Access pricing and unbundling in the electricity industry.

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Summary: In all network activities, liberalization requires some form of unbundling, in particular the unbundling of infrastructure operation and production/supply activities. In the energy industry, since the first electricity directive in 1996, the European Commission has been repeatedly calling for ownership separation whereas some Member States (in particular France and Germany) consider that management separation would be sufficient to guarantee fair use of the infrastructure. The question addressed in this paper is how to optimally determine access fees to the electricity network according to the legal regime of the transport operator. Using an elementary one-line/two-node network, we characterize the second-best prices for energy from which we deduce the essential features of the access tariff by an arbitrage condition. We show that access fees must not only cover network variable costs and congestion, but also the fixed cost of the infrastructure on the basis of market sensibility to price (demand elasticity and/or supply elasticity).

Keywords: unbundling, network access, price discrimination

JEL codes: L42, L5, L9, Q4

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The EC has repeatedly called for the vertical separation of network infrastructure on one hand and products and services provision on the other hand as a necessary condition for the success of liberalization in the energy industry. But which grade of structural unbundling? In its Communication to the Council and the European Parliament[1] on January 10, 2007 the EC contrasts legal unbundling (creation of a subsidiary for one of the activities), functional unbundling (independent accounting and management) and ownership unbundling. Under ownership unbundling, the Transmission System Operator (TSO) both owns the transmission assets and operates the network. It is independently owned, which means that supply and/or generation companies are not allowed to hold a significant stake in any TSO. The alternative solution contemplated by the EC consists in separating system operation from ownership of the assets. Supply/generation companies could no longer hold a significant stake in the system operator. However, the transmission assets themselves could remain within a vertically integrated group and the system operator would be solely responsible for operation and dispatch.

The EC is in favour of ownership unbundling as it clearly appears in the following quotation: "Economic evidence shows that ownership unbundling is the most effective means to ensure choice for energy users and encourage investment. This is because separate network companies are not influenced by overlapping supply/generation interests as regards investment decisions. It also avoids overly detailed and complex regulation and disproportionate administrative burdens".[2] Nevertheless, two months later, the European Council "… taking account of the characteristics of the gas and electricity sectors and of national and regional markets, (agreed) on the need for … effective separation of supply and production activities from network operations (unbundling), based on independently run and adequately regulated network operation systems which guarantee equal and open access to transport infrastructures and independence of decisions on investment in infrastructure."[3]

"Effective separation" is a very neutral expression that leaves member states free to choose between the two aforementioned types of unbundling. Therefore, in the near future one can expect that there will be no drastic change in the organisation of the EU electricity

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[1] Communication from the Commission to the Council and the European Parliament - Prospects for the internal gas and electricity market, COM/2006/0841 final.

[2] *Ibid* page 12.

[3] Brussels European Council 8/9 March 2007, Presidency conclusions, www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf

and gas industries … except if the EC keeps on challenging the conservative view of large member states like France and Germany.

One argument among others used by the EC to support ownership unbundling is that “non discriminatory third party access to networks would be guaranteed and perceived as such”.[4] The non-discriminatory-third-party-access mantra is thus once more invoked to justify the necessity of a benevolent marketplace’s operator that would behave “neutrally” as regards competition. Price discrimination and non-price discrimination are identified as the main hurdles faced by entry candidates when the incumbent is not vertically unbundled. In this paper we only address the price discrimination issue.[5] We know that the usual implementation of this neutrality principle is the “post stamp”, a uniform pricing policy imported from the postal services industry. Unfortunately, the only advantage of this solution is transparency.[6] It does not take into account efficiency, neither locational efficiency that requires sending price signals on congestion and power losses to producers and consumers, nor financial efficiency when the TSO has the obligation to balance its budget.

The objective of the paper is not to assess the relative advantages of alternative institutional organizations for the electricity industry either in the short run (despatching) or in the long run (investment).[7] We just want to show how different should be the access charge given the degree of unbundling.

The paper proposes a basic model for the electricity industry with the objective to determine the optimal access pricing rules under alternative organisational rules. The first section is devoted to the presentation of an elementary model of electric network, followed by the determination of the first-best and second-best allocations. In section 2, we compute the second-best access fee priced to entrants when the network is owned and managed by the incumbent. We then successively determine the second-best access fee under ownership unbundling (section 3) and management unbundling (section 4). In section 5, we propose some extensions and we conclude.

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[4] COM(2006) 841 final, p.11.

[5] As for non-price discrimination by a vertically integrated monopolist, see Cave *et al.* (2006).

[6] As Green (1997) wrote: "Prices should signal the costs of using the transmission system, but this may conflict with the need to produce a clear message that users can understand, given the complexity of transmission costs".

[7] Cremer *et al.* (2006) analyse the impact of legal unbundling compared to ownership unbundling on the incentives of a network operator to invest and maintain its assets.

1. Technical constraint and financial constraint

We successively present the hypotheses of the model for the electricity industry, determine the allocation of production and consumption that maximizes net social surplus, and determine the allocation that maximizes welfare and raises enough resources to recoup all costs.

1.1. Model setting

We assume that the electricity industry is composed of three elements (see figure 1):

a western node (labelled 1) with producers and consumers

an eastern node (labelled 2) with only consumers

a line interconnecting the two nodes.

