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An Anticompetitive Effect of Eliminating Transport Barriers in Network Markets

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Abstract This paper examines the welfare effects of physically interconnecting two (network) markets that were previously separated. In each market a different set of capacity-constrained firms operate. Firms engage in a supergame and collude whenever it is rational for them to do so. We find that, under certain parametric restrictions, interconnection of the two markets reduces total welfare. The collusive horizon may extend from a single market to the overall integrated market. In such case, interconnection can be viewed as "exporting" collusion, rather than competition.

Keywords Capacity constraints · Collusion · Market interconnection

JEL Classification L11 · L40 · F15

1 Introduction

A strong inclination towards market integration and physical interconnection has characterized the European Union policy in the last twenty years at least. It is supported by a number of studies, both in industrial organization and in international trade, that recognize market integration and interoperability as a source of welfare (see, e.g., Krugman and Obstfeld 2004; Markusen 1981).

These theoretical works stress the benefits of integration, in terms of higher productive efficiency—through exploitation of economies of scale—and lower prices due to

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greater competition (see, for instance, Emerson et al. 1988). However, on the empirical side, the issue is much less clear, and the evidence on the actual welfare effects of physical interconnection, which we will describe in greater details in the next section, is ambiguous.

Our paper finds conditions under which openness and physical interconnection, contrary to the conventional view, facilitate collusion and reduce welfare.[1] In building our framework, we target network markets, and, in particular, electricity; the insights of the models may, however, naturally be applied to other sectors as well.

Our results depend on two crucial assumptions: First, the productive capacity of competing firms is limited. Second, firms collude whenever it is rational for them to do so. Both assumptions fit utilities markets, and, specifically, electricity. Generators' capacity in electricity is generally bounded; furthermore, transactions in electricity generation are often centralized in spot markets, where firms interact frequently, and information on firm's strategic variables is easily available. These features hint at the prospect of a market with a high collusive potential.

Under these circumstances, improved physical interconnection may bring about not only greater competition, but greater collusion as well. The core of the argument is the following: Without integration, one market may be characterised by a collusive (monopoly) price, while in the other one, capacity may be so large that such an outcome is impossible. However, when the markets are interconnected, the "excess" capacity in the second market may be diverted to the first one. Monopoly price might thus prevail in the integrated market, so that monopoly would be "exported" from the first market to the second one. When each firm's individual capacity is smaller than aggregate output at the prevailing collusive market price, each firm's deviation profit from the collusive agreement[2] is limited by the capacity constraint. As a consequence, in addition to the discount factor, it is the relation between *aggregate capacity* and the market size, and not the number of firms alone (as we have in the standard setting, without capacity constraints), that determines whether or not the monopoly outcome can emerge as an equilibrium of the collusive game.

1.1 Motivating evidence and literature review

The available evidence on the effects of interconnection is mixed, as documented by a recent report by the UK Department of Trade and Industry (DTI 2007) on European countries. In many episodes, the actual outcome of market opening has been disappointing. In the early stages of market integration in electricity generation in Italy (April 2004–January 2005), for instance, wholesale prices were liberalised, and the market was opened in the hope of importing competition from abroad. On the contrary, prices in neighbouring countries (namely, France) rose, and converged upward to the Italian level, in a situation where fuel prices were possibly relevant in Italy, but not so much in France (where nuclear power generation is paramount). The Italian electric-

[1] Observe that the possibility that trade reduces welfare in one of the countries involved is well known in the literature (see, e.g., a standard textbook such as Krugman and Obstfeld 2004). However, our result is that the aggregate welfare effect in the two countries is negative.

[2] Deviation occurs through undercutting the rivals.

ity generation market has often been suspected of a collusive structure, and several investigations opened by the national antitrust authority[3] reflect these concerns. The French system operates on similar bases. Before interconnection, France had a larger excess capacity than Italy, and thus sellers were unable to enforce a monopolistic collusion; after integration, the French capacity has been partly diverted to the Italian market, thereby reducing its excess capacity, and allowing French firms to increase the equilibrium price. An hypothesis is that the Italian collusion has been "exported" to the French market as well, through a mechanism possibly similar to the one illustrated in our paper.

Our result is somewhat related to the multimarket contact argument illustrated by Bernheim and Whinston (1990) (BW henceafter). They analyze a situation where the same firms are allowed to operate in various markets, which, in spite of remaining physically separated, have a (partly) common supply side.[4] BW find that multimarket contacts may make collusion easier to sustain, thereby lowering welfare.

