text{otherwise} \end{cases} \\ q_e^{Rm} \text{ such that } F_e'(q_e^{Rm}) = v_m(c_e) + v_L(c_e) \end{cases} \quad (7)$$

¹⁸ We assume that direct transfers to the firm are impossible or costly, which explains the participation constraint for the firm.

¹⁹ Non-emptiness of this interval basically means that the value of the produced quantity of electricity at price p_e for each local market between 0 and $\mathbf{q}_e$ is higher than its average cost. In other words, it means that electricity production is socially desirable so we might reasonably assume that the set of possible values of t_e is non-empty.

Observe that the solution always includes marginal cost pricing and entry up to the point where the fixed cost of entry equals consumer surplus. The fixed part of the tariff is used by the regulator to allocate surplus depending on her social objectives. By comparing conditions (7) and (3), notice that the regulated outcome when $\mathbf{a}_p > \mathbf{a}_s$ can be successfully decentralized to the firm.

Also notice that the non discrimination constraint is not binding for the monopoly: as cost of service is transparent to customers, their consumption patterns are the same across different locations, and the monopoly will always choose to price at marginal cost and then set the fixed part of the tariff in order to extract all the remaining consumer surplus. This means that in our model the only reasons to discriminate between consumers arise from strategic considerations, namely the need to compete more aggressively with rivals in zones in which competition exists.

4. Duopoly with asymmetric USO

Let us consider a setting in which the only regulatory restrictions imposed are a full USO for the electricity company (namely both ubiquity and non discrimination constraints), and only a non discrimination constraint on the gas firm. In our context, the ubiquity constraint means that the electricity firm sets $\mathbf{q}_e = \bar{\mathbf{q}}$ and chooses tariffs in such a way that all consumers have a non-negative utility; the non discrimination constraints mean that each firm chooses a unique two-part tariff $\{t_i, p_i\}$. As shown in Figure 1, at each location there will be either an electricity-gas duopoly, or a single electricity monopolist.

Timing of the Game

Step 1. Gas firm chooses its entry level $\mathbf{q}_g$.

Step 2. The electricity firm observes $\mathbf{q}_g$ and both firms compete in two-part tariffs (simultaneously) subject to regulatory constraints.

The ubiquity USO imposed on the electricity company means that both firms know that the electricity grid will have full coverage. In other words, it is as if the electricity had a first mover advantage in the entry game and the network were already built when the gas firm evaluates entry. Thus, for simplicity in exposition and to be able to compare with previous results in the literature, we will treat the electricity firm as the incumbent and the gas firm as the entrant.

4.1 Two-part tariff competition: second stage equilibrium

Consumers in the monopoly segment will buy electricity at tariff $\{t_e, p_e\}$ iff:

$$t_e \leq v_m(p_e) + v_L(p_e) \quad (8)$$

Condition (8) states that it is in the interest of consumers to be connected to the electricity network, because what they pay is less than (or equal to) the utility they get from electricity consumption. This condition captures the primary motivation for the USO imposed on electricity: all consumers gain from being served. Hence, condition (8) serves a double purpose: it is the participation constraint of electricity consumers and ensures that the USO goals are attained.

Consumers in the duopoly segment will also buy gas if and only if the incremental utility they get exceeds the price they pay. Formally, this translates into the participation constraint for gas consumers:

$$v_m(p_e) + v_L(p_e) - t_e \leq v_d(p_e, p_g) + v_L(p_e) - t_e - t_g \Leftrightarrow t_g \leq v_d(p_e, p_g) - v_m(p_e) \quad (9)$$

The gas firm solves its profit maximisation problem subject to participation constraints of the gas firm and gas consumers:²⁰

$$\begin{aligned} \max_{p_g, t_g} \quad & \Pi_g(p_g, t_g, p_e, t_e, \mathbf{q}_g) = \mathbf{q}_g \cdot [(p_g - c_g)q_g^d(p_e, p_g) + t_g] - F_g(\mathbf{q}_g) \\ \text{s.t.} \quad & \frac{F_g(\mathbf{q}_g)}{\mathbf{q}_g} - (p_g - c_g)q_g^d(p_e, p_g) \leq t_g \leq v_d(p_e, p_g) - v_m(p_e) \end{aligned} \quad (10)$$

As $\Pi_g(p_g, t_g, p_e, t_e, \mathbf{q}_g)$ is separable, linear and increasing in t_g , the gas firm's best response is to set the fixed part of the tariff as high as possible. As in the monopoly case, the profit maximization problem collapses into that of efficient pricing, so the firm sets the variable part of the tariff to coincide with marginal cost.

Formally, its best reply functions are:

$$\begin{cases} p_g^*(p_e, t_e, \mathbf{q}_g) = c_g \\ t_g^*(p_e, t_e, \mathbf{q}_g) = v_d(p_e, c_g) - v_m(p_e) \end{cases} \quad (11)$$

Notice that the per-unit charge of the gas best reply tariff is independent from the electricity tariff, which means that the strategic interaction between firms operates through the fixed part only. The fixed part of the best reply gas tariff is increasing in p_e ,²¹ which is compatible with the straightforward intuition that both goods are strategic substitutes. Also observe that there is no direct effect of $\mathbf{q}_g$ on the best reply tariff (but as we will later show there is an indirect strategic effect through the changes in p_e).

In the case of the electricity firm, profits decompose into a part coming from “light”, across all $\mathbf{q}$, and a part coming from “heat”, the latter in turn differing according to whether consumers face a duopoly or a monopoly. Thus, we can write the profit function of the electricity firm as follows:

$$\Pi_e(p_g, t_g, p_e, t_e, \mathbf{q}_g) = \mathbf{q}_g (p_e - c_e) q_e^d(p_e, p_g) + (\bar{\mathbf{q}} - \mathbf{q}_g) (p_e - c_e) q_e^m(p_e) + \bar{\mathbf{q}} (p_e - c_e) q_L(p_e) + \bar{\mathbf{q}} \cdot t_e - F_e(\bar{\mathbf{q}})$$

The first term in Π_e corresponds to the variable revenue of heat sold in the duopoly segment, the second to the variable revenue of heat sold in the monopoly segment, the third to variable revenue of light (sold to all consumers), the fourth to revenue coming from the fixed part of the tariff and the fifth is the fixed cost of service.

The electricity firm solves its profit maximisation problem subject to its own participation constraint and that of electricity consumers:

$$\begin{aligned} \max_{p_e, t_e} \quad & \Pi_e(p_g, t_g, p_e, t_e, \mathbf{q}_g) \\ \text{s.t.} \quad & \frac{F_e(\bar{\mathbf{q}}) - (p_e - c_e) [\mathbf{q}_g \cdot q_e^d(p_e, p_g) + (\bar{\mathbf{q}} - \mathbf{q}_g) q_e^m(p_e) + \bar{\mathbf{q}} q_L(p_e)]}{\bar{\mathbf{q}}} \leq t_e \leq v_m(p_e) + v_L(p_e) \end{aligned} \quad (12)$$

²⁰ As earlier, non-emptiness of the feasible interval for t_g means that the value of the produced quantity of gas at these prices for each local market between 0 and $\mathbf{q}_g$ is higher than its average cost. In other words, it means that gas production is socially desirable so we might reasonably assume that the set of possible values of t_g is non-empty.

²¹ In fact, $\frac{\partial t_g^*(p_e, t_e, \mathbf{q}_g)}{\partial p_e} = q_e^m(p_e) - q_e^d(p_e, c_g) > 0$.