At node $i = 1,2$, when consumers are provided with the quantity q of electricity, they enjoy utility $u_i(q)$ with $u_i' > 0$ and $u_i'' < 0$. At node 1, the production of q costs $c_g q$, assuming to simplify the model that c_g is the long run marginal costs, which includes fixed costs. The transmission of a quantity q from node 1 to node 2 has a constant[8] unit cost c_t. The energy flow on the line cannot be larger than K that stands for the thermal capacity. This value is exogenous because we only consider short run optimization. The maintenance of the transportation system has a cost F that mainly depends on K. Consequently, in this short-run model F is fixed.

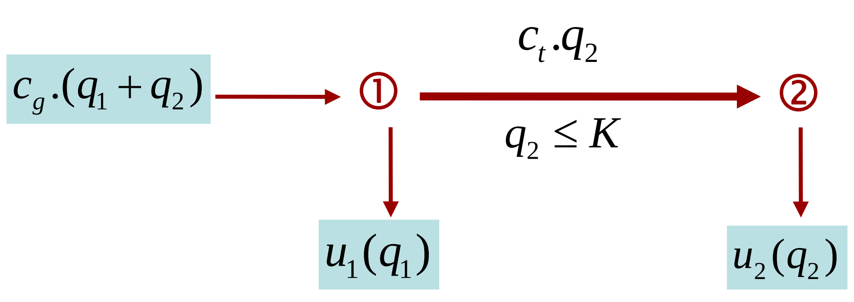

Figure 1: A one-line/two-node model of the electricity industry

[8] Actually, the main variable costs are power losses, which are increasing with the square of q. The linearity assumption is aimed at focusing on congestion costs.

1.2. First best

The first best allocation is the solution to the following problem:

$$\max_{q_1, q_2} \; u_1(q_1) + u_2(q_2) - c_g.(q_1 + q_2) - c_t.q_2 - F$$

$$s.t. \;\; q_2 \leq K \qquad (\eta)$$

$$q_1 \geq 0, q_2 \geq 0$$

Assuming that consumption is strictly positive at both nodes, the allocation is given by

$$u_1^{'}(q_1) = c_g, \quad u_2^{'}(q_2) = c_g + c_t + \eta$$

that is the standard rule of equating marginal utility with marginal cost. At node 1 where all production assets are located, marginal cost is simply made of the production cost. By contrast at node 2, marginal cost consists of the production and transportation cost plus the congestion cost when the capacity constraint is binding.

This solution can be implemented by nodal prices

$$p_1 = c_g \;, \;\; p_2 = c_g + c_t + \eta$$

but this decentralisation is not financially viable if $\eta q_2 < F.$ For example, in the case where marginal utility is low at node 2 and/or the transportation and the production costs are high and/or the line is oversized, we have $u_2^{'}(K) < c_g + c_t$ so that $q_2 < K$ at first best. This means $\eta = 0$ and the consequence is that the electricity industry as a whole (made of the transmitter and the producers) incur losses:

$$\pi \stackrel{def}{=} p_1 q_1 + p_2 q_2 - c_g(q_1 + q_2) - c_t q_2 - F = -F < 0.$$

1.3. Second best

The objective is to find prices p_1, p_2 that maximise net surplus without violating the budget balancing constraint of the industry.[9] Let us define the net consumer's surplus at node *i* as

$$S_i(p_i) \stackrel{def}{=} u_i(q_i(p_i)) - p_i q_i(p_i) \qquad i = 1, 2$$

where $q_i = q_i(p_i)$ is the direct demand function, that is the quantity that solves $\max_{q_i} u_i(q_i) - p_i q_i$.

On the supply side, let us define the net profit as

[9] The alternative is to raise funds from consumers in order to subsidize the industry.

$$\pi(p_1, p_2) \overset{def}{=} q_1(p_1)\,p_1 + q_2(p_2)\,p_2 - c_g.\big(q_1(p_1) + q_2(p_2)\big) - c_t q_2(p_2) - F$$

The second best prices are the solution to

$$\max_{p_1, p_2} \quad S_1(p_1) + S_2(p_2) + \pi(p_1, p_2)$$

$$s.t. \quad \pi(p_1, p_2) \geq 0 \qquad (\lambda)$$

$$q_2(p_2) \leq K \qquad (\eta)$$

$$q_1(p_1) \geq 0,\ q_2(p_2) \geq 0$$

As shown in the Appendix, the optimal energy prices are Ramsey prices

$$\frac{p_1 - c_g}{p_1} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_1}, \quad \frac{p_2 - (c_g + c_t) - \frac{\eta}{1+\lambda}}{p_2} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_2}$$

which means Lerner indices inversely proportional to the elasticity of demand $\varepsilon_i \overset{def}{=} -\frac{dq_i}{dp_i}\frac{p_i}{q_i}$ at each node *i*. This illustrates the well-known trade-off between efficiency that commands marginal cost pricing and the budget balancing requirement.

We first observe that when the budget constraint is binding $(\lambda > 0)$ it is optimal to charge consumers at node 1 a price above the marginal cost of energy c_g, despite they do not use the transmission line.[10]

Second, as compared with more standard problems of second best pricing, here we have the additional contribution of the congestion rent to the financing of the industry budget. Indeed, if the line is very small, the congestion rent can be so large that $\eta K > F$ with the consequences $\lambda = 0$, $p_1 = c_g$, $p_2 = c_g + c_t + \eta$. With a slightly binding capacity, we have $F > \eta K > 0$ so that $\lambda > 0$, $p_1 > c_g$ $p_2 > c_g + c_t + \eta$, but the operating profit is still insufficient to pay for the industry's costs. Therefore, the congestion rent can totally ($\lambda = 0$) or partially ($\lambda > 0$ but small) alleviate the budget constraint.[11] When the transmission capacity to maintain is very costly, $\frac{\lambda}{1+\lambda}$ converges to 1 and the second best policy is similar to the private monopoly policy.