Although similar in spirit (both their paper and ours identify channels through which collusion may be transferred across markets), the two papers differ in two main respects. First, the type of channel that is employed to spread collusion: capacity constraints in our paper, differences in the discount factor and in the number of firms across markets in theirs.[5] Second, BW find that multimarket contacts weakly increase the scope for collusion; our paper, on the contrary, shows that, depending to the parameter values, collusion may be favored or hampered by interconnection.

Our paper relates also to a wide literature on collusion and capacity constraints (in a *single* market). Brock and Scheinkman (1985) (BS henceafter) point out the role of aggregate capacity in determining the threat after a deviation. Given individual capacity levels, when aggregate capacity (the number of firms) is sufficiently low, and some firms are essential for producing the competitive outcome, Bertrand equilibrium involves positive profits (see Kreps and Scheinkman 1983). In such situations, the threat posed by deviating from collusion becomes less effective, making collusion harder to achieve. As capacity increases and hits the point at which no firm is essential

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[3] See, e.g., the provision A366 (April 2005) of the Italian antitrust authority on the electricity exchange or I530 on the relationships between Enel and Endesa Italia.

[4] For a review of the literature on multimarket contacts and their adverse welfare effects, see Van Wegberg et al. (1994).

[5] The industrial organization literature has identified a further alternative channel (with respect both to that proposed in our paper and to BW's) through which physical interconnection is conducive to welfare reduction, related to price discrimination. Indeed, third degree price discrimination is feasible in a two-market environment, while it is not in an integrated market framework, where a no-arbitrage condition ensures the prevalence of a uniform price. The welfare effect of third-degree price discrimination is ambiguous. In particular, under monopoly, discrimination may be welfare-enhancing, when it leads to an increase in output sufficient to offset the drawbacks due to unequal marginal utilities - see Varian (1989) for a survey of price discrimination with monopoly. Under linear demand, a condition for price discrimination to improve welfare is that without price discrimination one of the two markets would not be served; that is, the willingness to pay across the two markets is so different that, with a uniform price after interconnection, only consumers of the market with the higher willingness to pay are served. Conditions of welfare reduction related to third degree price discrimination appear particularly restrictive, and do not seem to fit any of the utilities markets.

to produce the competitive output, Bertrand equilibrium involves zero profit, while the output produced immediately after deviation is bounded by capacity.

For these reasons, BS find that, for a fixed capacity per firm, changes in the number of firms have a non-monotone effect on the best enforceable cartel price. Our paper extensively applies BS's insights to the market integration context.

The subsequent literature includes many variations of their framework of collusion under capacity constraints. Davidson and Deneckere (1990) and Penard (1997) endogenize firms' capacity choices. Lambson (1987) examines optimal punishment paths. Staiger and Wolak (1992) and Fabra (2006) illustrate the impact of demand fluctuations. Finally, an extensive literature (see, e.g., Barla 2000 and Compte et al. 2002) explicitly analyze asymmetric capacity.

The paper is organized as follows: The next section provides a motivating example that illustrates the contribution of our paper. Sect. 3 illustrates the basic model and derives equilibrium prices with separated markets. Sect. 4 derives the equilibrium prices for integrated markets and the consequent welfare comparison for the integrated and unintegrated cases. The final section contains some concluding remarks.

2 A numerical example

Consider two separate countries, each with the same linear demand function $p_r = a - Q_r$, where Q_r is the aggregate quantity and p_r is the price in market r. All firms have zero marginal cost and can produce up to capacity $k = \frac{a}{3}$.

Firms operate with an infinite time horizon and discount future profits at a factor $\delta = \frac{3}{4}$, common to all firms.

In the first country, four identical firms operate. These firms may form a cartel, and, by assumption, select the "best" (i.e., the one maximizing aggregate profit) equilibrium pair (price and quantity) in a supergame supported by a Bertrand-Nash reversion trigger strategy.

The individual rationality (henceafter, IR) constraint, when firm i is capacity constrained (and the collusive output exceeds individual capacity k), requires the profit from a small ($\varepsilon \to 0$) deviation from the cartel price[6] $\mathrm{p^c}$ to be smaller than the profit from remaining in the cartel and producing q^i. It differs from the IR constraint of a collusive supergame in which firms have unlimited capacity, in that capacity constraints here bind the deviation output, thereby limiting the deviation profit (at a level of $p^c k$). This suggests that collusion may be easier to sustain when firms are capacity constrained (see Brock and Scheinkman 1985).