Just like in the case of gas, $\Pi_e(p_g, t_g, p_e, t_e, \mathbf{q}_g)$ is separable, linear and increasing in t_e , so the electricity firm must set the fixed part of the tariff as high as possible. However, the difference in demand between the duopoly and monopoly segments, and the non discrimination constraint, imply that here the profit maximisation problem no longer resembles that of efficient pricing. In fact, the first order condition for pricing is in this case:

$$(p_e - c_e) \left[\mathbf{q}_g \frac{\partial q_e^d}{\partial p_e}(p_e, p_g) + (\bar{\mathbf{q}} - \mathbf{q}_g) \frac{\partial q_e^m}{\partial p_e}(p_e) + \bar{\mathbf{q}} \frac{\partial q_L}{\partial p_e}(p_e) \right] = \mathbf{q}_g (q_e^m(p_e) - q_e^d(p_e, p_g)) \quad (13)$$

The second order condition for (13) to define a maximum is $\frac{\partial^2 \Pi_e}{\partial p_e^2} \leq 0$, that is:

$$2\mathbf{q}_g \frac{\partial}{\partial p_e}(q_e^d - q_e^m) + \bar{\mathbf{q}} \frac{\partial}{\partial p_e}(q_L + q_e^m) + (p_e - c_e) \frac{\partial^2}{\partial p_e^2} [\mathbf{q}_g q_e^d + (\bar{\mathbf{q}} - \mathbf{q}_g) q_e^m + \bar{\mathbf{q}} q_L] \leq 0 \quad (14)$$

In Appendix C we show an example of a standard quadratic utility function with substitutability between goods for which this condition holds. If it does not hold, then profits are not globally concave in p_e and condition (13) does not necessarily define a maximum of Π_e . If the left-hand side term in expression (14) is always positive, it means that the profits of the electricity firm are globally convex in p_e , so condition (13) defines a minimum: it is in the firm's interest to pick a corner solution with the highest feasible p_e . Finally, if the sign of the left-hand side term in expression (14) is undetermined, condition (13) defines critical points for firm profits, that must then be compared with the corner values to select the global maximum.

Proposition 1. *Regardless of the level of entry of gas, electricity will be priced below marginal cost if the second order condition (14) holds.*

Proof.

As all the price derivatives of quantities are non positive, and all three variables $\mathbf{q}_g$, $\bar{\mathbf{q}}$ and $(\bar{\mathbf{q}} - \mathbf{q}_g)$ non negative, it follows that the expression in square brackets in condition (13) is negative. Given that, for a given price, the electricity firm sells at least as much “heat” when it is alone as when it faces competition from gas, the right hand side of (13) is positive, so we need $p_e - c_e \leq 0$ for the equality to hold. *Q.E.D.*

We can write the electricity firm's best reply functions by replacing demand price elasticities into expression (13):

$$\begin{cases} t_e^*(p_g, t_g, \mathbf{q}_g) = v_m(p_e^*(p_g, t_g, \mathbf{q}_g)) + v_L(p_e^*(p_g, t_g, \mathbf{q}_g)) \\ p_e^*(p_g, t_g, \mathbf{q}_g) \text{ such that } \frac{p_e^* - c_e}{p_e^*} = \frac{1}{\mathbf{e}_{(q_e^m - q_e^d)} - \mathbf{e}_{(q_e^m + q_L)} \frac{\bar{\mathbf{q}}}{\mathbf{q}_g} \cdot \frac{q_e^m + q_L}{q_e^m - q_e^d}} \end{cases} \quad (15)$$

$\mathbf{e}_{(q_e^m - q_e^d)} = -\frac{p_e \cdot \frac{\partial}{\partial p_e}(q_e^m - q_e^d)}{q_e^m - q_e^d}$ and $\mathbf{e}_{(q_e^m + q_L)} = -\frac{p_e \cdot \frac{\partial}{\partial p_e}(q_e^m + q_L)}{q_e^m + q_L}$ are respectively the price elasticities of incremental monopoly demand for electricity (with respect to the duopoly demand level) and total monopoly demand for electricity.

Thus, equilibrium tariffs in the second stage of the game are obtained by intersecting the best reply functions of both firms, given by (11) and (15). Notice that the optimal price chosen by the

electricity firm depends on the entry level of the gas firm q_g . Thus, any change in the entry decision of the gas firm will induce a modification in the electricity tariff, a distortion that would otherwise be absent. Observe that the form of the variable price distortion is similar to a standard monopoly pricing equation, except that instead of having the total elasticity of demand in the denominator of the right-hand side, we find an “adjusted elasticity” consisting of the weighted difference between the price elasticity of the total demand for electricity in the monopoly segment, and the elasticity of the demand for electric “heat” lost in the duopoly situation.

We can study the size and direction of this distortion by differentiating the first order condition (13) with respect to q_g . We obtain:

$$\frac{\partial p_e^*(q_g)}{\partial q_g} \frac{\partial^2 \Pi_e}{\partial p_e^2} = (p_e - c_e) \frac{\bar{q}}{q_g} \frac{\partial}{\partial p_e} (q_e^m + q_L) \quad (16)$$

Expression (16) states that if the second order condition (14) holds, then $p_e^*(q_g)$ is decreasing in q_g , which implies the following lemma:

Lemma 1. *If the second order condition (14) holds, then the electricity price distortion increases with the level of service chosen by the gas firm.*

We also find that:

Proposition 2. *Regardless of the level of entry of gas, electricity profits under USOs (ubiquity and non discrimination) increase in the duopoly situation with respect to the monopoly case, if the second order condition (14) holds.*

Proof.

$$\Pi_e^* = \Pi_e(p_g^*, t_g^*, p_e^*, t_e^*, q_g) \geq \Pi_e(p_g^*, t_g^*, c_e, v_m(c_e) + v_L(c_e), q_g) = \Pi_e^m(c_e, v_m(c_e) + v_L(c_e), \bar{q})$$

The first inequality holds because of the definition of a maximum and the second equality is straightforward. See section 4.3 for further comments. Q.E.D.

We now turn to the coverage choice of the gas firm in the first stage.

4.2 Choice of the level of entry: first stage equilibrium

The gas firm anticipates the second stage equilibrium tariff and solves:

$$\max_{q_g} \Pi_g^*(q_g) = \Pi_g(p_g^*(q_g), t_g^*(q_g), p_e^*(q_g), t_e^*(q_g), q_g) = q_g \cdot [v_d(p_e^*(q_g), c_g) - v_m(p_e^*(q_g))] - F_g(q_g)$$

And the first order condition is :

$$\frac{\partial \Pi_g^*}{\partial q_g} = 0 \Leftrightarrow F_g'(q_g^*) = [v_d(p_e^*(q_g^*), c_g) - v_m(p_e^*(q_g^*))] + q_g^* \cdot [q_e^m(p_e^*(q_g^*)) - q_e^d(p_e^*(q_g^*), c_g)] \frac{\partial p_e^*(q_g^*)}{\partial q_g} \quad (17)$$

Proposition 3. *If the second order condition (14) holds, then the gas firm chooses to serve a fraction of the market smaller than the level of service it would choose without taking into account the effect of its entry decision on the pricing of electricity.*

Proof.