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[10] By the Le Chatelier principle, imposing separate budget balancing constraints (one for each node) would decrease welfare.

[11] With quadratic power losses, the marginal cost of transportation is an increasing linear function of the flow transmitted by the line. Consequently, marginal cost pricing for losses would provide additional revenues to the industry (see Crampes 2003). Other resources can arise from infra marginal rents when the marginal cost of production is increasing.

Except for the interconnectors[12], most European electricity networks are oversized so that congestion rents are small as compared with the infrastructure costs. Consequently, budget balancing requires some form of second best pricing, including when competitors enter the market.

2. Access pricing by an integrated operator

Assume now that competitors want to install production capacity at node 1 to sell to node 2's consumers. Consequently, they need access to the transmission line. In this section, we assume that before entry there was a public monopoly for both production and transmission. Given this inherited institutional framework, the agency in charge of the regulation of the industry has the task to compute the access charge.[13]

We define the following notations:

c_e: entrants' generation cost,

a: access price

$p_e = (1+\alpha).(c_e + a)$ price fixed by the entrants

$\alpha \geq 0$ index of imperfect competition between entrants.

Given α and c_e, we see that it is indifferent to fix p_e and to fix *a*. In the following lines, we will suppose perfect competition ($\alpha = 0$) so that the net profit of entrants is zero. The profit of the incumbent can be written as

$$\begin{aligned}\pi(p_1, p_2, a) &\overset{def}{=} p_1 q_1 + p_2 q_2 + a q_e - c_g(q_1 + q_2) - c_t(q_2 + q_e) - F \\ &= \left(p_1 - c_g\right) q_1 + \left(p_2 - c_g - c_t\right) q_2 + \left(p_e - c_e - c_t\right) q_e - F \\ &\overset{def}{=} \pi(p_1, p_2, p_e)\end{aligned}$$

The second-best pricing policy with entry is given by[14]

$$\begin{aligned}&\max_{p_1, p_2, p_e} S_1\left(p_1\right) + S_2\left(p_2, p_e\right) + \pi\left(p_1, p_2, a\right) \\ &\quad s.t. \quad \pi\left(p_1, p_2, p_e\right) \geq 0 \qquad (\lambda) \\ &\qquad\qquad q_2 + q_e \leq K \qquad (\eta) \\ &\qquad\qquad q_1 \geq 0, q_2 \geq 0, q_e \geq 0\end{aligned}$$

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[12] See Bjørnebye (2006) on interconnections between the EU countries.

[13] The basic model used in this section is akin to the one developed by Laffont and Tirole (1994, 1999) for the telecommunications industry.

[14] When the entrants' cost of generation is convex or when competition at node 2 is imperfect, the social welfare function must also include the profit of the fringe.

where $q_1 = q_1(p_1), q_2 = q_2(p_2, p_e),\ q_e = q_e(p_2, p_e)$ and

$$S_1(p_1) \stackrel{def}{=} u_1(q_1(p_1)) - p_1 q_1(p_1)$$

$$S_2(p_2, p_e) \stackrel{def}{=} u_2(q_2(p_2, p_e), q_e(p_2, p_e)) - p_2 q_2(p_2, p_e) - p_e q_e(p_2, p_e)$$

Indeed, at node 2, consumers solve $\max_{q_2, q_e} u_2(q_2, q_e) - p_2 q_2 - p_e q_e$ because the incumbent and the entrants do not necessarily offer perfect substitutes.[15]

In the Appendix, we show that energy provided by the entrants should be sold at node 2 at the implicit price $p_e = c_e + c_t + \frac{\eta}{1+\lambda} + \frac{\lambda}{1+\lambda}\frac{p_e}{\overline{\varepsilon}_e}$. Using this formula and the perfect equilibrium condition $p_e = c_e + a$, we can write the access price as

$$a^0 = c_t + \frac{\eta}{1+\lambda} + \frac{\lambda}{1+\lambda}\frac{p_e}{\overline{\varepsilon}_e} \qquad (1)$$

where $\overline{\varepsilon}_e$ stands for the super-elasticity[16] of demand for the energy sold by the entrants at node 2.

Formula (1) allows to identify the three elements the entrants should pay for when they demand access to the network. First they provoke a variable cost (mainly energy losses), second they create or increase congestion, and finally they should pay for the fixed cost of the infrastructure.

The rules implemented in electricity systems are far from this second-best pricing rule. In particular, they most of the cases rely on “postage stamps”, which means that they do not take into account the congestion factor. As regards the payment for the infrastructure cost, it is totally independent from the elasticity of demand whereas efficiency commands to charge higher electricity prices to inelastic consumers, and consequently to charge higher access prices to producers who use the line to serve electricity’s consumers with inelastic demand.

If we apply to this industry the Efficient Component Pricing Rule originally proposed by Baumol and popularized by Baumol and Sidak (1994) in the telecoms industry[17], the access price should compensate the incumbent for the lost margin due to entry, that is $a = p_2 - c_g$. The drawback of this proposal is that it says nothing on how p_2 should be fixed.