Formally, the sustainability of the cartel requires the following individual rationality (IR) constraint to hold for each of the four firms:

$$\frac{p^c q^i(p^c)}{1-\delta} \geq kp^c \Longrightarrow \frac{q^i(p^c)}{1-\delta} \geq k = \frac{a}{3} \qquad (1)$$

[6] Notice that the capacity of the firms is such that none of the firms is essential to produce the competitive output. Hence, the static Bertrand equilibrium prescribes zero profit, as will be explained in greater detail later.

$$q^i \geq (1-\delta)\,\frac{a}{3} = \frac{a}{12} \tag{2}$$

Therefore, a firm will find it optimal to remain within the cartel only if its production is not lower than $\frac{a}{12}$.

Therefore, the minimum *aggregate* sustainable output in the first country, $\frac{a}{3}$, is lower than the monopoly output $\frac{a}{2}$. Hence, the monopoly outcome can be sustained as an equilibrium of the collusive supergame, and will indeed be sustained, being the "best" (in the sense of aggregate profit maximizing) equilibrium.[7]

In the second country, 7 identical firms operate. The IR constraint for each *individual* firm is (2) - the same as in the first country. However, as the number of firms in the two markets differ, the minimum aggregate sustainable output in the second market is $(1-\delta)\,\frac{7}{3}a = \frac{7}{12}a$ - higher than the monopoly output $\frac{a}{2}$ and lower than the competitive output a. Therefore, in the second country, the monopoly outcome is not an equilibrium of the game. The minimum aggregate sustainable output is in this case also the supergame equilibrium output that maximizes aggregate profit, on which firms coordinate. It follows that the optimal collusive output in the second country exceeds the monopoly output, and the equilibrium price in this country is lower than monopoly price.

Suppose now that, in order to strengthen competition, the two countries decide to remove all of the barriers that separate the two markets. They then create an integrated market. The new aggregate demand function is thus: $Q = 2\,(a-p)$. The 11 firms face an infinite horizon and collude whenever rational. The individual rationality constraint for the sustainability of the eleven-firm cartel is again given by (2).

The minimum aggregate sustainable output *in the integrated market* is then $(1-\delta)\,\frac{11a}{3} = \frac{11}{12}a$, which is lower than the monopoly output a.

Therefore, in the interconnected market the monopoly output, and hence the monopoly price $p^{mon} = \frac{a}{2}$, can be sustained.

The creation of an integrated market - far from bringing about more competition - has "exported" the monopoly outcome from the first market into the second one. Loosely speaking, the reason is that from the viewpoint of the country where seven firms operate, the increase in market size due to integration is more important than the increase in total capacity due to the additional firms, which are located abroad, but which can now sell at home. The seven firms located in the second market are now (i.e., after integration) able to divert part of their capacity to serve the first market, where the monopoly price prevails. As a result, the decrease in the capacity utilized to serve the second market allows them to sustain a monopoly outcome there. At the same time, the first market (where only four firms are located) is able to absorb the extra capacity, while preserving the monopoly outcome. Indeed, the new capacity available for the first market (resulting from the sum of the capacity of the four firms and the portion of capacity originated from the second market) is still lower than the threshold below which the monopoly outcome may emerge as a supergame equilibrium.

[7] Notice that - as proved by Brock and Scheinkman (1985) - with capacity constraints the collusive price depends on capacity.
Also, observe that any other equilibrium price/output pair would not be "better" than the monopoly outcome, as it would yield a lower aggregate profit.

How general is this result? Is it pathological, or should it raise a genuine concern in markets - such as electricity generation or railway transport - where capacity constraints are often binding in the equilibrium? We will show in the next sections conditions under which this result may be obtained. This helps us understand how the interplay of market size, number of firms, and capacity levels can determine this outcome.