Expression (17) says that the gas firm will distort its choice of coverage to account for the induced effects of entry on the pricing of electricity. This indirect effect has the same sign than

$\frac{\partial p_e^*(q_g)}{\partial q_g}$, because $q_e^m - q_e^d \geq 0$ for any price. But we know from Lemma 1 that $\frac{\partial p_e^*(q_g)}{\partial q_g}$ is negative if condition (14) holds, so the gas firm enters less. *Q.E.D.*

Other side effects worth mentioning are the fact that total gas sales are reduced by more aggressive pricing by the electricity firm (because of the lower entry level and the substitution effect) and that as a consequence profits of the gas firm will fall. In fact, the gas firm breaks even for customers such that $q = q_g^*$ and makes a profit for every q below q_g^* , so if q_g^* is lower, profits decrease accordingly.

4.3 Interpretation

The intuition of the mechanism at work is as follows: entry of the gas firm raises total surplus in the economy. As long as the level of service of the gas firm is lower than that of the electricity firm, gas entry divides consumers in two groups, those who can buy both products and those to whom only electricity is available. The duopoly consumers can be thought of as “high valuation” consumers, because they perceive an indirect utility $v_d > v_m$. This increase should normally be shared between the gas firm and its consumers. Knowing that all consumers are captive because all of them want to consume light, the electricity firm would like to price discriminate between both groups by increasing the fixed part of its tariff to the “high valuation” consumers. Nevertheless, the non discrimination constraint prevents it from doing so but incites the electricity firm to modify its tariffs. Should the electricity firm increase the fixed part of its tariff only, it would lose the demand on the monopoly segment where the tariff was set so as to precisely leave zero utility to consumers before the entry of gas. In some cases this might be profitable, but the ubiquity constraint forbids not to serve all customers. So, the only way for the electricity firm to be able to increase the fixed part of its tariff in the “high valuation” group is through a simultaneous reduction of its variable price. This is a standard cross-subsidization effect with two-part tariffs: the electricity firm reduces its variable price so as to transfer some of the extra surplus from the duopoly consumers to the monopoly consumers (in order to relax their participation constraint), and is thus able to increase the fixed part of its tariff to all consumers. By doing so, the electricity firm prevents the gas firm from extracting the full incremental surplus associated to its entry, so the gas firm enters less than it would if the electricity prices weren’t distorted.

Although the behaviour of the electricity firm described above might at a first glance be perceived as successful predatory pricing, there are some important differences that must be stressed. First, whereas the concept of predation usually implies present losses (or some other kind of ‘sacrifice’) in exchange of future gains (normally related to increased market power), here this is not the case. In fact, it is in the interest of the electricity firm to accommodate the entry of the gas firm, because the electricity firm actually benefits from the presence of the gas company, that allows it to increase the fixed part of its tariffs so as to extract the extra surplus created by gas availability. In other words, reducing variable tariffs is no ‘sacrifice’ at all, as shown by Proposition 2. Second, the electricity firm would like to reduce the quantities it sells, because it makes a loss on every unit sold due to its pricing below marginal cost. As the electricity firm is unable to discriminate across consumer categories or usage of electricity, these losses are made on all market segments. The electricity firm distorts prices downwards only because it knows it can recover these price reductions through the increase in the fixed part of the tariff. Third, usually predatory prices are aimed at inducing the exit of the rival firm, or at least the saturation of its participation constraint. Here, what we have is an equilibrium in which both firms make positive profits, and are able to jointly extract all consumer surplus completely.

This last observation brings forward the importance of regulation. As was seen in the previous section, the implementation of the regulated outcome can be delegated to a monopoly if the regulator

values firm profits more than consumer surplus, or if she values them equally and does not care about their distribution. In a context in which the regulator cares about leaving consumers a strictly positive utility, regulation is unavoidable. The problem is, then, how to implement the regulated production whenever it is possible, and otherwise how to minimize the distortions linked to regulatory objectives. We turn to this problem in the following section.

5. Regulation

As earlier, the problem faced by the regulator consists in maximising the global welfare function subject to the participation constraints of the consumers and of the firms, and to the ubiquity constraint on electricity. Here we also assume that the global welfare function is a weighted sum of firm profits and consumer surplus, where the respective weights $\mathbf{a}_p$ and $\mathbf{a}_s$ represent the redistributive preferences of the regulator:²²

$$\begin{aligned} \max \quad & W_c(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) = \mathbf{a}_p \cdot \Pi_e(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) + \mathbf{a}_p \cdot \Pi_g(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \\ & + \mathbf{a}_s \cdot \mathbf{q}_g \cdot S_d(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) + \mathbf{a}_s \cdot (\mathbf{q}_e - \mathbf{q}_g) \cdot S_m(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \quad (18) \\ \text{s.t.} \quad & S_i(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \geq 0; \quad \Pi_i(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \geq 0; \quad \mathbf{q}_e = \bar{\mathbf{q}} \end{aligned}$$

The complete solution of (18) is given by:²³

$$\left\{ \begin{array}{l} p_g^{**} = c_g \text{ and } p_e^{**} = c_e \\ \text{if } \mathbf{a}_p > \mathbf{a}_s, t_g^{**} = v_d(c_e, c_g) - v_m(c_e) \text{ and } t_e^{**} = v_m(c_e) + v_L(c_e) \\ \text{if } \mathbf{a}_p < \mathbf{a}_s, t_g^{**} = \frac{F_g(\mathbf{q}_g)}{\mathbf{q}_g} \text{ and } t_e^{**} = \frac{F_e(\bar{\mathbf{q}})}{\bar{\mathbf{q}}} \\ \text{if } \mathbf{a}_p = \mathbf{a}_s, t_g^{**} \in \left[\frac{F_g(\mathbf{q}_g)}{\mathbf{q}_g}; v_d(c_e, c_g) - v_m(c_e) \right] \text{ and } t_e^{**} \in \left[\frac{F_e(\bar{\mathbf{q}})}{\bar{\mathbf{q}}}; v_m(c_e) + v_L(c_e) \right] \\ \mathbf{q}_g^{**} \text{ such that } F_g'(\mathbf{q}_g^{**}) = v_d(c_e, c_g) - v_m(c_e) \end{array} \right. \quad (19)$$

As in section 3, by observing that W_c is linear in t_e and t_g , we find that regulator will use the fixed parts as instruments to allocate surplus depending on her social objectives, by setting them either to their minimum or maximum values, depending on which of the two components of global welfare she values the most. This means that if $\mathbf{a}_p > \mathbf{a}_s$, the regulator will set consumer surplus to zero and give the whole surplus to the firm; or if $\mathbf{a}_p < \mathbf{a}_s$, the regulator will set firm profits to zero and give all surplus to consumers; if $\mathbf{a}_p = \mathbf{a}_s$, the regulator can arbitrarily set them to any value she likes within the intervals defined by the participation constraints without altering the welfare outcome. As usual, we then find that marginal cost pricing is efficient and welfare maximizing, and that the optimal extension of the gas network is such that the marginal (fixed) cost of service equals the marginal benefit in terms of increased consumer surplus. We compare this situation with the competitive equilibrium in the following proposition.

²² Alternatively, one might consider different weights for each firm and each category of consumers (that would result in marginal cost pricing not being optimal). However, preferences in which the regulator distinguishes only between consumers and firms, seem more realistic and relevant to our analysis.

²³ See Appendix A for details.

Proposition 4. *If regulation is limited to:*

(i) *a ubiquity and non discrimination constraint on the electricity firm, and*

(ii) *only a non discrimination constraint for gas,²⁴ then*

the gas network is underdeveloped and the electricity prices are too low, with respect to their socially optimal levels.

Proof. See Appendix A.

