Regulation and electricity market integration: When trade introduces inefficiencies

Billette de Villemeur, Etienne and Pineau, Pierre-Olivier

Université de Lille, EQUIPPE, HEC Montréal

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Etienne Billette de Villemeur
Université de Lille (EQUIPPE)

Pierre-Olivier Pineau
HEC Montréal

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Abstract

Electricity markets vary greatly across jurisdictions, in terms of regulatory institutions, cost levels and environmental impacts. Integrating such different markets can lead to significant changes. This paper considers two jurisdictions – one with a regulated monopoly selling at average cost and one with a competitive market – and compares three different institutional regimes: autarky, a mixed-market structure with trade and a fully integrated market, where electricity is sold at marginal cost. We show that, in the second regime, the regulated monopoly always exports toward the jurisdiction pricing at marginal cost, up to inducing productive *in*efficiencies. By contrast, a shift from the second to the third regime, *i.e.* "integrated deregulation" yields a decrease in overall consumption. We identify the exact conditions under which the shift from one regime to the other results in environmental gains.

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1 Introduction

Electricity market reforms aim at increasing welfare by changing how price and investment decisions are made. Most reforms were designed with only one jurisdiction in mind, *e.g.* England, California or Ontario. However, increased market access over different jurisdictions - such as in the Nordic countries or in the United States, where Regional Transmission Operator (RTO) are active - can also have important welfare impacts. This paper is concerned with such integration reforms and their consequences upon price levels and the environment. The motivation for this contribution comes from the observation that there is little research explicitly characterizing electricity market integration outcomes. As Blumsack (2007) puts it, "neither industry nor academia has produced a definitive study of the costs and benefits of RTO markets and regional grid integration". While we do not provide such a definitive study on electricity market integration, nor are we conducting a cost-benefit analysis, our contribution is to present important results with respect to change in market outcomes (price, production and emission levels) when two electricity markets integrate. Such results are otherwise absent from the literature and help assessing the benefits of integration.

We directly build on Billette de Villemeur and Pineau (2010), where we have shown that electricity trade across regions is likely to increase environmental externalities, possibly preventing market integration to be welfare enhancing. We take a further step in the study of electricity market integration by looking at the role of regulatory institutions. More specifically, we compare the case where one of the trading jurisdictions maintains average cost pricing regulation over its internal market to the case where market integration also comes with a shift to marginal cost pricing in both jurisdictions.
Our paper evidences that institutions matter. In particular, we show that, if market integration is *not* accompanied by deregulation, the regulated monopolist always finds it profitable to export toward the other jurisdiction. This happens whenever average costs are increasing because, by doing so, the monopolist is able to induce a raise in the cost-based regulated price. As a result, market integration is likely to introduce productive *in*efficiencies, especially if the regulated jurisdiction is neighbour to a relatively inexpensive market.
By contrast, deregulation within an integrated market always leads to a decrease in overall consumption. Environmental externalities consequently decrease, unless the change to marginal cost pricing leads the importing (initially deregulated) jurisdiction to increase its production *and* the latter happens to have a higher carbon content.

In order to study these electricity integration outcomes, we propose a two-jurisdiction electricity market model and consider three different regimes. More specifically:

Regime 1 The two jurisdictions are in autarky (no interconnection). In one jurisdiction, price is equal to average cost (through regulation, including a return on investment). In the other one, price is equal to marginal cost (through a competitive market, with price-taking firms).

Regime 2 The two jurisdictions trade through an *un*limited interconnection. However, (internal) market structures are as in regime 1: one jurisdiction prices at average cost, in the other, price is equal to marginal cost.

Regime 3 The two jurisdictions are "fully integrated": they again trade through an *un*limited interconnection and they both price at marginal cost.

The assumption of *un*limited interconnection is deliberately maintained throughout the paper. This is obviously unrealistic, although real interconnections are far from being congested all the time; see for instance Pineau and Lefevbre (2009) for a North American example. It however allows us *i)* to limit the number of cases and subcases that would follow from having the constraint attached to the limited interconnection capacity binding or not, *ii)* to bring out more clearcut results and ultimately, *iii)* to identify in which direction market forces are pushing.

The three regimes represent policy options for many jurisdictions that still regulate electricity price using average cost principles, while their neighbors have prices closer to the marginal cost of electricity. For instance, in the United States, many states enjoy low regulated power prices, even if they share a border with a higher-price, deregulated, jurisdiction. This is the case of Idaho where, in 2009, the regulated industrial electricity price was 5.17 cents per kWh (EIA, 2011) - thanks to its abundant hydropower production (79% of total generation). In the neighboring Nevada, electricity was competitively sold at 7.97 cents, on average, to the industry. The share of generation coming from coal and natural gas, 88%, largely explains the difference (EIA, 2011). Similarly, in Canada, electricity in the provinces of Quebec, Manitoba and British Columbia is sold at a (regulated) price almost half the level of the (competitive) prices prevailing in Ontario and Alberta (Pineau, 2009). This can be explained by the larger share of relatively cheap hydropower available in these provinces, sold under cost-based rates, very similar to an average-cost pricing regulation. In Europe, the situation is similar between France (lower cost nuclear power) and the United Kingdom (with higher cost fossil fuel generation).

We are particularly interested in analyzing the consequences of adopting one of the three different policy options, upon prices, consumption and greenhouse gas (GHG) emissions. The rest of the paper is divided into three sections. In section 2, we provide a literature review. Section 3 offers an analysis of electricity trade and regime changes over two jurisdictions, along with some theoretical results. A conclusion follows.

2 Electricity Market Integration Literature Review

Surprisingly, despite major liberalization reforms and electricity market integration initiatives, few contributions formally look at market outcomes when different jurisdictions integrate their electricity markets. Price and production levels are usually not the focus of integration studies. It is rather the volume of trade, the amount of reserve margins, the efficiency of power plants and investment incentives that are considered. See for instance Müller-Jentsch (2005) or Hooper and Medvedev (2009) for discussions on the benefits of electricity market integration. Empirical studies conducted in the US for the Federal Energy Regulatory Commission on RTO (IFC Consulting, 2002) or on the PJM market (Krapels and Flemming, 2005) are mostly looking at these same issues, leaving aside regional variations in economic outcomes (even if the topic is briefly mentioned in IFC Consulting, 2002). This is could probably be explained because they do not want to deal with "native load commitments", *i.e.* the obligation to serve local consumers before being able to sell elsewhere, even at a higher price. For instance, Blumsack (2007), in his attempt to measure the benefits and costs of regional electricity market integration, prefers to leave aside "institutional changes associated with restructuring, such as the movement away from cost-based rates". Our paper directly deals with such a movement. It provides a "systematic analysis of the effect of competition reforms on electricity prices", something Joskow (2008a) observes as being seldom done.