3 The model

A good is produced in two markets (e.g., two regions), labeled A and B. In region r a given number of firms $N_r \geq 2$ operates (with $N_A + N_B = N$). The demand curve for region $r = A, B$ is $Q_r = Q_r(p_r)$. It is constant across different time periods, and it is decreasing, continuous, and differentiable. Its inverse is $p_r = p_r(Q_r)$. Assume the maximal willingness to pay is the same in both markets (i.e., $p_A(0) = p_B(0)$).[8] If the good can be freely traded between the two markets (i.e., if they are perfectly physically interconnected), in each period the market price is p_{ic} and total demand ($Q_{ic} = Q_A + Q_B$) is $Q(p_{ic})$. Its inverse is given by: $(Q_A + Q_B)^{-1}(p_{ic})$.

Also, assume for simplicity that the demand functions are such that[9] $Q_{ic}^{mon} \leq Q_A^{mon} + Q_B^{mon}$. This assumption clearly holds, under the assumed common reservation price, for linear demand functions (for which $Q_{ic}^{mon} = Q_A^{mon} + Q_B^{mon}$), and for a variety of other specifications as well.[10] Considering this assumption allows us to rule out situations in which interconnection may increase welfare simply because the monopoly output absent price discrimination (i.e., with interconnection) is above the sum of the optimal (monopoly) quantities under price discrimination (i.e., under two separate markets).[11]

Firms are capacity constrained. All firms have the same capacity k. The assumption of symmetric capacity across all firms was adopted for ease of exposition (see Sect. 5 for a more detailed discussion of how asymmetries would modify the results). The main result of the paper obtains even dispensing with that assumption (see Boffa 2006). More importantly, symmetric capacity implies that capacity is exogenous in our model.

This assumption stems from two features of the recently liberalized utilities industry. First, at the beginning of the liberalization process, capacity was generally distributed to the various market players after a divestiture processes by the incumbent. Hence, the endowment of capacity was not the result of previous choices of capacity accumulation. Second, increasing capacity is a lengthy and costly venture due to the interplay of many factors, including environmental concerns and the necessary compatibility of the extra capacity with the existing transmission system (the issue becomes particu-

[8] This assumption ensures continuity and differentiability of the demand function in the interconnected market as well.

[9] Notice that this assumption refers to the output levels that *would emerge* in the two markets under monopoly prices, and not to equilibrium outputs.

[10] For an extensive analysis of this, see Shih et al. (1988).

[11] Observe that $Q_{ic}^{mon} \leq Q_A^{mon} + Q_B^{mon}$ is a sufficient, yet not necessary, condition, for our main result (i.e., that interconnection reduces welfare) to hold.

larly critical after liberalization, when the decisions on generation and on transmission capacity are taken separately).

Firm i produces output q^i at a constant marginal cost c up to capacity k and cannot produce beyond it:

$$C\left(q^i\right) = \begin{cases} cq^i \ if \ q^i \leq k \\ \infty \ if \ q^i > k \end{cases}$$

Competition takes place in prices over an infinite number of periods. If in any period rationing occurs, it follows the efficient rationing rule, proposed by Levitan and Shubik (1972). For ease of exposition, we assume throughout the paper that no firm is essential for producing the market-wide competitive output both in A and in B. That is,

$$(N_r - 1)\, k > Q_r\,(c) \tag{3}$$

This assumption, identified as the "non-essentiality condition", or NEC, ensures that no firm is essential for producing the competitive quantity. This is necessary for the Bertrand equilibrium price in the static game p^b to be set at $p^b = c$. Hence, under (3), Bertrand profit, and as a consequence the deviation profit, is null. This greatly simplifies computations and in no way determines the qualitative nature of our result (for a version of the paper where NEC assumption is relaxed, see Boffa 2006).

We compare two different scenarios. In the first one, markets are separated, while in the second one A and B are interconnected into a single market. In each market (indices omitted), the flow of profit of each firm i starting at a given t_0 depends on a demand function $Q_r\,(p_r)$, a constant marginal cost c, and the vector of prices of all future periods.

Firms adopt a standard Bertrand-Nash reversion trigger strategy. At each t, the price named by a firm i, $p^{i,t}$, equals the collusive price p^c if all firms operating in that market named at $t-1$ a price $p^{i,t-1}$ equal to the collusive price (this implies as well that market price p_r^{t-1} equals the collusive price p^c). Otherwise, if, for some i, $p^{i,t-1} < p^c$ (i.e., if any firms defected at time $t-1$ by undercutting the collusive price), every firm i will charge the static Bertrand equilibrium price at time t (and the static Bertrand will be the prevailing price at time t). Hence, $p^{i,t} = p_r^t = p^b = c$, which obviously represents a credible punishment.