Q.E.D.

Another effect worth mentioning is that the fixed part of the equilibrium gas tariff is lower in the competitive scenario than in the regulated outcome with more weight on firms (because $p_e^* < p_e^{**}$).

Notice that the profit maximization problem of a merged gas-electricity firm constrained by a USO on electricity collapses into the social welfare maximization problem with zero weights on consumers. This means that the integrated producer would set the variable part of tariffs equal to marginal costs and the fixed parts equal to their maximum feasible value (i.e. $t_g = v_d(c_e, c_g) - v_m(c_e)$ and $t_e = v_m(c_e) + v_L(c_e)$), and would decide to enter up to the socially optimal entry level.

This is summarized in the following lemma.

Lemma 2. *If the regulator does not care about the firm appropriating all global welfare, then she can delegate the implementation of the regulated outcome to an unregulated integrated dual-product monopoly.*

Corollary to Lemma 2. *In welfare terms, the outcome with an unregulated integrated producer is better than the outcome with two competing unregulated single-product firms.*

This last corollary provides an argument for firm integration different to the standard “double marginalization” issue usually present in vertical integration debates. Here, instead of focusing in efficient pricing of inputs, we focus on efficient (variable) pricing of final goods and efficient entry: integration eliminates price distortions and incites firms to produce efficiently at the socially optimal levels of entry. It goes without saying that the vertical links existing in the energy industry imply that the standard arguments also apply. However, our argument is no longer valid if the regulator prefers consumers over firms.

6. Extensions

Effects of price caps

The mechanism through which the electricity firm appropriates the incremental welfare brought to the economy by the entry of the gas firm described in Section 4 depends on the electricity firm being able to raise the fixed component of its tariff. If tariffs are capped, then the electricity firm would not be able to raise its fixed part, and any downward distortion on the variable part will engender losses.

However, it all depends on the way regulators set the price caps. In fact, if they are set so as to leave a minimum utility level to consumers, as is often the case, then the mechanism can regain its full power: entry of the gas firm raises consumer utility, so the regulatory price cap can be relaxed so as to push residual consumer utility back to its previous level. So, in settings with such regulatory

²⁴ This is the case, for example, in France, where gas firms are not subject to ubiquity constraints. Notice that in our context this non discrimination constraint is not binding.

objectives, if the electricity firm has a say in the calculation of price caps, it will be in its interest to understate variable cost and overstate fixed cost.

Endogenous choice of entry by the electricity firm

Replacing the first stage of the game described in Section 4 by allowing both firms to simultaneously choose their level of service (i.e. no ubiquity constraint for the electricity firm) does not change the second stage equilibrium as long as the electricity firm has a higher level of entry ($q_g < q_e$). We still find marginal cost pricing for gas, below marginal cost pricing for electricity and distortions increasing with the gas level of entry. However, the costlier locations will not be served, because electricity will choose a level of service given by:

$$F'_e(\hat{q}_e) = (p_e^* - c_e)[q_e^m(p_e^*) + q_L(p_e^*)] + [v_L(p_e^*) + v_m(p_e^*)] \quad (20)$$

Equation (20) is the standard optimality condition that equals marginal costs and marginal gains. The right hand side term is the marginal benefit of a consumer in the monopoly zone, including the losses due to sales below marginal cost. It is easy to show that $\hat{q}_e < q_e^m = q_e^{Rm}$, that is, the electricity firm enters less when facing a competitor than when it is a monopolist.

Discrimination across consumer categories.

In our model, the only reason for the electricity firm to distort its variable price, is to avoid losing its consumers in the monopoly segment, when raising the fixed part to extract the extra consumer surplus generated by gas entry. If the electricity firm is allowed to price discriminate between its monopoly and duopoly consumers, distorting variable prices would no longer be profitable. In fact, as all consumers are identical except as regarding their fixed cost of service, the electricity firm would simply set the variable part of its tariffs equal to marginal cost (which is optimal at all locations), and then extract the whole consumer surplus from each category of consumers by choosing the maximum feasible fixed part. The gas firm is thus constrained to set the fixed part of its tariff to zero to allow gas consumption, and then to distort its variable price upwards.

Equilibrium tariffs in this scenario are given by the following expressions:²⁵

$$\text{For the electricity firm:} \quad \begin{cases} t_e^m = v_m(c_e) + v_L(c_e) \\ t_e^d = v_d(c_e, \tilde{p}_g) + v_L(c_e) \\ \tilde{p}_e = c_e \end{cases} \quad (21)$$

$$\text{For the gas firm :} \quad \begin{cases} \tilde{t}_g = 0 \\ \tilde{p}_g \text{ such that } \frac{\tilde{p}_g - c_g}{\tilde{p}_g} = \frac{1}{e_{q_g^d}} \\ \tilde{q}_g \text{ such that } F'_g(\tilde{q}_g) = (\tilde{p}_g - c_g) \cdot q_g^d(c_e, \tilde{p}_g) \end{cases} \quad (22)$$

In expression (21), $e_{q_g^d} = -\frac{p_g \cdot \frac{\partial}{\partial p_g} q_g^d}{q_g^d}$ is the price elasticity of gas demand.

As the electricity firm can discriminate between its duopoly and monopoly consumers, it has no incentives to distort the variable part of the tariff, and thus sets it equal to marginal cost. It then

²⁵ See Appendix A for details.

picks t_e so as to fully extract all consumer surplus, leaving the gas firm no option but to set t_g to zero, which ensures that duopoly consumers will buy gas. The gas firm is thus constrained to use linear pricing, and seeks profits by distorting the variable part of the tariff (and sets it to the monopoly level). Basically, the electricity firm is even less constrained to appropriate the welfare increase due to gas entry. We can see from (21) that the electricity firm successfully extracts all consumer surplus, and from (22) that the gas firm practices traditional linear monopoly pricing. Its profits come only from its post-entry absolute advantage in the sense of Salop (1979), i.e. production costs lower than those of electricity.²⁶ In welfare terms, consumer surplus continues to be equal to zero because it is fully extracted by the firms, and both firms still have positive profits in equilibrium. However, comparisons in terms of total industry profits (i.e. in terms of global welfare) are not trivial, because of the change in q_g , as can be seen in the example in Appendix C: gains of the electricity firm might be offset by losses of the gas firm.

Necessity of the essential good hypothesis

The only purpose of the essential good in our model is to ensure that consumers are captive of the incumbent. In fact, in our illustration the main motivation for the existence of USOs is the ‘light’ good, electric ‘heat’ is welcome as an added bonus. However, captivity of the incumbent’s consumers could be captured otherwise. A natural alternative to our ‘essential good’ hypothesis is to impose a particular timing to customers’ decisions. In fact, as long as they are constrained to subscribe to the incumbent’s offer before being offered the possibility to subscribe also to the entrant’s, our findings remain unchanged.

7. Conclusions

Conventional wisdom holds that USOs impose a heavier burden on the concerned firms, but a simple model has allowed us to show that, under some (likely) conditions, this might in fact not be the case. While it is true that competitors take some profitable energy sales away from the incumbent (through traditional ‘cream-skimming’ mechanisms), their entry increases total surplus, and the incumbent is in a strong position to appropriate a part (or all) of this extra value. In fact, the combination of the ubiquity constraint for the incumbent and the ‘essential’ nature of the provided good ensures that his consumers are captive, so he can extract all available surplus through the fixed charge of a two-part tariff. The non discrimination constraint creates strategic links between both markets segments (the one served by both firms and the one served only by the incumbent) and induces the incumbent to distort its variable price below marginal cost, in order to compete more aggressively in the duopoly segment and thus increase the extra surplus he knows he can, in the end, extract. This, in turn, induces the entrant to serve fewer locations, which is socially detrimental. Although these effects show some similarities with predatory pricing by the incumbent, here it is in the interest of the incumbent to accommodate the entrant and, in equilibrium, both firms make positive profits and completely extract all consumer surplus.