Understanding differences in outcomes for the various jurisdictions potentially involved in electricity market integration is key for their success, because groups losing in the integration process may resist any change. Indeed, Benjamin (2007) explains the opposition to "standard market design" in the US South by the fear "that broader regional markets enabled by it would result in export of the region's cheap power to higher-priced areas". Similarly, van den Hoven and Froschauer (2004) illustrate this problem in their analysis of the French and Canadian cases. More recently, Finon (2008) raises the question of electricity market integration from a consumer's perspective, in France. He questions the benefit of such integration for consumers, as they may face higher prices. Although these papers provide intuition for the problem they describe, they do not formalize the resulting market outcomes, nor do they rigorously characterize price and quantity outcomes of integration.

In the vast literature on restructuring of the electricity sector, Newbery (2000) or Stoft (2002) offer very good theoretical frameworks. However, neither discusses the consequences of integrating different electricity markets. Theoretical and applied economic results on electricity market integration are not common in the literature, despite its importance. Joskow (2008b) calls for a US "comprehensive national electricity policy framework" to adequately tackle the climate change challenge, among other benefits. In such a framework, electricity market would be more integrated. Electricity market integration is currently happening in Europe (Meeus and Belmans, 2008) and promoted across the world (UN, 2006). See also Pineau (2008) for a discussion of electricity market integration in West Africa.

Integration of different jurisdictions takes place through increased electricity trade, as studied by Aune et al. (2004), Haaparanta (2004) and von der Fehr and Sandsbråten (1997). However, these papers do not look at regional welfare impacts, but on induced technological and industrial changes following integration. Furthermore, they leave aside all political economy questions on whether increased trade could receive support from consumers and producers in the concerned jurisdictions. Bye and Holmøy (2010) study the impact of an industrial electricity price increase in the Norway through a computable general equilibrium model, but leave aside regional outcomes.

Chen (2009) studies how a cap-and-trade system could lead to CO_2 leakages in the PJM electricity market, integrating six different states (Maryland, New Jersey, Pennsylvania, West Virginia, Delaware and Virginia as well as Washington, DC). Our paper also looks at emissions from different jurisdictions, but in a context where they are not already sharing the same market structure. We build on Billette de Villemeur and Pineau (2010), where conditions under which trade leads to damaging environmental impacts are characterized. Regarding environmental effects, our contribution, in this paper, is twofold. We first extend our previous results to the case where one of the jurisdictions is regulated. Second, we identify the circumstances under which, in an integrated market, the shift to marginal cost pricing of a previously regulated jurisdiction is environmentally beneficial.

Recently, integration through increasing transmission capacity between two markets and its welfare impacts was studied by Sauma and Oren (2009). Their analysis is mostly concerned with the ownership of financial transmission rights (FTRs), market power and its impacts on investment in new transmission. Our paper looks at a more general situation, where two markets have different cost structures and price regulation. Our analysis is not centered on investment in transmission capacity nor on market power, but on specific market outcomes, including environmental ones. To some extent, it builds on Bernard and Chatel (1985), where marginal cost pricing is introduced in a single jurisdiction where electricity production mostly comes from hydropower. However, again, our focus is more on the impact of integrating markets than on the pricing structure change within one market only.

Political economy questions on the distribution of gains and losses after introducing trade have received attention in the general trade literature. Dixit and Norman (1986) look at a Pareto superior outcome from free trade without lump-sum compensation. They suggest using taxes and subsidies to redistribute gains. Davidson et al. (2007) and Brusco and Hopenhayn (2007) follow this avenue and study transfer schemes that will lead to political support for the removal of all trade barriers and further market integration, in the general case. Such political and trade issues are increasingly linked with environmental considerations. Furthermore, environmental policy is becoming a political question, and voters have different sensitivities to it. Questions of political parties gaining votes through earmarked environmental spending are dealt with in Anesi (2006). Anesi and De Donder (2008) look at the interplay between environmental issues and other ones in the political game played by parties. Although our model would offer a good basis for such analysis we do not expand on the political economy questions in this paper. These issues are however key for the successful implementation of market integration reforms.

3 Trade in Electricity Markets

3.1 The model

Consider two jurisdictions, A and M (for Average cost pricing and Marginal cost pricing, respectively), characterized by dissimilar features regarding their electricity sector. More precisely, we assume that there is a single provider in A which is regulated and prices at the average cost of production. Throughout the paper, we assume that the industry is beyond the efficiency point and exhibits decreasing returns to scale. In other words, average cost in A is assumed to be increasing. By contrast, electricity in M is sold at marginal cost. Moreover, we assume that jurisdictions A and M also differ in two other dimensions: their production costs and the environmental impact of their production technologies. We also assume that marginal costs in M are always higher than average costs in A. Otherwise, unbounded trade from M to A would lead to the complete shutdown of production in A, a case we wish to exclude because of its very limited relevance.

Let $p_A\left(X_A^D\right)$ and $p_M\left(X_M^D\right)$ denote the (inverse) demand functions of the respective jurisdictions, where X_A^D and X_M^D are the quantities consumed in A and M. Let $C_A\left(X_A^S\right)$ and $C_M\left(X_M^S\right)$ be the respective production costs for X_A^S and X_M^S, the quantities supplied. We assume that both cost functions $C_A(\cdot)$ and $C_M(\cdot)$ are increasing and convex in their argument. Similarly, let $E_A\left(X_A^S\right)$ and $E_M\left(X_M^S\right)$ denote the environmental impact (emissions) of production in each jurisdiction. Emissions E_j, $j = A, M$ increase with production X_j. It is a "public bad" whose damage functions $D_j(E)$, $j = A, M$ are increasing in their argument $E \equiv E_A + E_M$.