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[15] For example, entrants target industrial consumers with specific needs.

[16] Super-elasticity includes all the direct and indirect relative changes in demands q_2 and q_e due to a 1% variation in price p_e.

[17] See Laffont and Tirole (1999) for a deeper analysis of the implications of the Efficient Component Pricing Rule.

If we use the Ramsey price determined at second best, $p_2 = c_g + c_t + \frac{\eta}{1+\lambda} + \frac{\lambda}{1+\lambda}\frac{p_2}{\overline{\varepsilon}_2}$ where $\overline{\varepsilon}_2$ stands for the super-elasticity of demand for the energy sold by the incumbent at node 2, we obtain

$$a^B = c_t + \frac{\eta}{1+\lambda} + \frac{\lambda}{1+\lambda}\frac{p_2}{\overline{\varepsilon}_2} \tag{2}$$

that differs from a^0 defined in (1) by the fact that entrants pay on the basis of the demand characteristics of the incumbent's consumers at node 2 instead of the demand characteristics of their own consumers. Consequently, the ECPR can be optimal only if the entrants and the incumbent sell perfect substitutes at node 2.

3. Access pricing under ownership unbundling

We now switch to the case where the TSO is totally independent from the electricity producers. In this framework, producers are users of the network in the same way as their clients at the remote node: without access they cannot sell and their clients cannot consume. How to define second best in this configuration? We assume that the TSO is the middle-man between producers and consumers: it buys electricity at price p^g and sells it at price p^w. Because there is separate ownership, the TSO faces the production segment as a whole. A detailed analysis would require to distinguish the unit cost of the incumbent c_g and the unit cost of the entrants c_e and the cases where one is larger than the other. To keep the model as simple as possible, we assume that the energy producers are aggregated and the industry cost function to produce energy is $C(q)$ where $C'(q) > 0$ and $C''(q) > 0$. For the same reason, we assume that the entrants and the incumbent produce perfect substitutes for consumers at node 2.

Given the prices fixed by the TSO, the network users maximize their net utility and net profit:

* consumers at node *i*: $\max_q \ u_i(q) - p_i^w q$ which gives the demand function $p_i^w(q)$ or $q_i^w(p)$. The net surplus of consumers at node *i* is $S_i^w(p_i^w) = u_i\left(q_i^w\left(p_i^w\right)\right) - p_i^w q_i^w\left(p_i^w\right)$;

* producers at node 1: $\max_q \ pq - C(q)$ which gives the supply function $p^g(q)$ or $q^g(p)$. The aggregate profit of producers is $\pi^g\left(p^g\right) = p^g q^g\left(p^g\right) - C\left(q^g\left(p^g\right)\right)$.

The objective of the TSO is to maximize the "Merchandizing Surplus", that is the surplus created by trade on the line. We face two possibilities. When the agent in charge of the infrastructure is a pure transport operator, he only cares about trade between consumers at node 2 and their providers at node 1. In this institutional setting, the merchandising surplus is $MS = p_2^w q_2^w - p^g q_2^w - c_t q_2^w - F$. Nevertheless, because the TSO is often also in charge of the whole system (balancing, reliability, reserves management) we will rather adopt the hypothesis that there is no direct sales of energy between producers and the consumers located at node 1, so that

$$MS\left(p_1^w, p_2^w, p^g\right) = p_1^w q_1^w\left(p_1^w\right) + p_2^w q_2^w\left(p_2^w\right) - p^g q^g\left(p^g\right) - c_t q_2^w\left(p_2^w\right) - F \text{ .}$$

The second best pricing policy is the solution to

$$\underset{p^g, p_1^w, p_2^w}{Max} \quad S_1\left(p_1^w\right) + S_2\left(p_2^w\right) + \pi^g\left(p^g\right) + MS\left(p_1^w, p_2^w, p^g\right)$$

$$s.t. \quad q_2^w \le K \qquad (\eta)$$

$$MS \ge 0 \qquad (\lambda)$$

$$q_1^w + q_2^w \le q^g \qquad (\mu)$$

The Ramsey prices for energy are

$$p_1^w = \frac{\mu}{1+\lambda} + \frac{\lambda}{1+\lambda}\frac{p_1^w}{\varepsilon_1^w}, \quad p_2^w = c_t + \frac{\eta+\mu}{1+\lambda} + \frac{\lambda}{1+\lambda}\frac{p_2^w}{\varepsilon_2^w}, \quad p^g = \frac{\mu}{1+\lambda} - \frac{\lambda}{1+\lambda}\frac{p^g}{\varepsilon^g}$$

where μ , the shadow price of the demand/supply balancing constraint, stands for the “value of energy” $\varepsilon^g \overset{def}{=} \frac{dq^g}{dp^g}\frac{p^g}{q^g}$ is the price elasticity of supply and $\varepsilon_i \overset{def}{=} -\frac{dq_i^w}{dp_i^w}\frac{p_i^w}{q_i^w}$ is the demand elasticity at node i , $i = 1,2.$ Once again we observe the distortions created by the requirement to balance the budget of the transport manager. As compared with the former section, we observe an additional distortion. Because price discrimination is efficient, the social planner discriminates between consumers and producers at node 1 with the consequence that the principle of uniqueness of price at one node is lost[18]. In effect, it is easy to check that $p_1^w > p^g$.