3.1 Equilibrium analysis: separated markets

We focus on characterizing equilibria in an oligopoly supergame when markets are separate and firms are capacity constrained. Capacity constraints may generate two effects. First, they limit the profit achievable by each firm in the collusive agreement (however, this is not the case in our framework). Second, they make deviation from the collusive agreement less attractive, as a deviating firm cannot serve the whole market (this aspect is relevant to our analysis). As a consequence, they widen the set of discount factors for which a cartel is sustainable.

Moreover, unlike the case of collusion with unlimited capacity, when firms are relatively small, the feasibility of collusion depends on the collusive price on which firms coordinate. Hence, as shown by Brock and Scheinkman (1985), under capacity constraints, it may well happen that collusion at the monopoly price p^{mon} is not feasible, while a cartel coordinating at a lower price $c < p^c < p^{mon}$, an intermediate price between the competitive and the monopoly ones, is. To see this, consider that for p^c to be an equilibrium price, the following has to hold:

$$\frac{q^i\left(p^c\right)\left(p^c-c\right)}{1-\delta} \geq \left(p^c-c\right)\min\left(k, Q\left(p^c\right)\right) \tag{4}$$

where the optimal deviation price is arbitrarily close to the collusive price (we omitted the subscript r for notational simplicity). Suppose that $p^c \leq p^{mon}$ and that the collusive price is such that $k < Q(p^c)$. In this case, the optimal deviation output[12] will be $q^i = k$, and (4) can be written as

$$\frac{q^i\left(p^c\right)}{1-\delta} \geq k \tag{5}$$

The IR constraint for sustainability of collusion depends on p^c. It holds more easily when p^c is low and thus $q^i\left(p^c\right)$ is large.

We can now characterize the equilibrium price in the oligopoly supergame in market r, denoted by p_r^c, in the following:

Proposition 1 *Under (3), the aggregate profit maximizing equilibrium price of the supergame in market r for all t is:*

$$p_r^c = \begin{cases} p_r^{mon} & if \;\; N_r \leq \dfrac{\max\left(\frac{Q_r\left(p_r^{mon}\right)}{k}, 1\right)}{(1-\delta)} \\ p_r\left(N_r k\left(1-\delta\right)\right) \in \left(c, p_r^{mon}\right) & if \;\; \dfrac{\max\left(\frac{Q_r\left(p_r^{mon}\right)}{k}, 1\right)}{(1-\delta)} \leq N_r \leq \dfrac{\max\left(\frac{Q_r(c)}{k}, 1\right)}{(1-\delta)k} \\ c & if \;\; N_r \geq \dfrac{\max\left(\frac{Q_r(c)}{k}, 1\right)}{(1-\delta)k} \end{cases} \tag{6}$$

See the Appendix for the proof.

Some comments are in order. Starting from the bottom of (6), as usual a very high number of firms (relative to the discount factor) leads to a supergame equilibrium which is a mere repetition of static Bertrand outcomes.

As the number of competitors decreases, output decreases and equilibrium price increases until the monopoly level is reached. Firms will find it easier to sustain a *monopolistic* cartel when the following holds:

- when capacity constraints do not matter, and the number of firms is sufficiently small, in that each individual firm is able to supply the monopoly output (as in the standard case of collusion);

[12] Notice that in this case we will have rationing, with k^i units sold at $p^c - \epsilon$ and others sold at p^c. This argument, which focuses on the incentive of firm i, does not depend on the rationing rule.

- when capacity constraints matter, in that they do not allow any individual firm to supply the monopolistic output, and aggregate capacity is sufficiently low.

Moreover, collusion arises at an *intermediate price* (between monopoly and competition) if and only if the three following conditions hold simultaneously:

- firms are relatively numerous (so that, were they to have unlimited capacity, they would not be able to sustain a cartel);
- capacity constraints are such that each individual firm cannot produce the competitive outcome (this condition is represented by $k < Q_r(c)$, which holds in (6)), when $p^{mon} > p^c > c$; [13]
- aggregate capacity is above discounted monopoly, but below the discounted competition level (otherwise, they would find it rational to produce the Bertrand output).

4 Integration and welfare reduction

Having discussed the equilibrium in an isolated market, we now turn to consider the effects of integrating the two markets. Our goal consists in showing that interconnection may, for certain values of the parameters, reduce welfare.