When jurisdictions A and M trade, X_t denotes the quantity flowing from A to M, with this convention: $X_A^S = X_A^D + X_t$ and $X_M^S = X_M^D - X_t$. We do not consider the case where trade goes from M to A, as we assume higher costs in M.

3.2 Regime 1: Mixed-market structure in autarky

If both markets run in autarky ($X_t = 0$) and there is no shortage, equilibrium quantities $X_A^1 = X_A^S = X_A^D$ and $X_M^1 = X_M^S = X_M^D$ are defined by the implicit equations[1]

$$p_A\left(X_A^1\right) = \frac{C_A\left(X_A^1\right)}{X_A^1}, \quad (1)$$

$$p_M\left(X_M^1\right) = C_M'\left(X_M^1\right). \quad (2)$$

Note that both equations follow from "profit maximization".[2] As a result of supply obligation, the provider in A must produce as to exactly match consumer demand X_A^D, which given the pricing rule imposed in A is defined by Eq. (1). By contrast, producers in M are assumed to be price takers, hence Eq. (2), which follows from equalizing marginal returns to marginal costs.

Note that, because we assumed the average cost function $C_A(X)/X$ to be increasing, average cost pricing in jurisdiction A is *not* socially efficient. This is true, even abstracting from the possibility of non-linear pricing[3] and ignoring the environmental dimension. More precisely, prices are inefficiently low. Instead, marginal cost pricing in M is efficient as long as environmental damages are

[1] Superscripts 1, 2 and 3 are used to refer to Regimes 1, 2 and 3, respectively. When there is no ambiguity, these superscripts are dropped.

[2] In all the paper, we consider the production capabilities to be given. This says that we consider only short-term profit-maximization by output adjustments and ignore long-term issues like capital investment. For traditional capacity expansion models under cost-based regulation, see Bates and Fraser (1974) or Kahn (1988), among many others.

[3] We thank one of the referees for pointing that out.

neglected. However, if environmental impacts are accounted for, prices are also too low.

3.3 Regime 2: Mixed-market structure with trade

Consider now a situation where there is some trade between the two jurisdictions. Yet, we assume that, while the A-producer may sell in the M-market, the quantities involved are small enough for the A-producer not to have any market power in jurisdiction M.

3.3.1 Trade flows

Recall that $p_A\left(X_A^D\right)$ denotes the inverse demand function in jurisdiction A. Given the price-taking behavior in market M, the profits of the A-monopolist are its revenue in A minus its total cost, plus the trade revenues. These profits write:

$$\pi_A\left(X_A^S, X_t\right) = p_A\left(X_A^S - X_t\right)\left[X_A^S - X_t\right] - C_A\left(X_A^S\right) + p_M X_t. \tag{3}$$

The pricing rule also imposes that

$$p_A\left(X_A^S - X_t\right) = \frac{C_A\left(X_A^S\right)}{X_A^S}. \tag{4}$$

The latter equation determines implicitly X_A^S, for any level of X_t.
By differentiating with respect to X_t, one obtains

$$0 < \frac{dX_A^S}{dX_t} = \frac{-p'_A X_A^S}{C'_A\left(X_A^S\right) - \left[C_A\left(X_A^S\right)/X_A^S\right] - p'_A X_A^S} < 1. \tag{5}$$

In words, supply increases with exports, but less than proportionally. Indeed, as exports grow, the price $p_A = \left[C_A\left(X_A^S\right)/X_A^S\right]$ grows and induces a decrease in internal demand $X_A^D = X_A^S - X_t$.

The A-monopolist chooses its export X_t as to maximize its profits. Note that, thanks to Eq. (4), these profits write

$$\pi_A\left(X_A^S, X_t\right) = \left(p_M - \frac{C_A\left(X_A^S\right)}{X_A^S}\right) X_t. \tag{6}$$

We thus have

$$\begin{aligned} \frac{d\pi_A}{dX_t} &= \frac{\partial \pi_A}{\partial X_t} + \frac{\partial \pi_A}{\partial X_A^S}\frac{dX_A^S}{dX_t} \\ &= \left(p_M - \frac{C_A\left(X_A^S\right)}{X_A^S}\right) \\ &\quad + \left[\frac{C'_A\left(X_A^S\right) - \left[C_A\left(X_A^S\right)/X_A^S\right]}{C'_A\left(X_A^S\right) - \left[C_A\left(X_A^S\right)/X_A^S\right] - p'_A X_A^S}\right] p'_A X_t. \end{aligned} \tag{7}$$

It follows that, as long as $p_M = C'_M(X^S) > p_A = [C_A(X_A^S)/X_A^S]$, which we assumed, the A-monopolist has always an interest to export toward the M jurisdiction. Formally:

Proposition 1 *Provided that $p_M > p_A$ and $p_A = [C_A(X_A^S)/X_A^S]$, profit-maximization yields the A-monopolist to always export toward jurisdiction M.*

Remark 2 *This holds true even when $p_M = C'_M(X_M^S)$ is lower than $C'_A(X_A^S)$.*

This remark says that the A-monopolist may export at a price lower than its marginal production cost. The intuition for this comes from the fact that the marginal unit is sold below its production cost also in jurisdiction A. Selling in the export market raises production and therefore p_A. The loss made in the export market is more than compensated by the resulting reduction in internal demand, over which, marginally, an even greater loss was made.

In fact, absent restrictions on trade, (or provided the transmission capacity is not reached), one can show[4] that, at equilibrium:

$$C'_A(X_A^S) - C'_M(X_M^S) = \left[\frac{C'_A(X_A^S) - p_A - p'_A(X_A^S - X_t)}{C'_A(X_A^S) - p_A - p'_A X_A^S}\right](C'_A(X_A^S) - p_A) > 0. \tag{8}$$

In words, production is *not* distributed efficiently across producers.