[18] Except if the congestion rent is so high that the financial constraint is not binding. In that case, it is easy to check that $p_1^w = \mu = p^g$ and $p_2^w = c_t + \eta + \mu$. The merchandizing surplus is $MS = \mu q_1^w + (\eta + \mu)K - \mu q^g - F$ and, using the demand/supply balancing constraint $q^g = q_1^w + K$ we can check that $MS = \eta K - F > 0$. Note that additional resources actually arise from energy losses: because they are a quadratic function of energy flows, marginal cost pricing provides profits.

In the perspective of decentralizing the transmission activity under the supervision of a regulation agency, how can we use the above results to propose rules for access fees charged to users? Assume there are traders allowed to buy energy at node 1 and sell to consumers at node 2. When the trading activity is perfectly competitive, at equilibrium the traders cannot extract profit, which means that the access fee should be fixed at the value $\hat{a}$ such that

$$p^g + \hat{a} = p_2^w .$$

Using the former results on the Ramsey prices for energy, we therefore obtain

$$\hat{a} = c_t + \frac{\hat{\eta}}{1+\hat{\lambda}} + \frac{\hat{\lambda}}{1+\hat{\lambda}}\left(\frac{p_2^w}{\varepsilon_2^w} + \frac{p^g}{\varepsilon^g}\right) \qquad (3)$$

The common features between (1) and (3) are the necessity to pay for variable costs, a payment for congestion and a contribution to fixed costs. But there are some differences. Apparently, the independent TSO has only one source of revenues (access fees) whereas the integrated monopoly (constrained to second best) also had revenues from energy sales. Actually, thanks to the access revenues the independent TSO extracts money from all consumers at node 2 (including those of the incumbent) and/or from producers. Indeed, we see that the elasticity of supply appears in (3) beside the elasticity of demand.

Another difference is that the integrated monopoly is potentially more efficient. In effect, if entrants have lower cost $\left(c_e < c_g\right)$, the integrated monopoly can reduce its own production and obtain compensation through a higher access fee. And in the opposite case $\left(c_e > c_g\right)$, the incumbent can efficiently deny access to entrants. By contrast under the independent TSO regime, competition between the incumbent *g* and entrants *e* does not systematically eliminate *g* when $c_e < c_g$ and *e* when $c_e > c_g$.[19]

Finally note that with the access fee defined in (3), the infrastructure's owner does not systematically recover all its cost. In effect, when the constraint $MS \geq 0$ is binding, we have that

$$p_1^w q_1^w + p_2^w q_2^w - p^g q^g - c_t q_2^w - F = 0$$

or $$\left(p_1^w - p^g\right) q_1^w + \left(p_2^w - p^g - c_t\right) q_2^w - F = 0$$

or $$\left(\hat{a} - c_t\right) q_2^w - F = -\left(p_1^w - p^g\right) q_1^w < 0 .$$

[19] For instance when firms compete "à la Cournot", as long as the cost difference is not drastic, they all are dispatched. The independent TSO is only allowed to deny access to providers for technical reasons.

The left hand side of the last line above is the net revenue of the transport activity and we see that it is negative. The reason is that we have computed the access fee from the Ramsey nodal prices, including the consumers of node 1 in the system because we have assumed that the TSO is in charge of the electric system operation. Therefore, this service should be charged to consumers of node 1 (or their providers) for an amount $\hat{a}_{s1} = p_1^w - p^g = \frac{\hat{\lambda}}{1+\hat{\lambda}}\left(\frac{p_1^w}{\varepsilon_1^w} + \frac{p^g}{\varepsilon^g}\right)$ per unit of local consumption. Comparing with (3), we see that the second best access fee $\hat{a}$ can be interpreted as made of two pieces: $\hat{a} = \hat{a}_t + \hat{a}_{s2}$ where $\hat{a}_{s2} = \frac{\hat{\lambda}}{1+\hat{\lambda}}\left(\frac{p_2^w}{\varepsilon_2^w} + \frac{p^g}{\varepsilon^g}\right)$ is the payment by users at node 2 for the system management and $\hat{a}_t = c_t + \frac{\hat{\eta}}{1+\hat{\lambda}}$ is the transportation fee from node 1 to node 2.

4. Access pricing by an independent transport manager

In the EC texts, the alternative to the independent transport firm is the independent system operator (SO). In this solution, the incumbent may keep ownership of the infrastructure but management is given to a separate independent entity. The consequence is that the SO has no entitlement to extract the congestion rent and its revenues are only made of the access fee. At each node, consumers trade with producers given the access charge fixed by the SO. Keeping the hypothesis of perfect competition at each node, consumers solve $\max_q \; u_i(q) - p_i q$ and producers solve $\max_{q_1,q_2} p_1 q_1 + p_2 q_2 - C(q_1+q_2) - a q_2$ s.t. $q_2 \le K$.