Our results depend directly on the interplay of three main ingredients: the asymmetry of USOs between incumbents and entrants, the presence of an essential good, and two-part tariff competition. If the USO is symmetric, then the incumbent no longer has a first-mover advantage over the entrant and both can be equally aggressive in tariffs.²⁷ If there is no essential good, then aggressive pricing by the (more efficient) entrant might induce exit of the incumbent from the competitive segment altogether, thus making it impossible to transfer consumer surplus from the competitive to the monopoly segment. Finally, two-part tariffs are necessary to implement cross subsidies between both market segments as described here. However, these three characteristics are frequently found in the network industries

²⁶ Notice that the USO may be thought of as a pre-entry asymmetry advantage in the sense of Salop (1979) for the electricity firm, given that it is as if consumers had “already paid” their fixed electricity charge when deciding whether to buy gas.

²⁷ Equilibria in two-part tariffs are much harder to determine in such a context.

relevant to our analysis, such as energy, telecommunications, and postal services, so our approach seems nevertheless justified.

Typically, monopolies will rather discriminate than not, because by doing so they are able to extract all consumer surplus and thus increase their profits. In the textbook case, two-part tariffs are presented as a simple instrument through which a fully informed monopoly may implement Pigou's first-degree price discrimination: it sets the per-unit charge to marginal cost, and the fixed charge equal to each consumer's surplus. But even in the presence of non discrimination constraints, two-part tariffs enhance the monopoly position with respect to standard linear pricing by allowing more flexible cross-subsidization between market segments. In other words, the ordering of preferences of a monopoly with regards to pricing is (1) perfect discrimination (2) non discriminating two-part tariffs (3) non discriminating linear pricing. Our results show that this ordering of preferences still holds for the incumbent in an environment open to competition under asymmetric USOs, as his competitive position is strengthened by the enrichment of his strategy space. Two-part tariffs will allow him not only to cross-subsidize between market segments, but also to compete more aggressively for market shares while at the same time compensating margin losses through fixed charge increases, thanks to the extra surplus brought to the economy by the entrant. Thus, two-part tariffs relax the traditional trade-off between market shares and unit margins that lead to soft competition in the duopoly segment.

From a more dynamic perspective, it is interesting to analyse the long term incentives created by the distortions we expose. First, given that the incumbent can extract part of the entrants' rent, the latter has fewer incentives to enter the market. Considering that the entrant is relatively more efficient, reduced entry is highly undesirable. USOs might in this sense be interpreted as creating additional barriers to efficient entry or protecting inefficient incumbents. Second, below marginal cost pricing of electricity induces consumption above the efficient levels or, in other words, inefficient overproduction of electricity. Moreover, inefficient consumption is higher in costlier areas, which means that society is suffering doubly from the monopolization of high cost customers by the incumbent subject to the USO.

In the presence of regulation, our results raise some important new concerns. In the kind of network industries where this configuration is likely to rise (network utilities), traditionally tariffs are set by means of price caps on their fixed and variable parts. Conventional economic wisdom holds that, for tariffs to be efficient, the fixed part should be set to reimburse total fixed cost and the variable part equal to marginal cost. In practice, usually fixed parts are calculated to leave the firms some rent while ensuring consumers are left with at least a minimum utility level. However, in the presence of informational asymmetries, firms are traditionally believed to overstate their (unknown) costs. In our setting, on the contrary, the incumbent has all the incentives to understate marginal cost. The lower variable tariffs obtained in this way will allow him to compete more aggressively with his rivals in the competitive segment while recovering the losses through a captive higher fixed income (obtained by overstating his fixed costs in the 'normal' way). These 'reverse incentives' constitute an interesting avenue for future research.

Appendix A

The problem faced by the regulator consists in maximising the global welfare function subject to the participation constraints of the consumers and of the firms, and to the ubiquity constraint on electricity. We assume that the global welfare function is a weighted sum of firm profits and consumer surplus, with respective weights $\mathbf{a}_p$ and $\mathbf{a}_s$ representing the redistributive preferences of the regulator:

$$\begin{aligned} \max \quad & W_c(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) = \mathbf{a}_p \cdot \Pi_e(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) + \mathbf{a}_p \cdot \Pi_g(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \\ & + \mathbf{a}_s \cdot \mathbf{q}_g \cdot S_d(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) + \mathbf{a}_s \cdot (\bar{\mathbf{q}} - \mathbf{q}_g) \cdot S_m(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \quad (\text{A.1}) \\ \text{s.t.} \quad & S_i(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \geq 0; \quad \Pi_i(p_g, t_g, \mathbf{q}_g, p_e, t_e, \mathbf{q}_e) \geq 0; \quad \mathbf{q}_e = \bar{\mathbf{q}} \end{aligned}$$

The global welfare function can be rewritten as follows:

$$\begin{aligned} W_c = & \mathbf{a}_p [\bar{\mathbf{q}}(p_e - c_e)q_L(p_e) + \mathbf{q}_g(p_e - c_e)q_e^d(p_e, p_g) + (\bar{\mathbf{q}} - \mathbf{q}_g)(p_e - c_e)q_e^m(p_e, p_g) - F_e(\bar{\mathbf{q}})] \\ & + \mathbf{a}_p [\mathbf{q}_g(p_g - c_g)q_g^d(p_e, p_g) - F_g(\mathbf{q}_g)] + \mathbf{a}_s \cdot \mathbf{q}_g [v_d(p_e, p_g) + v_L(p_e)] \quad (\text{A.2}) \\ & + \mathbf{a}_s \cdot (\bar{\mathbf{q}} - \mathbf{q}_g) [v_m(p_e) + v_L(p_e)] + (\mathbf{a}_p - \mathbf{a}_s) \cdot [\bar{\mathbf{q}} \cdot t_e + \mathbf{q}_g \cdot t_g] \end{aligned}$$

By observing that W_c is linear in t_e and t_g , we find that whenever $\mathbf{a}_p \neq \mathbf{a}_s$ the regulator will always set the fixed parts either to their minimum or maximum values, depending on which of the two components of global welfare she values the most. This means that:

- If $\mathbf{a}_p > \mathbf{a}_s$, the regulator will set consumer surplus to zero by taking $t_e^{**} = v_m(p_e) + v_L(p_e)$ and $t_g^{**} = v_d(p_e, p_g) - v_m(p_e)$, and give the whole surplus to the firm; or
- if $\mathbf{a}_p < \mathbf{a}_s$, the regulator will set firm profits to zero by taking $t_e^{**} = \frac{F_e(\bar{\mathbf{q}}) - \bar{\mathbf{q}}(p_e - c_e)(q_L(p_e) + q_e^m(p_e, p_g)) - \mathbf{q}_g(p_e - c_e)(q_e^d(p_e, p_g) - q_e^m(p_e, p_g))}{\bar{\mathbf{q}}}$ and $t_g^{**} = \frac{F_g(\mathbf{q}_g)}{\mathbf{q}_g} - (p_g - c_g)q_g^d(p_e, p_g)$, thus giving the whole surplus to consumers; or finally,
- if $\mathbf{a}_p = \mathbf{a}_s$, the fixed parts of the tariffs disappear from the welfare function, because they merely constitute transfers between consumers and the firm, so the regulator can arbitrarily set them to any value she likes in the intervals defined by the participation constraints without altering the welfare outcome.