3.3.2 Effects on prices and quantities

As just shown, the A-monopolist always has an incentive to export towards jurisdiction M. It follows that the introduction of trade results in an increase in p_A and a decrease in p_M. We also know that, despite the demand reduction in jurisdiction A, the supply X_A^S increases. By contrast X_M^S decreases but less than X_t, so that X_M^D increases. More precisely, by differentiating the equality

$$p_M(X_M^S + X_t) = C'_M(X_M^S), \tag{9}$$

we obtain:

$$-1 < \frac{dX_M^S}{dX_t} = \frac{p'_M}{C''_M(X_M^S) - p'_M} < 0. \tag{10}$$

This, together with the analytical expression of (dX_A^S/dX_t) in (5) allows us to establish the precise conditions under which electricity trade results in a higher overall consumption. We find:

Proposition 3 *Provided that $p_M > p_A$ and $p_A = [C_A(X_A^S)/X_A^S]$, allowing trade between the two jurisdictions has the following impacts: price and production increase in A and decrease in M. Total supply increases with trade iff*

$$\frac{\varepsilon_M [1 + (X_t/X_A^D)]}{\varepsilon_A [1 - (X_t/X_M^D)]} > \eta_M \left(\frac{C'_A(X_A^S) - p_A}{p_A}\right),$$

[4] This follows directly from rewriting equation (7) by setting $(d\pi_A/dX_t) = 0$

where ε_A and ε_M stand respectively for the (absolute value of the) price elasticity of demand in jurisdictions A and M,while η_M denotes the price elasticity of supply in jurisdiction M.

Proof. See appendix A.1. ■

3.3.3 Environmental impact

Environmental impacts of trade between two jurisdictions is already analyzed in Billette de Villemeur and Pineau (2010). Supply and demand elasticity conditions under which trade between two jurisdictions leads to greater or lower overall production levels are indeed provided. We complement this analysis with the following result:

Proposition 4 *Within a jurisdiction, emissions increase with exports and decrease with imports. Since when one jurisdiction is exporting, the other is importing, the overall environmental impact of trade is ambiguous. This ambiguity is present even if the low-emission jurisdiction is exporting. More precisely, trade is environmentally adverse if and only if:*

$$\frac{\varepsilon_M}{K_M\left(1-X_t/X_M^D\right)}\frac{1}{\eta_M}-\frac{\varepsilon_A}{K_A\left(1+X_t/X_A^D\right)}\left(\frac{C_A'\left(X_A^S\right)-p_A}{p_A}\right)$$
$$>\frac{K_M-K_A}{K_AK_M}\left(1-X_t/X_M^D\right)\left(1+X_t/X_A^D\right),$$

where K_A and K_M denote the carbon content of the marginal units of power produced in jurisdictions A and M respectively.

Proof. See appendix A.2. ■

Remark 5 *If the supply in jurisdiction M is almost inelastic (that is $\eta_M \simeq 0$), say, because this jurisdiction is under capacity, trade is likely to have a negative environmental impact.*

Remark 6 *If trade results in large environmental damages, it may even yield to a decrease in social welfare. Again, for more specific results on this, see Billette de Villemeur and Pineau (2010).*

3.4 Regime 3: Fully integrated markets

Assume now that A and M are fully integrated and that, in both jurisdictions, producers are price-takers and sell at marginal cost. Ignoring environmental costs, both A and M-markets are now “efficient”. Accounting for environmental damages, electric power is however underpriced in both jurisdictions.
Figures 1 and 2 illustrate two possible market outcomes under the mixed-market structure with trade (Regime 2) and under the "fully integrated" situation

(Regime 3). Recall that we assumed no restrictions in trade across jurisdiction. Since, in Regime 3, both jurisdictions price at marginal cost, they end up with a common price $p_A^3 = p_M^3$.

In Figure 1, the move from Regime 2 to Regime 3 leads to a decrease of X_t ($X_t^3 \leq X_t^2$), while in Figure 2 X_t increases. In both cases, p_A^3 increases. However, p_M^3 increases in the first case (Figure 1), while it decreases in the second case (Figure 2). These two cases are further discussed in Proposition 7.

Figure 1 here

Figure 2 here

3.4.1 Effects on prices and quantities

Assuming no restriction on trade across jurisdictions, equilibrium prices write simply as:

$$p_A^3 = p_M^3 = C_A' \left(X_A^{D3} + X_t \right) = C_M' \left(X_M^{D3} - X_t \right). \tag{11}$$

To compare with autarky, note that $X_t \geq 0$ means that $p_M^3 \leq p_M^1$, simply because marginal costs are increasing. The comparison between p_A^1 and p_A^3 is also straightforward. As $X_t \geq 0$, it must be the case that $p_A^3 \geq p_A^1$.
To see that, observe that

$$p_A^1 = \frac{C_A \left(X_A^1 \right)}{X_A^1} < C_A' \left(X_A^1 \right),$$

because the capacity of the A-monopolist is already used beyond its efficient point in autarky. Suppose $p_A^1 > p_A^3$ and $X_t \geq 0$ and look for a contradiction. From $p_A^1 > p_A^3$, it follows $X_A^{D1} < X_A^{D3}$ hence $C_A' \left(X_A^1 \right) < C_A' \left(X_A^{D3} + X_t \right)$ because $X_t \geq 0$. Since $p_A^1 < C_A' \left(X_A^1 \right)$, we finally get $p_A^1 < C_A' \left(X_A^{D3} + X_t \right) = p_A^3$, a contradiction. Thus, if jurisdiction A exports after a shift from autarky to fully integrated markets, it must be the case that $p_A^3 \geq p_A^1$. In words, consumers in jurisdiction A see a price increase.
To sum up, if $X_t \geq 0$,which we assumed,

$$p_A^1 \leq p_A^3 = p_M^3 \leq p_M^1.$$

It is however the comparison with the mixed-market structure that is the most interesting, as few markets directly move from autarky to a common marginal cost pricing structure. A very interesting proposition can indeed be proven for this latter type of market structure change:

Proposition 7 *When two jurisdictions A and M (respectively pricing at average cost and at marginal cost) move into a common market structure where all firms are price-takers (hence price at marginal costs),* total consumption *always decreases. There are two cases. Either the price increases in both jurisdictions, in which case* consumption *decreases in both jurisdictions; or the price decreases in M and increases in A in which case* production *decreases in both jurisdiction.*