Therefore, unconstrained nodal equilibria $(q_2 < K)$ are characterized by

$$p_1 = u_1'(q_1) = C'(q_1+q_2)$$

$$p_2 = u_2'(q_2) = C'(q_1+q_2) + a$$

from which it is easy to derive $\frac{dq_1}{da} > 0$ and $\frac{dq_2}{da} < 0$. In this context, the problem to solve is

$$\max_a u_1(q_1) + u_2(q_2) - C(q_1+q_2) - a q_2 + (1+\lambda)(a q_2 - c_t q_2 - F).$$

In the Appendix, we show how to derive the access charge

$$\hat{a} = c_t + \frac{\hat{\lambda}}{1+\hat{\lambda}}\frac{1}{\varepsilon_E} \qquad (4)$$

where $\varepsilon_E \overset{def}{=} -\frac{dq_2}{da}\frac{a}{q_2}$ is the elasticity of equilibrium at node 2 to changes in the access fee. It does not contain any congestion rent because the transmission line is oversized. It depends on the whole equilibrium at node 2 because a change in *a* shifts the supply curve at node 2, which changes the quantity traded. This affects the supply function at node 1 with the effect to modify the volume of trade. This creates a feedback effect at node 2, etc.

By contrast, when the line is congested $(q_2 = K)$, nodal equilibria are

$$p_1 = u_1^{'}(q_1) = C'(q_1 + K)$$

$$p_2 = u_2^{'}(K) = C'(q_1 + K) + a + \eta$$

so that $\frac{dq_1}{da} = \frac{dq_2}{da} = 0$ because increases in the access fee only decrease the congestion rent by an equal amount. In this context, the SO's profit is $aK - c_t K - F$ and we once more suppose that it should not be made negative by surplus maximization. This can be met by average cost pricing:

$$\hat{a} = c_t + \frac{F}{K} \tag{5}$$

Actually, as illustrated in Figure 2, the fee can be increased up to

$$a = u_2^{'}(K) - u_1^{'}(q_1(K)) \tag{6}$$

where $q_1(K)$ is the solution to $u_1^{'}(q_1) = C'(q_1 + K)$.

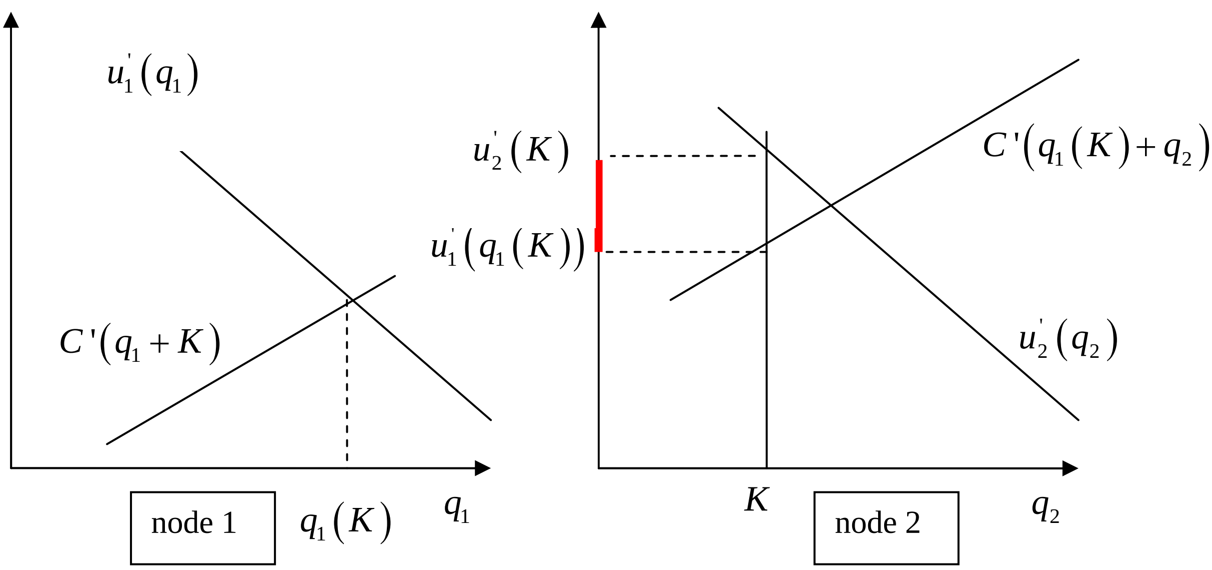

Figure 2: Potential congestion rent for the system operator

Doing so, the SO confiscates the whole congestion rent without violating the objective of surplus maximization. Therefore, it appears that when the ownership of the transportation assets is separated from management, the rules on how to share the congestion rent have no effect on dispatching. Nevertheless, they must be clearly specified since they will have an effect on the incentives to invest in the infrastructure and/or in production plants at the importing node.

5. Conclusions

The paper has shown that the structure and value of the tariff to access the electricity infrastructure should depend on the institutional framework of the electricity industry, even though the consumers, producers and system operators behave competitively. Contrary to the uniform pricing system used all around the EU (postage stamp), congestion costs and users' elasticity should be key ingredients for the computation of access charges. When the incumbent remains vertically integrated, the price elasticity of the demand served by the entrants matters. Under ownership unbundling, the access fee should be based on demand elasticity and supply elasticity of the users of the line. When the system operator is not the owner of the transportation assets, the responsiveness of the equilibrium at the importing node must be used to compute the access fee.

Starting from these basic results, the model can be extended in various directions. In particular, it should take account of distinct technologies for the incumbent and the entrants and introduce market power and the resulting imperfect competition. A second avenue of research is to consider meshed networks that are common in most country of continental Europe and the counter-flows and netting effects that result from the topological characteristics of more complex infrastructure. Also, any form of separation creates informational gaps, in particular on the thermal capacity of lines, the actual level of congestion and the costs of the system. Therefore, a fraction of the rents should be abandoned to the agents endowed with private information, which means that the congestion fee should be adapted accordingly. Finally, the analysis in this paper is limited to short run. A natural extension is to make the capacity of the lines endogenous and to compare the alternative institutional settings in terms of investment.