In all cases, by replacing the socially optimal values of the fixed parts, we obtain:

$$\begin{aligned} W_c = & \mathbf{a} [(p_e - c_e) \bar{\mathbf{q}} q_L(p_e) + \mathbf{q}_g q_e^d(p_e, p_g) + (\bar{\mathbf{q}} - \mathbf{q}_g) q_e^m(p_e, p_g)] - F_e(\bar{\mathbf{q}}) + \bar{\mathbf{q}} [v_m(p_e) + v_L(p_e)] \\ & + \mathbf{a} [(p_g - c_g) \mathbf{q}_g q_g^d(p_e, p_g) - F_g(\mathbf{q}_g) + \mathbf{q}_g [v_d(p_e, p_g) - v_m(p_e)]] \end{aligned} \quad \text{where } \mathbf{a} = \max\{\mathbf{a}_p, \mathbf{a}_s\}.$$

First order conditions for the maximization problem in p_g and p_e are:

$$\begin{aligned} \frac{\partial W_c}{\partial p_g} &= (p_e - c_e) \mathbf{q}_g \frac{\partial q_e^d}{\partial p_g}(p_e, p_g) + (p_g - c_g) \mathbf{q}_g \frac{\partial q_g^d}{\partial p_g}(p_e, p_g) = 0 \quad (\text{A.3}) \\ \frac{\partial W_c}{\partial p_e} &= (p_e - c_e) \left[\bar{\mathbf{q}} \left(\frac{\partial q_e^m}{\partial p_e}(p_e) + \frac{\partial q_L}{\partial p_e}(p_e) \right) + \mathbf{q}_g \left(\frac{\partial q_e^d}{\partial p_e}(p_e, p_g) - \frac{\partial q_e^m}{\partial p_e}(p_e) \right) \right] + (p_g - c_g) \mathbf{q}_g \frac{\partial q_g^d}{\partial p_e}(p_e, p_g) = 0 \end{aligned}$$

The system (A.3) is invertible iff the indirect utility function v_d is convex, so the solutions are $p_g^{**} = c_g$ and $p_e^{**} = c_e$, that is, marginal cost pricing is efficient and welfare maximizing. Optimal extension of the gas network is then given by the following expression, stating that the marginal cost of service equals the marginal benefit in terms of increased consumer surplus :

$$F'_g(\mathbf{q}_g^{**}) = v_d(c_e, c_g) - v_m(c_e) \quad (\text{A.4})$$

So social optimality is attained with marginal cost pricing and gas entry up to the point described by equation (A.4), with fixed charges being used by the regulators as instruments to allocate surplus depending on her social objectives. By replacing the optimal values of the variable parts, we obtain the full solution given in expression (19) in the main text.

Proof of Proposition 3. *If regulation is limited to a ubiquity and non discrimination constraint on the electricity firm and to only a non discrimination constraint for gas, then the gas network is underdeveloped and the electricity prices are too low, with respect to their socially optimal levels.*

Proof.

As shown above, marginal cost pricing of electricity is socially optimal, so the last part of Proposition 3 is equivalent to Proposition 1.

Regarding optimal entry of gas, the first part of Proposition 3 means $\mathbf{q}_g^* < \mathbf{q}_g^{**}$, or, as F'_g is an increasing function of $\mathbf{q}$, $F'_g(\mathbf{q}_g^*) < F'_g(\mathbf{q}_g^{**})$. By replacing these expressions by their respective definitions (in expression (17) in the main text and expression (A.4) above), we obtain :

$$\begin{aligned} & [v_d(p_e^*(\mathbf{q}_g^*), c_g) - v_m(p_e^*(\mathbf{q}_g^*))] + \mathbf{q}_g^* \cdot [q_e^m(p_e^*(\mathbf{q}_g^*)) - q_e^d(p_e^*(\mathbf{q}_g^*), c_g)] \frac{\partial p_e^*(\mathbf{q}_g^*)}{\partial \mathbf{q}_g} < [v_d(c_e, c_g) - v_m(c_e)] \\ \Leftrightarrow & \mathbf{q}_g^* \cdot [q_e^m(p_e^*(\mathbf{q}_g^*)) - q_e^d(p_e^*(\mathbf{q}_g^*), c_g)] \frac{\partial p_e^*(\mathbf{q}_g^*)}{\partial \mathbf{q}_g} < [v_d(c_e, c_g) - v_m(c_e)] - [v_d(p_e^*(\mathbf{q}_g^*), c_g) - v_m(p_e^*(\mathbf{q}_g^*))] \end{aligned}$$

We know that the incremental consumer surplus ($v_d - v_m$) brought by gas entry is increasing in p_e (the more expensive electricity is, the more consumers benefit from gas entry), so the right-hand side term is positive. We also know from Lemma 1 that the left-hand side term is negative, so this last inequality holds. Q.E.D.

Appendix B

Equilibrium with USO and discrimination

If the electricity firm can discriminate between its consumers, it will choose to practice different prices to those that are also served by the gas firm, this being the only factor that affects consumption decisions in our specification. For simplicity, we allow the electricity firm to discriminate only in the fixed part of the tariff.²⁸ This determines the new participation constraints as follows.

Consumers in the monopoly segment will buy electricity at tariff $\{t_e^m, p_e\}$ iff:²⁹

$$0 \leq v_m(p_e) + v_L(p_e) - t_e^m \quad (\text{B.1})$$

Consumers in the duopoly segment will also buy gas if and only if the incremental utility they get exceeds the price they pay. Formally, this translates into:

$$v_m(p_e) + v_L(p_e) - t_e^m \leq v_d(p_e, p_g) + v_L(p_e) - t_e^d - t_g \quad (\text{B.2})$$

The gas firm solves its profit maximisation problem subject to the participation constraint of gas consumers:

$$\begin{aligned} \max_{p_g, t_g} \quad & \Pi_g(p_g, t_g, p_e, t_e^m, t_e^d, \mathbf{q}_g) = \mathbf{q}_g \cdot [(p_g - c_g)q_g^d(p_e, p_g) + t_g] - F_g(\mathbf{q}_g) \\ \text{s.t.} \quad & 0 \leq t_g \leq v_d(p_e, p_g) - v_m(p_e) + t_e^m - t_e^d \end{aligned} \quad (\text{B.3})$$

As $\Pi_g(p_g, t_g, p_e, t_e^m, t_e^d, \mathbf{q}_g)$ is separable, linear and increasing in t_g , the gas firm's best reply is to set the fixed part of the tariff as high as possible, that is, to $v_d(p_e, p_g) - v_m(p_e) + t_e^m - t_e^d$ if this quantity is positive, or to zero if it is not.