Proof. See appendix A.3. ■

Remark 8 *Although total consumption decreases when shifting from a mixed structured market (where one jurisdiction is regulated while the other has a competitive market) to an integrated market where all firms are price-takers, consumption in Regime 3 nevertheless* exceeds *the socially optimal level. In fact, marginal pricing does not induce efficiency in presence of externalities.*

3.4.2 Environmental impact

As evidenced above, the shift toward an integrated market with price-taker firms in both jurisdictions may result in two different cases, as illustrated in Figures 1 and 2. Either the price increase experimented by the now deregulated jurisdiction A propagates to jurisdiction M (Figure 1), or jurisdiction M observes a price decrease, as a result of reduced consumption in A and a larger exported quantity X_t (Figure 2). For what regards environmental effects, we are able to prove:

Proposition 9 *When two jurisdictions A and M (respectively pricing at average cost and at marginal cost) move into a common market structure where all firms are price-takers (hence price at marginal costs), emissions always decrease* as long as *the carbon content of production in jurisdiction M is not strictly higher than the carbon content of jurisdiction A's production.*
Moreover, emissions decrease in both jurisdictions whenever the shift to a competitive market results in a price decrease in jurisdiction M. Formally, if $p_M^3 \leq p_M^2$, then

$$\begin{aligned} \Delta E_M &= E_M\left(X_M^{D3} - X_t^3\right) - E_M\left(X_M^{D2} - X_t^2\right) \leq 0, \\ \Delta E_A &= E_A\left(X_A^{D3} + X_t^3\right) - E_A\left(X_A^{D2} + X_t^2\right) \leq 0. \end{aligned}$$

Proof. See appendix A.4. ■

Remark 10 *Both prices p_M^3 and p_A^3 nevertheless remain strictly below their socially optimal values as they do* not *account for environmental damages.*

4 Conclusion

Although electricity market integration is promoted across the word, no formal analysis of its consequences in terms of prices and quantities was available so far in the literature. We provide results on these issues, with their environmental implications.

We propose a generic electricity market model involving two jurisdictions, and study these jurisdictions in three different institutional regimes. In the first regime, one jurisdiction is pricing at average production cost, while the other prices at marginal cost. No trade happens between them. In the second regime, trade is introduced. In the third regime, marginal cost pricing prevails in both jurisdictions.
We are able to show that a move from Regime 1 to Regime 2 leads to opposite

price and consumption change in the two jurisdictions, so that the overall effect on the combined consumption level depends on specific price elasticities in both jurisdictions. Obviously, the overall environmental impact is also ambiguous and depends on the marginal emission rates of both jurisdictions. More interestingly, we evidence that the asymmetry in pricing policies results in productive *in*efficiencies, the regulated monopolist having excessive incentives to export.
In a shift from Regime 2 to Regime 3 (marginal cost pricing in both jurisdictions), we show that total consumption always decreases, even if the price in the importing jurisdiction can either increase or decrease. This global consumption reduction always results in less emissions, unless the importing jurisdiction increases its production *and* this production has a higher carbon content than the exporting jurisdiction's production. This may happen if the exporting jurisdiction was trading large quantities in Regime 2, which becomes largely unprofitable after the shift to Regime 3, leading to a higher production in the importing jurisdiction.

The contribution of this paper is thus to provide clear evidence that electricity market integration generally calls for the adoption of marginal cost pricing in all jurisdictions. It also unveils the complex picture attached to such changes. Price movements are ambiguous for the importing jurisdiction and environmental impacts also depend on specific generation characteristics. Empirical studies are required to assess these impacts in more specific contexts. Global welfare impacts of electricity market integration depend on the level of the environmental damages involved in electricity generation and are not studied here. Further research avenues include deeper distributional analysis of regime changes and the study of transmission capacity, the impact of transmission costs on prices, profits and trade volumes.

References

[1] Anesi V. (2006) "Earmarked taxation and political competition", Journal of Public Economics, vol. 90, 679-701.

[2] Anesi V. and De Donder P. (2008) "Secondary Issues and Party Politics: An Application to Environmental Policy", No 6774, CEPR Discussion Papers.

[3] Aune F.R., Golombek R., Kittelsen S.A.C. and Rosendahl K.E. (2004) "Liberalizing the energy markets of Western Europe - a computable equilibrium model approach", Applied Economics, vol. 36, 2137–2149.

[4] Bates R. and Fraser N. (1974) Investment decisions in the nationalised fuel industries, London: Cambridge University Press.

[5] Benjamin R. (2007) "Principles for Interregional Transmission Expansion", The Electricity Journal, vol. 20 (8) 36-47.

[6] Bernard J.-T. and Chatel J. (1985) "The Application of Marginal Cost Pricing Principles to a Hydro-Electric System: The Case of Hydro-Quebec", Resources and Energy, vol. 7, 353-375.

[7] Billette de Villemeur, E. and Pineau, P-O. (2010) "Environmentally Damaging Electricity Trade", Energy Policy, vol. 38 (3) 1548-1558.

[8] Blumsack S. (2007) "Measuring the Costs and Benefits of Regional Electric Grid Integration," Energy Law Journal, vol. 28 (1) 147-184.

[9] Brusco S. and Hopenhayn H. (2007) "Deregulation with consensus", Economic Theory, vol. 32, 223-250.

[10] Bye T. and Holmøy E. (2010) "Removing Policy-based Comparative Advantage for Energy Intensive Production: Necessary Adjustments of the Real Exchange Rate and Industry Structure", The Energy Journal, vol. 31 (1) 177-198.

[11] Chen Y. (2009) "Does a regional greenhouse gas policy make sense? A case study of carbon leakage and emissions spillover", Energy Economics, vol. 31 (5) 667-675.

[12] Davidson C. Matusz S.J. and Nelson D.R. (2007) "Can compensation save free trade?", Journal of International Economics, vol. 71, 167-186.

[13] Dixit A. and Norman V. (1986) "Gains from Trade without Lump-Sum Compensation", Journal of International Economics, vol. 21, 111-122.

[14] EIA (2011) Electric Power Annual 2009 - State Data Tables, Washington D.C.: Energy Information Administration, Department of Energy.