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Appendix

Second best

First observe that when they face price p_i, consumers at node *i* choose q_i to solve $\max_{q_i} u_i(q_i) - p_i q_i$. From the first-order condition $u_i^{'}(q_i) - p_i = 0$, we deduce the direct demand function at node *i*, $q_i = q_i(p_i)$, a function of price that is decreasing because of the concavity of $u_i(q_i)$.

Then, let us define the net consumer's surplus at node *i* as $S_i(p_i) \overset{def}{=} u_i(q_i(p_i)) - p_i q_i(p_i)$. Note that $\dfrac{dS_i}{dp_i} = (u_i^{'} - p_i)\dfrac{dq_i}{dp_i} - q_i(p_i) = -q_i(p_i)$ by the first order condition.

Finally, let us define

$$\pi(p_1, p_2) \overset{def}{=} q_1(p_1)\,p_1 + q_2(p_2)\,p_2 - c_g.\big(q_1(p_1) + q_2(p_2)\big) - c_t q_2(p_2) - F$$

We can now determine the second best prices as the solution to

$$\max_{p_1, p_2} \quad S_1(p_1) + S_2(p_2) + \pi(p_1, p_2)$$

$$\text{s.t.} \quad \pi(p_1, p_2) \geq 0 \qquad (\lambda)$$

$$q_2(p_2) \leq K \qquad (\eta)$$

$$q_1(p_1) \geq 0,\ q_2(p_2) \geq 0$$

The Lagrange function is

$$L = S_1(p_1) + S_2(p_2) + (1+\lambda)\pi(p_1, p_2) + \eta.\big(K - q_2(p_2)\big).$$

The solution is given by the Kuhn and Tucker conditions for a saddle-point $\dfrac{\partial L}{\partial p_i} = 0, \quad i = 1, 2$ and the complementary slackness conditions

$$\lambda \geq 0 \quad , \quad \pi(p_1, p_2) \geq 0 \quad , \quad \lambda.\pi(p_1, p_2) = 0$$

$$\eta \geq 0 \quad , \quad K \geq q_2(p_2), \quad \eta.\big(K - q_2(p_2)\big) = 0$$

By developing the K-T conditions, we obtain

$$-q_1 + (1+\lambda)\left[q_1 + \left(p_1 - c_g\right)\frac{dq_1}{dp_1}\right] = 0, \quad -q_2 + (1+\lambda)\left[q_2 + \left(p_2 - c_g - c_t\right)\frac{dq_2}{dp_2}\right] - \eta\frac{dq_2}{dp_2} = 0$$

to jointly solve with the complementary slackness conditions for the two energy prices p_1, p_2 and the two shadow prices $\lambda, \eta.$ The resulting energy prices are Ramsey prices

$$\frac{p_1 - c_g}{p_1} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_1}, \quad \frac{p_2 - (c_g + c_t) - \dfrac{\eta}{1+\lambda}}{p_2} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_2} \text{ where } \varepsilon_i \overset{def}{=} -\frac{dq_i}{dp_i}\frac{p_i}{q_i} \quad i = 1, 2.$$

Access price when the incumbent is vertically integrated

To solve $\max_{p_1, p_2, p_e} S_1\left(p_1\right) + S_2\left(p_2, p_e\right) + \pi\left(p_1, p_2, p_e\right)$

$$\begin{aligned} s.t. \quad & \pi\left(p_1, p_2, p_e\right) \geq 0 && (\lambda) \\ & q_2 + q_e \leq K && (\eta) \\ & q_1 \geq 0, q_2 \geq 0, q_e \geq 0 \end{aligned}$$

we write the Lagrange function

$$L = S_1(p_1) + S_2(p_2, p_e) + (1+\lambda)\pi(p_1, p_2, p_e) + \eta.\left(K - q_2\left(p_2, p_e\right) - q_e\left(p_2, p_e\right)\right)$$

The first-order conditions of the second best problem with entrants are

$$-q_1 + (1+\lambda)\left[q_1 + (p_1 - c_g)\frac{dq_1}{dp_1}\right] = 0$$

$$-q_2 + (1+\lambda)\left[q_2 + (p_2 - c_g - c_t)\frac{dq_2}{dp_2} + (p_e - c_e - c_t)\frac{dq_e}{dp_2}\right] - \eta\left(\frac{dq_2}{dp_2} + \frac{dq_e}{dp_2}\right) = 0$$

$$-q_e + (1+\lambda)\left[q_e + (p_2 - c_g - c_t)\frac{dq_2}{dp_e} + (p_e - c_e - c_t)\frac{dq_e}{\partial p_e}\right] - \eta\left(\frac{dq_2}{dp_e} + \frac{dq_e}{dp_e}\right) = 0$$

Joint with the complementary slackness conditions derived from the financial constraint and the technical constraint, these equations allow to compute the shadow prices λ, η and the energy prices p_1, p_2, p_e. The above system of equations is solved for the margins extracted from the three activities of the incumbent ($p_1 - c_g$ for local consumers, $p_2 - c_g - c_t - \dfrac{\eta}{\left(1+\lambda\right)}$ for remote consumers, and $p_e - c_e - c_t - \dfrac{\eta}{\left(1+\lambda\right)}$ for access to entrants).