Its best reply functions are then:

$$\text{If } v_d(p_e, p_g) - v_m(p_e) + t_e^m - t_e^d > 0, \begin{cases} p_g^*(p_e, t_e^m, t_e^d, \mathbf{q}_g) = c_g \\ t_g^*(p_e, t_e^m, t_e^d, \mathbf{q}_g) = v_d(p_e, c_g) - v_m(p_e) + t_e^m - t_e^d \end{cases} \quad (\text{B.4})$$

$$\text{If } v_d(p_e, p_g) - v_m(p_e) + t_e^m - t_e^d = 0, \begin{cases} p_g^*(p_e, t_e^m, t_e^d, \mathbf{q}_g) = p_g^m, \frac{p_g^m - c_g}{p_g^m} = \frac{1}{\mathbf{e}_{q_g^d}} \\ t_g^*(p_e, t_e^m, t_e^d, \mathbf{q}_g) = 0 \end{cases} \quad (\text{B.5})$$

When there is an available consumer surplus the gas firm can recover through the fixed part,³⁰ the profit maximization problem collapses into that of efficient pricing once the fixed part is set to its maximum value, so the firm sets the variable part of the tariff to coincide with marginal cost and thus extract the maximum available consumer surplus. On the contrary, when the fixed charges of

²⁸ Allowing for variable price discrimination leads to the same results. In fact, marginal cost pricing is optimal in both market segments as long as the firm is able to extract consumer surplus through the fixed parts.

²⁹ This condition is exactly the same as condition (8) in the main text, except that we have substituted the unique fixed charge t_e with t_e^m .

³⁰ Or, in other words, slackness in the participation constraint of gas consumers.

electricity are such that the gas firm cannot raise its own fixed part, then the gas firm is forced to set its fixed charge to zero in order not to lose all its demand, and then sets the variable part as a monopolist with linear pricing.

In the case of electricity, we can write the profit function as follows:³¹

$$\begin{aligned} \Pi_e(p_g, t_g, p_e, t_e^m, t_e^d, \mathbf{q}_g) = & \mathbf{q}_g(p_e - c_e)q_e^d(p_e, p_g) + (\bar{\mathbf{q}} - \mathbf{q}_g)(p_e - c_e)q_e^m(p_e) + \bar{\mathbf{q}}(p_e - c_e)q_L(p_e) - F_e(\bar{\mathbf{q}}) \\ & + \mathbf{q}_g \cdot t_e^d + (\bar{\mathbf{q}} - \mathbf{q}_g) \cdot t_e^m \end{aligned} \quad (\text{B.6})$$

The electricity firm solves its profit maximisation problem subject to the participation constraints of electricity consumers in both segments, stating that fixed parts are limited by available consumer surplus:

$$\begin{aligned} \max_{p_e, t_e} \quad & \Pi_e(p_g, t_g, p_e, t_e^m, t_e^d, \mathbf{q}_g) \\ \text{s.t.} \quad & \begin{cases} t_e^m \leq v_m(p_e) + v_L(p_e) \\ t_e^d \leq v_d(p_e, p_g) + v_L(p_e) - t_g \end{cases} \end{aligned} \quad (\text{B.7})$$

Just like in the case of gas, $\Pi_e(p_g, t_g, p_e, t_e^m, t_e^d, \mathbf{q}_g)$ is separable, linear and increasing in t_e^m and t_e^d , so the electricity firm must set the fixed parts of the tariffs as high as possible. By replacing t_e^m and t_e^d by their maximum values we obtain the first order condition for variable pricing :

$$\frac{\partial \Pi_e}{\partial p_e} = 0 \Leftrightarrow (p_e - c_e) \left[\mathbf{q}_g \frac{\partial q_e^d}{\partial p_e}(p_e, p_g) + (\bar{\mathbf{q}} - \mathbf{q}_g) \frac{\partial q_e^m}{\partial p_e}(p_e) + \bar{\mathbf{q}} \frac{\partial q_L}{\partial p_e}(p_e) \right] = 0 \quad (\text{B.8})$$

As all the price derivatives of quantities are non positive, and all three variables $\mathbf{q}_g$, $\bar{\mathbf{q}}$ and $(\bar{\mathbf{q}} - \mathbf{q}_g)$ non negative, it follows that the expression in square brackets in condition (B.8) is negative, so $p_e^*(p_g, t_g, \mathbf{q}_g) = c_e$. Overall, the best reply functions of the electricity firm are:

$$\begin{cases} p_e^*(p_g, t_g, \mathbf{q}_g) = c_e \\ t_e^{m*}(p_g, t_g, \mathbf{q}_g) = v_m(c_e) + v_L(c_e) \\ t_e^{d*}(p_g, t_g, \mathbf{q}_g) = v_d(c_e, p_g) + v_L(c_e) - t_g \end{cases} \quad (\text{B.9})$$

Equilibrium is given by the intersection of these best reply functions with the ones for the gas firm given by (B.4) and (B.5). It is possible to simplify the intersection by noticing that some equilibrium values do not depend on the rival's actions: $\tilde{p}_e = c_e$ and $\tilde{t}_e^m = v_m(c_e) + v_L(c_e)$ for any p_g and t_g . In this subset the best reply functions of the gas firm are given by:

$$\text{If } v_d(c_e, p_g) + v_L(c_e) - t_g > 0, \begin{cases} p_g^*(t_g^d, \mathbf{q}_g) = c_g \\ t_g^*(t_e^d, \mathbf{q}_g) = v_d(c_e, c_g) + v_L(c_e) - t_e^d \end{cases} \quad (\text{B.10})$$

³¹ Notice that this is the same expression as in (12) in the main text, excepting the last two terms in (B.6) that replace the fixed part in (12).

$$\text{If } v_d(c_e, p_g) + v_L(c_e) - t_e^d = 0, \begin{cases} p_g^*(t_e^d, \mathbf{q}_g) = \tilde{p}_g, \frac{\tilde{p}_g - c_g}{\tilde{p}_g} = \frac{1}{e^{q_g^d}} \\ t_g^*(t_e^d, \mathbf{q}_g) = 0 \end{cases} \quad (\text{B.11})$$

The intersection of the best reply functions of both firms is shown in the following figure:

Figure B.1. Best reply functions (fixed parts)

So, in equilibrium, the gas firm sets its fixed charge to zero, its variable price to the monopoly price (while the electricity firm extracts all consumer surplus), and enters up to the level given by:

$$F'_g(\tilde{\mathbf{q}}_g) = (\tilde{p}_g - c_g)q_g^d(c_e, \tilde{p}_g) \quad (\text{B.12})$$

Equilibrium values are summarized in expressions (20) and (21) in the main text.

Appendix C: Example

We illustrate the effects presented in this article by means of a simple example. Consumers are characterized by their utility functions for heat and light:

$$U^h(q_e, q_g) = a_h(q_e + q_g) - \frac{1}{2}(q_e^2 + q_g^2) - \mathbf{b} \cdot q_e \cdot q_g$$

$$U^l(q_l) = a_l \cdot q_l - \frac{1}{2} \cdot q_l^2$$

The function for heat is a utility function with substitutability between two goods that has the attractive feature of producing linear demands for both goods. Parameter $0 \leq \mathbf{b} \leq 1$ measures the level of substitutability, with 0 being independent goods and 1 perfect substitutes. The utility function for light is a univariate utility function of a similar form, and we allow for a different ‘total’ demand parameter $a_l \neq a_h$. The corresponding indirect utility functions (using our standard notations) are:

$$v_d(p_e, p_g) = \frac{p_e^2 + p_g^2 - 2\mathbf{b} \cdot p_e \cdot p_g + 2a_h(1 - \mathbf{b})(a_h - p_e - p_g)}{2(1 - \mathbf{b}^2)}$$

$$v_m(p_e) = \frac{1}{2}(a_h - p_e)^2$$

$$v_L(p_e) = \frac{1}{2}(a_l - p_e)^2$$

Uniform pricing

Second order conditions for the maximization problems of the firms are verified :

$$\frac{\partial^2}{\partial p_g^2} \Pi_g(p_g, v_d - v_m, p_e, t_e, \mathbf{q}_g) = -\frac{\mathbf{q}_g}{1 - \mathbf{b}^2} \leq 0$$

$$\frac{\partial^2}{\partial p_e^2} \Pi_e(p_g, t_g, p_e, v_L + v_m, \mathbf{q}_g) = -2 \left((\bar{\mathbf{q}} - \mathbf{q}_g) + \frac{\mathbf{q}_g}{1 - \mathbf{b}^2} \right) \leq 0$$