[15] Finon D. (2008) Does electricity market integration benefit to consumers?, EU Energy Policy Blog, web page accessed February 10, 2009. http://www.energypolicyblog.com/?p=116

[16] Haaparanta P. (2004) Electrified Trade, Discussion Paper No. 5., Helsinki: Helsinki School of Economics and HECER.

[17] Hooper E. and Medvedev A. (2009) "Electrifying integration: Electricity production and the South East Europe regional energy market", Utilities Policy, vol. 17 (1) 24-33.

[18] ICF Consulting (2002) Economic Assessment of RTO Policy, prepared for the Federal Energy Regulatory Commission, Fairfax: ICF International.

[19] Joskow P.L. (2008a) "Lessons Learned From Electricity Market Liberalization", The Energy Journal, Special Issue. The Future of Electricity: Papers in Honor of David Newbery, vol. 29 (Special Issue #2) 9-42.

[20] Joskow P.L. (2008b) Challenges For Creating A Comprehensive National Electricity Policy, Working Paper, Technology Policy Institute.

[21] Kahn A.E. (1988) The Economics of Regulation - Principles and Institutions, Cambridge: MIT Press.

[22] Krapels E.N. and Flemming P. (2005) Impacts of the PJM RTO Expansion - A Report Prepared for PJM, Wakefield: Energy Security Analysis Inc. (ESAI)

[23] Meeus L. and Belmans R. (2008) " Electricity Market Integration in Europe," PSCC 2008, 16th Power Systems Computation Conference, Glasgow, Scotland, July 14-18, 2008.

[24] Müller-Jentsch D. (2005) Deeper Integration and Trade in Services in the Euro-Mediterranean Region - Southern Dimensions of the European Neighbourhood Policy, Washington, D.C.: International Bank for Reconstruction and Development / The World Bank.

[25] Newbery D.M. (2000) Privatization, Restructuring, and Regulation of Network utilities, Second Printing, Cambridge: The MIT Press.

[26] Pineau P.-O. (2008) "Electricity Sector Integration in West Africa", Energy Policy, vol. 36 (1) 210-223.

[27] Pineau P.-O. (2009) "An Integrated Canadian Electricity Market? The Potential for Further Integration", in Governing the Energy Challenge: Canada and Germany in a Multilevel Regional and Global Context, Eberlein B. and Doern B. (eds.), Toronto: University of Toronto Press.

[28] Pineau P.-O. and Lefebvre V. (2009) "The Value of Unused Interregional Transmission: Estimating the Opportunity Cost for Quebec (Canada)", International Journal of Energy Sector Management, vol. 3 (4) 406-423.

[29] Sauma E.E. and Oren S.S. (2009) "Do Generation Firms in Restructured Electricity Markets Have Incentives to Support Social-Welfare-Improving Transmission Investments?", Energy Economics, vol. 31 (5) 676-689.

[30] Stoft S. (2002) Power Systems Economics: Designing Markets for Electricity, Piscataway: IEEE Press and New York: Wiley-Interscience.

[31] UN (2006) Multi Dimensional Issues in International Electric Power Grid Interconnections, Department of Economic and Social Affairs, Division for Sustainable Development, New York: United Nations

[32] van den Hoven A. and Karl Froschauer (2004) "Limiting Regional Electricity Sector Integration and Market Reform : The Cases of France in the EU and Canada in the NAFTA Region", Comparative Political Studies, vol. 37 (9) 1079-1103

[33] von der Fehr N.-H. M. and Sandsbråten L. (1997) "Water on Fire: Gains from Electricity Trade", The Scandinavian Journal of Economics, vol. 99 (2) 281-29.

A Proofs

A.1 Proof of Proposition 3

Proposition 11 (3) *Provided that* $p_M > p_A$ *and* $p_A = \left[C_A\left(X_A^S\right)/X_A^S\right]$, *allowing trade between the two jurisdictions has the following impacts: price and production increase in A and decrease in M. Total supply increase with trade iff*

$$\frac{\varepsilon_M\left[1+\left(X_t/X_A^D\right)\right]}{\varepsilon_A\left[1-\left(X_t/X_M^D\right)\right]} > \eta_M\left(\frac{C_A'\left(X_A^S\right)-p_A}{p_A}\right),$$

where ε_A *and* ε_M *stand respectively for the (absolute value of the) price elasticity of demand in jurisdiction A and jurisdiction M,while* η_M *denote the price elasticity of supply in jurisdiction M.*

Proof. As already evidenced, by differentiating equation (4)(average cost pricing rule), it is possible to obtain an analytical expression for $\left(dX_A^S/dX_t\right)$, namely equation (5). The latter can be rewritten as

$$\frac{dX_A^S}{dX_t} = \frac{1+X_t/X_A^D}{1+X_t/X_A^D+\varepsilon_A\left(C_A'\left(X_A^S\right)-p_A\right)/p_A}, \tag{12}$$

where

$$\varepsilon_A = \frac{p_A}{X_A^D}\left(\frac{-dX_A^D}{dp_A}\right)$$

stands for the (absolute value of the) price elasticity of demand in jurisdiction A.

Similarly, by differentiating equation (9)(marginal cost pricing), we already obtained an analytical expression for $\left(dX_M^S/dX_t\right)$, namely equation (10). The latter can be rewritten as

$$\frac{dX_M^S}{dX_t} = \frac{-\left(1-X_t/X_M^D\right)}{1-X_t/X_M^D+\left(\varepsilon_M/\eta_M\right)}, \tag{13}$$

where

$$\varepsilon_M = \frac{p_M}{X_M^D}\left(\frac{-dX_M^D}{dp_M}\right) \qquad \textit{and} \qquad \eta_M = \frac{p_M}{X_M^S}\left(\frac{dX_M^S}{dp_M}\right)$$

stand respectively for the (absolute value of the) price elasticity of demand and the price elasticity of the supply in jurisdiction M.