The Lerner indices are

$$\frac{p_1 - c_g}{p_1} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_1}, \quad \frac{p_2 - \left(c_g + c_t + \dfrac{\eta}{1+\lambda}\right)}{p_2} = \frac{\lambda}{1+\lambda}\frac{1}{\overline{\varepsilon}_2}, \quad \frac{p_e - \left(c_e + c_t + \dfrac{\eta}{1+\lambda}\right)}{p_e} = \frac{\lambda}{1+\lambda}\frac{1}{\overline{\varepsilon}_e} \text{ where}$$

$$\overline{\varepsilon}_e \overset{def}{=} \frac{\varepsilon_e \varepsilon_2 - \varepsilon_{e2}\varepsilon_{2e}}{\varepsilon_2 - \varepsilon_{e2}}, \quad \overline{\varepsilon}_2 \overset{def}{=} \frac{\varepsilon_2 \varepsilon_e - \varepsilon_{2e}\varepsilon_{e2}}{\varepsilon_e - \varepsilon_{2e}}, \quad \varepsilon_i \overset{def}{=} -\frac{dq_i}{dp_i}\frac{p_i}{q_i} \text{ and } \varepsilon_{ij} \overset{def}{=} \frac{dq_i}{dp_j}\frac{p_j}{q_i} \quad i = 1, 2, e, \quad i \neq j.$$

Access price under ownership unbundling

In order to solve $\underset{p^g, p_1^w, p_2^w}{Max} \quad S_1\left(p_1^w\right)+S_2\left(p_2^w\right)+\pi^g\left(p^g\right)+MS\left(p_1^w, p_2^w, p^g\right)$

$$s.t. \quad q_2^w \le K \qquad (\eta)$$

$$MS \ge 0 \qquad (\lambda)$$

$$q_1^w + q_2^w \le q^g \qquad (\mu)$$

we build the Lagrange function

$$L = S_1\left(p_1^w\right)+S_2\left(p_2^w\right)+\pi^g\left(p^g\right)+(1+\lambda)MS\left(p_1^w, p_2^w, p^g\right)+\eta.\left(K-q_2^w\left(p_2^w\right)\right)+\mu.\left(q^g\left(p^g\right)-q_1^w\left(p_1^w\right)-q_2^w\left(p_2^w\right)\right)$$

The first-order conditions are

$$\frac{\partial L}{\partial p_1^w} = -q_1^w + (1+\lambda)\left[q_1^w + p_1^w \frac{dq_1^w}{dp_1^w}\right] - \mu \frac{dq_1^w}{dp_1^w} = 0$$

$$\frac{\partial L}{\partial p_2^w} = -q_2^w + (1+\lambda)\left[q_2^w + p_2^w \frac{dq_2^w}{dp_2^w} - c_t \frac{dq_2^w}{dp_2^w}\right] - \eta \frac{dq_2^w}{dp_2^w} - \mu \frac{dq_2^w}{dp_2^w} = 0$$

$$\frac{\partial L}{\partial p^g} = q^g - (1+\lambda)\left[q^g + p^g \frac{dq^g}{dp^g}\right] + \mu \frac{dq^g}{dp^g} = 0$$

From these equations and the complementary slackness conditions, one can derive the Ramsey prices for energy

$$\frac{p_1^w - \frac{\mu}{1+\lambda}}{p_1^w} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_1^w}, \quad \frac{p_2^w - \left(c_t + \frac{\eta+\mu}{1+\lambda}\right)}{p_2^w} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon_2^w}, \quad \frac{p^g - \frac{\mu}{1+\lambda}}{p^g} = -\frac{\lambda}{1+\lambda}\frac{1}{\varepsilon^g}$$

where $\varepsilon^g \overset{def}{=} \frac{dq^g}{dp^g}\frac{p^g}{q^g}$ and $\varepsilon_i \overset{def}{=} -\frac{dq_i^w}{dp_i^w}\frac{p_i^w}{q_i^w} \quad i = 1, 2.$

Access price when the system operator is not the owner of transport assets

When the thermal capacity of the line is very large, the problem to solve is

$$\max_a u_1\left(q_1\right)+u_2\left(q_2\right)-C\left(q_1+q_2\right)-aq_2+\left(1+\lambda\right)\left(aq_2-c_tq_2-F\right).$$

The first order condition is

$$\left(u_1'\left(q_1\right)-C'\left(q_1+q_2\right)\right)\frac{dq_1}{da}+\left(u_2'\left(q_2\right)-C'\left(q_1+q_2\right)-a\right)\frac{dq_2}{da}-q_2+\left(1+\lambda\right)\left(q_2+\left(a-c_t\right)\frac{dq_2}{da}\right)=0$$

and, using the equilibrium conditions $u_1'\left(q_1\right)=C'\left(q_1+q_2\right)$, $u_2'\left(q_2\right)=C'\left(q_1+q_2\right)+a$, we obtain $\lambda q_2+\left(1+\lambda\right)\left(a-c_t\right)\frac{dq_2}{da}=0$ from which $\hat{a}=c_t+\frac{\hat{\lambda}}{1+\hat{\lambda}}\frac{1}{\varepsilon_E}$ where $\varepsilon_E \overset{def}{=} -\frac{dq_2}{da}\frac{a}{q_2}$.