Through the first order conditions we obtain the optimal tariffs chosen by the firms :

$$p_g = c_g, \quad t_g = \frac{(a_h(1 - \mathbf{b}) - c_g + \mathbf{b} \cdot c_e)^2 (2\bar{\mathbf{q}}(1 - \mathbf{b}^2) + \mathbf{b}^2 \mathbf{q}_g)^2}{8(1 - \mathbf{b}^2)(\bar{\mathbf{q}}(1 - \mathbf{b}^2) + \mathbf{b}^2 \mathbf{q}_g)^2}$$

$$p_e = \frac{2\bar{\mathbf{q}}(1 - \mathbf{b}^2)c_e - \mathbf{b} \cdot \mathbf{q}_g(a_h(1 - \mathbf{b}) - c_g - \mathbf{b} \cdot c_e)}{2(\bar{\mathbf{q}}(1 - \mathbf{b}^2) + \mathbf{b}^2 \mathbf{q}_g)} < c_e, \quad t_e = \frac{1}{2}[(a_h - p_e)^2 + (a_l - p_e)^2]$$

And the entry level chosen by the gas firm $\mathbf{q}_g^*$ is given by:

$$F'_g(\mathbf{q}_g) = \frac{(a_h(1 - \mathbf{b}) - c_g + \mathbf{b} \cdot c_e)^2 (2\bar{\mathbf{q}}(1 - \mathbf{b}^2) + \mathbf{b}^2 \mathbf{q}_g) (2\bar{\mathbf{q}}^2(1 - \mathbf{b}^2)^2 + \mathbf{b}^2 \mathbf{q}_g (\bar{\mathbf{q}}(1 - \mathbf{b}^2) + \mathbf{b}^2 \mathbf{q}_g))}{8(1 - \mathbf{b}^2)(\bar{\mathbf{q}}(1 - \mathbf{b}^2) + \mathbf{b}^2 \mathbf{q}_g)^3}$$

Socially optimal entry $\mathbf{q}_g^{**}$ is given by:

$$F'_g(\mathbf{q}_g^{**}) = \frac{(a_h(1-b) - c_g + b \cdot c_e)^2}{2(1-b^2)}$$

$$\begin{aligned} & \text{As } F_g(\mathbf{q}) \text{ is increasing and convex function, we check that } \mathbf{q}_g^* < \mathbf{q}_g^{**} \Leftrightarrow F'_g(\mathbf{q}_g^*) < F'_g(\mathbf{q}_g^{**}) \\ & \Leftrightarrow \frac{(a_h(1-b) - c_g + b \cdot c_e)^2 (2\bar{q}(1-b^2) + b^2 \mathbf{q}_g) (2\bar{q}^2(1-b^2)^2 + b^2 \mathbf{q}_g (\bar{q}(1-b^2) + b^2 \mathbf{q}_g))}{8(1-b^2)(\bar{q}(1-b^2) + b^2 \mathbf{q}_g)^3} < \frac{(a_h(1-b) - c_g + b \cdot c_e)^2}{2(1-b^2)} \\ & \Leftrightarrow (2\bar{q}(1-b^2) + b^2 \mathbf{q}_g) (2\bar{q}^2(1-b^2)^2 + b^2 \mathbf{q}_g (\bar{q}(1-b^2) + b^2 \mathbf{q}_g)) < 4(\bar{q}(1-b^2) + b^2 \mathbf{q}_g)^3 \\ & \Leftrightarrow 0 < b^2 \mathbf{q}_g (8\bar{q}^2(1-b^2)^2 + 3b^2 \mathbf{q}_g (3\bar{q}(1-b^2) + b^2 \mathbf{q}_g)). \end{aligned}$$

So effectively the electricity firm prices below marginal cost and induces underdevelopment of the gas network.

Discrimination across consumer categories

Second order conditions for the maximization problems of the firms are verified :

$$\frac{\partial^2}{\partial p_g^2} \Pi_g(p_g, t_g, p_e, t_e^m, t_e^d, \mathbf{q}_g) = -\frac{2\mathbf{q}_g}{1-b^2} \leq 0$$

$$\frac{\partial^2}{\partial p_e^2} \Pi_e(p_g, t_g, p_e, v_L + v_m, v_L + v_d - t_g, \mathbf{q}_g) = -\frac{2\bar{q}(1-b^2) + b^2 \mathbf{q}_g}{1-b^2} \leq 0$$

Through the first order conditions we obtain the optimal tariffs chosen by the firms :

$$p_g = \frac{1}{2}(a_h(1-b) + c_g + b \cdot c_e), \quad t_g = 0$$

$$p_e = c_e, \quad t_e^m = \frac{1}{2}[(a_h - c_e)^2 + (a_l - c_e)^2], \quad t_e^d = v_d(c_e, p_g) + v_L(c_e)$$

And the entry level chosen by the gas firm $\mathbf{q}_g^d$ is given by:

$$F'_g(\mathbf{q}_g^d) = \frac{(a_h(1-b) - c_g + b \cdot c_e)^2}{4(1-b^2)} = \frac{1}{2} F'_g(\mathbf{q}_g^{**})$$

This level of entry is of course lower than the socially optimal level, but comparisons with the uniform pricing case are less clear. In fact $\mathbf{q}_g^d < \mathbf{q}_g^* \Leftrightarrow F'_g(\mathbf{q}_g^d) < F'_g(\mathbf{q}_g^*)$

$$\begin{aligned} & \Leftrightarrow \frac{(a_h(1-b) - c_g + b \cdot c_e)^2}{4(1-b^2)} < \frac{(a_h(1-b) - c_g + b \cdot c_e)^2 (2\bar{q}(1-b^2) + b^2 \mathbf{q}_g) (2\bar{q}^2(1-b^2)^2 + b^2 \mathbf{q}_g (\bar{q}(1-b^2) + b^2 \mathbf{q}_g))}{8(1-b^2)(\bar{q}(1-b^2) + b^2 \mathbf{q}_g)^3} \\ & \Leftrightarrow 2(\bar{q}(1-b^2) + b^2 \mathbf{q}_g)^3 < (2\bar{q}(1-b^2) + b^2 \mathbf{q}_g) (2\bar{q}^2(1-b^2)^2 + b^2 \mathbf{q}_g (\bar{q}(1-b^2) + b^2 \mathbf{q}_g)) \\ & \Leftrightarrow (\bar{q}(1-b^2) + b^2 \mathbf{q}_g)^3 < \bar{q}^2(1-b^2)^2 (3\bar{q}(1-b^2) + b^2 \mathbf{q}_g), \text{ which is always true if } b \rightarrow 0 \text{ and} \\ & \text{always false if } b \rightarrow 1, \text{ so it is impossible to rank } \mathbf{q}_g^d \text{ and } \mathbf{q}_g^* \text{ without specifying } F_g. \end{aligned}$$

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