Combining both (12) and (13) allows to establish that a marginal increase in trade result in an increased total supply if and only if

$$\frac{\varepsilon_M\left[1+\left(X_t/X_A^D\right)\right]}{\varepsilon_A\left[1-\left(X_t/X_M^D\right)\right]} > \eta_M\left(\frac{C_A'\left(X_A^S\right)-p_A}{p_A}\right).$$

■

A.2 Proof of Proposition 4

Proposition 12 (4) *Within a jurisdiction, emissions increase with exports and decrease with imports. Since when one jurisdiction is exporting, the other is importing, the overall environmental impact of trade is ambiguous. This ambiguity is present even if the low-emission jurisdiction is exporting.*

From an environmental point of view, trade has a threefold effect. We know that $X_t^2 \geq 0$, so that $p_M^2 \leq p_M^1$. First, this decrease in p_M induces a decrease in supply by M-producers. Formally, from the monotonicity of $C_M'(\cdot)$, we have $X_M^{S2} = X_M^{D2} - X_t^2 \leq X_M^1$. Thus, there is an environmental gain made upon M-generated emissions

$$\Delta E_M = E_M\left(X_M^{D2} - X_t^2\right) - E_M\left(X_M^1\right) \leq 0. \tag{14}$$

Second, this decrease in p_M also induces an increase in demand by M-consumers. Formally, $X_M^{D2} \geq X_M^1$. This increase is met by the quantity X_t^2 supplied by the A-producer. Third, as already mentioned, this increase in production by the A-monopolist leads in turn to an increase in p_A, since $C_A(X)/X$ is assumed to be increasing. Thus, the increase in A-production due to trade is mitigated by the decrease in demand by A-consumers. However, in any case, $X_A^{S2} = X_A^{D2} + X_t^2 \geq X_A^1$. Assume this is not the case and look for a contradiction. If the equilibrium A-production $X_A^{S2} = X_A^{D2} + X_t^2$ is strictly lower than X_A^1, the price p_A^2 is strictly smaller than p_A^1 because average costs are increasing. As a result of this decrease in price, A-consumption increases. Formally $X_A^{D2} \geq X_A^1$, which contradicts $X_A^{D2} + X_t^2 < X_A^1$. Thus $X_A^{S2} = X_A^{D2} + X_t^2 \geq X_A^1$ and the environmental impact in A increases with trade:

$$\Delta E_A = E_A\left(X_A^{D2} + X_t^2\right) - E_A\left(X_A^1\right) \geq 0. \tag{15}$$

Equations (14) and (15) make it clear that, even if marginal costs and marginal environmental impact are smaller in A (the exporting jurisdiction) than in M (the importing jurisdiction), the introduction of trade may not be welfare enhancing. This would be case if the introduction of trade were mostly increasing export from A while barely reducing production in M. Expressions (12) and (13) make it clear that this follows in particular from having an inelastic supply in jurisdiction M.

More precisely, let K_A and K_M denote the carbon content of a marginal electricity unit as produced in jurisdiction A and jurisdiction M respectively. Expressions (12) and (13) allow to compute the carbon impact of an additional traded electricity unit X_t. Straightforward calculations allow to evidence that trade is environmentally adverse whenever

$$\frac{\varepsilon_M}{K_M\left(1 - X_t/X_M^D\right)}\frac{1}{\eta_M} - \frac{\varepsilon_A}{K_A\left(1 + X_t/X_A^D\right)}\left(\frac{C_A'\left(X_A^S\right) - p_A}{p_A}\right) > \frac{K_M - K_A}{K_A K_M}\left(1 - X_t/X_M^D\right)\left(1 + X_t/X_A^D\right).$$

A.3 Proof of Proposition 7

Proposition 13 (7) *When two jurisdictions A and M (respectively pricing at average cost and at marginal cost) move into a common market structure where all firms are price-takers (hence price at marginal costs),* total consumption *always decreases. There are two cases. Either the price increases in both jurisdictions, in which case* consumption *decreases in both jurisdictions; or the price decrease in M and increase in A in which case* production *decreases in both jurisdiction.*

We know from our assumptions that $p_A^2 < p_M^2$ and $X_t^2 \geq 0$. Absent constraints on trade (*i.e.* provided the capacity constraints are not binding), there are theoretically three possible cases, depending upon whether the (common) price $p_A^3 = p_M^3$ is smaller than p_A^2, larger than p_M^2, or in-between the prices p_A^2 and p_M^2.

It is easy to exclude the first case. In fact, $p_M^3 < p_M^2$ implies $X_M^{S3} < X_M^{S2}$ and $X_M^{D3} > X_M^{D2}$, or equivalently, $X_M^{S3} + X_t^3 > X_M^{S2} + X_t^2$. This implies in turn that $X_t^3 - X_t^2 > X_M^{S2} - X_M^{S3} > 0$. Similarly, $p_A^3 \leq p_A^2$ implies $X_A^{D3} \geq X_A^{D2}$. Thus $X_A^{S3} = X_A^{D3} + X_t^3 > X_A^{D2} + X_t^2 = X_A^{S2}$. Production increases in jurisdiction A. It follows that $p_A^3 = C'_A\left(X_A^{S3}\right) \geq C'_A\left(X_A^{S2}\right) > C_A\left(X_A^{S2}\right)/X_A^{S2} = p_A^2$, a contradiction.

Consider now the second case, that is, assume that

$$p_A^3 = p_M^3 \geq p_M^2.$$

From $p_M^3 \geq p_M^2$, it follows that $X_M^{S3} \geq X_M^{S2}$: production increases in jurisdiction M. We also know that $X_M^{D3} \leq X_M^{D2}$ which implies in turn that $X_t^3 \leq X_t^2$. From $p_A^3 > p_A^2$ we have $X_A^{D3} < X_A^{D2}$. As a result $X_A^{S3} = X_A^{D3} + X_t^3 < X_A^{D2} + X_t^2 = X_A^{S2}$. Production decreases in jurisdiction A. However, since both $p_A^3 \geq p_A^2$ and $p_M^3 \geq p_M^2$ consumption decreases in both jurisdiction.

Consider now the third case

$$p_A^2 < p_A^3 = p_M^3 < p_M^2.$$

From $p_M^3 < p_M^2$, it follows that $X_M^{S3} < X_M^{S2}$: production decreases in jurisdiction M. Suppose that, by contrast, production increases in jurisdiction A and look for a contradiction. From (8), we know that $C'_A\left(X_A^{S2}\right) > C'_M\left(X_M^{S2}\right)$. Thus $X_A^{S3} > X_A^{S2}$ would imply that $C'_M\left(X_M^{S3}\right) = C'_A\left(X_A^{S3}\right) > C'_A\left(X_A^{S2}\right) > C'_M\left(X_M^{S2}\right)$, contradicting $X_M^{S3} < X_M^{S2}$. It follows that production decreases in both jurisdiction, despite consumption increases in jurisdiction M.

It is plain that in both cases, total consumption is always decreasing.

A.4 Proof of Proposition 9

Proposition 14 *When two jurisdictions A and M (respectively pricing at average cost and at marginal cost) move into a common market structure where all firms are price-takers (hence price at marginal costs), emissions always decrease* as long as *the carbon content of production in jurisdiction M is not*

strictly higher than the carbon content of jurisdiction A's production.
Moreover, emissions decrease in both jurisdictions whenever the shift to a competitive market result in a price decrease in jurisdiction M. Formally, if $p_M^3 \leq p_M^2$*, then*

$$\begin{aligned} \Delta E_M &= E_M\left(X_M^{D3} - X_t^3\right) - E_M\left(X_M^{D2} - X_t^2\right) \leq 0, \\ \Delta E_A &= E_A\left(X_A^{D3} + X_t^3\right) - E_A\left(X_A^{D2} + X_t^2\right) \leq 0. \end{aligned}$$

As shown in Proposition **7,** the price in jurisdiction M may either increase or decrease as a result to a shift to an integrated competitive market. If the price increases, that is $p_M^3 > p_M^2$, then production increases in jurisdiction M. As long as the production in the latter jurisdiction is not polluting strictly more than that of jurisdiction A, emissions decreases as total consumption decreases and the production mix has a lower or equal carbon content.
If instead price decreases, that is $p_M^3 < p_M^2$, then production has been shown to decrease in both jurisdictions. It is plain that the resulting emissions also decrease.

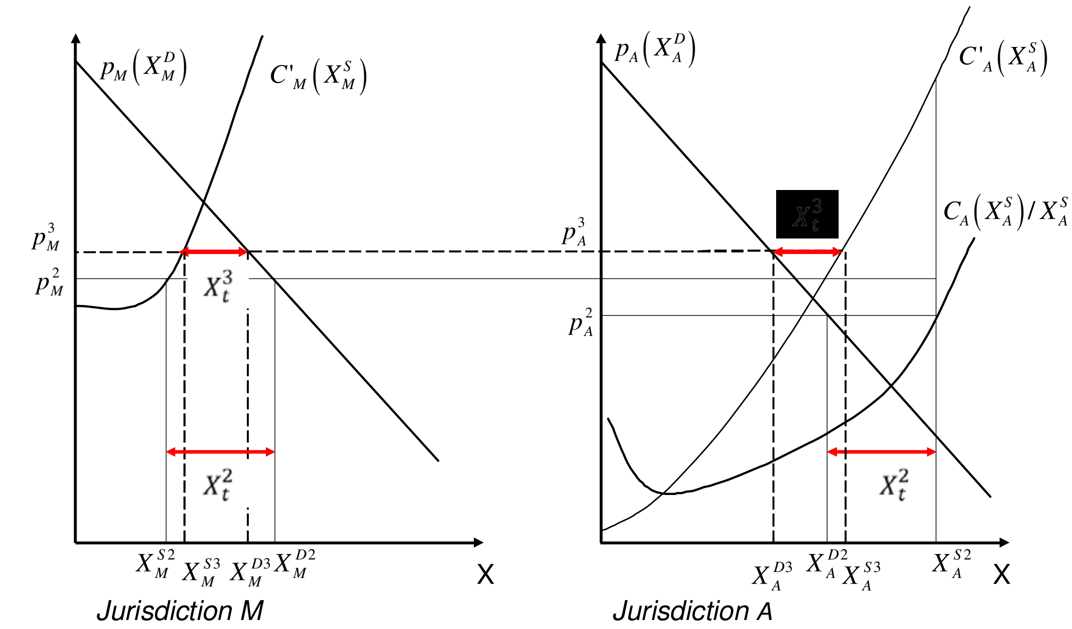

Figure 1: Case 1 - Price after full integration is above the price that prevailed in both jurisdictions, when A was regulated

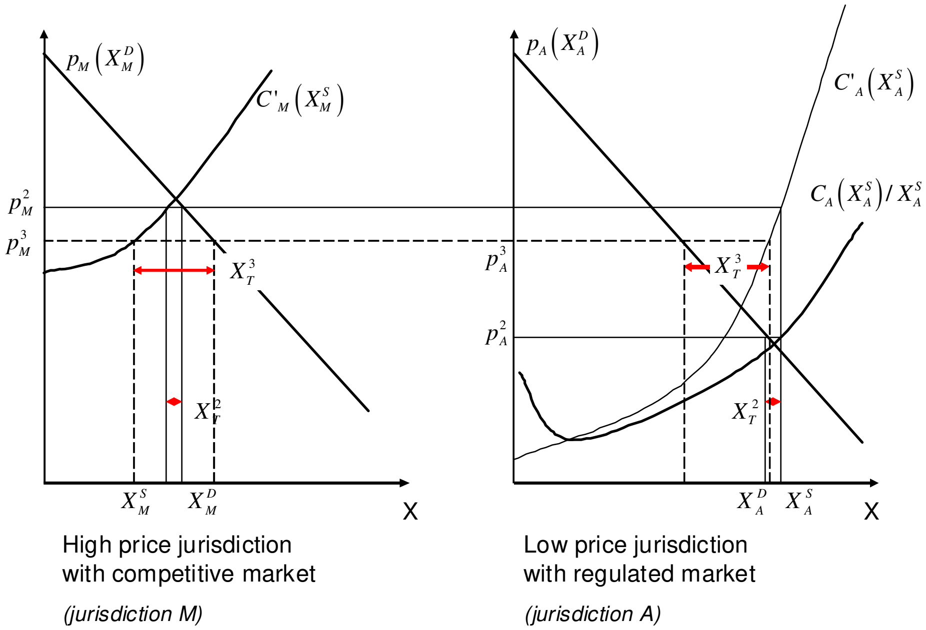

Figure 2: Case 2 - Price after full integration is in-between the two prevailing prices when jurisdiction A was regulated.