We begin by characterizing the outcome of the dynamic game when the two markets are integrated. In this case, we only have one price, p_{ic}.

Under our usual assumption that condition (3) holds in both markets, the collusive price in the supergame played by N firms in the interconnected market is the following:[14]

$$p_{ic}^{c} = \begin{cases} p_{ic}^{mon} & if \;\; N \leq \dfrac{\max\left(\frac{(Q_A+Q_B)\left(p_{ic}^{mon}\right)}{k},1\right)}{(1-\delta)} \\ p\left(Nk\left(1-\delta\right)\right) & if \;\; \dfrac{\max\left(\frac{(Q_A+Q_B)\left(p_{ic}^{mon}\right)}{k},1\right)}{(1-\delta)} < N \leq \dfrac{\max\left(\frac{(Q_A+Q_B)(c)}{k},1\right)}{(1-\delta)k} \\ c & if \;\; N > \dfrac{\max\left(\frac{(Q_A+Q_B)(c)}{k},1\right)}{(1-\delta)} \end{cases} \tag{7}$$

As for the relationship between integrated (collusive) price and the (collusive) prices in the separated markets, we obtain the following result.

Proposition 2 *If the NEC condition* (3) *holds,* $p_{ic}^{c} \leq \max\left(p_A^c, p_B^c\right)$*, i.e., the price in the interconnected market has to be lower or equal to the higher of the prices in the two nodes.*

The proof is reported in the Appendix.

The Proposition shows that the price cannot strictly increase in both markets. However, this does not exclude the event that the price increases in one market, while remaining constant in the other one. We explore this occurrence in the next section.

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[13] If this condition did not hold, we would revert back to the standard case of no capacity constraints.

[14] The proof of this statement would be a trivial replica of the proof of Proposition 1 and is thus omitted.

Total surplus in market r is TS_r, the sum of consumer surplus CS_r and aggregate profit Π_r. Hence, total surplus is: $TS_r = \int_{v=0}^{Q_r} p_r(v)\,dv - cQ_r(p_r)$.

The computation of total surplus in market B is analogous. In the interconnected market: $TS_{ic} = \int_{v=0}^{Q_{ic}} p_{ic}(v)\,dv - cQ_{ic}(p_{ic})$.

Interconnection lowers total welfare if and only if:

$$TS_A + TS_B > TS_{ic}$$

We now investigate a sufficient condition under which this may happen.

Remark 3 As long as $p_A \neq p_B$, a sufficient condition for $TS_{ic} < TS_A + TS_B$ is that $p_{ic} \geq \max(p_B, p_A)$

Under this condition welfare is not increased in *either* market. Obviously, given Proposition 2, the only relevant case is the one where $p_{ic} = \max(p_B, p_A)$. However, could such a price be the outcome of integration?

In what follows, we provide sufficient conditions under which interconnection increases the price in one market, while leaves it unaltered in the other one. Export of collusion results from the interplay between collusive output and aggregate capacity. If the relationship were linear, collusive output in the integrated market would simply equal the sum of the collusive outputs in the non-integrated markets, and the price would be an average. However, the non-linearity broadens the set of possible outcomes, and makes it possible that price in the interconnected market equals the higher of the two prices.

Exporting collusion The ability to collude mainly depends on **two** countervailing factors. First, it depends on the number of firms, which increases with interconnection. This makes collusion harder in the interconnected market (pro-competitive effect), and tends to raise welfare.

Second, it depends on the relationship between aggregate capacity and the size of the market both with separation and with integration. Aggregate capacity determines the minimum output (i.e., the maximum price) that can be sustained in the collusive agreement, when the capacity constraint does not allow any single firm to produce by itself the monopoly output (possibly anti-competitive effect).

The reason why this happens may be better understood by the example provided in Sect. 2. Intuitively, collusion is being exported from the market with the smallest number of firms to the integrated market. The following proposition characterizes a set of sufficient conditions under which collusion is exported.

Proposition 4 *Suppose $p_A^c = p_A^{mon}$ and $p_B^c < p_B^{mon}$. A sufficient condition for interconnection to reduce overall welfare is*:

$$N \in \left(\frac{Q_A(c) + Q_B(c) + k}{k}; \frac{\max\left(\frac{(Q_A+Q_B)(p_{ic}^{mon})}{k}, 1\right)}{(1-\delta)} \right) \tag{8}$$

and there are always parameters configurations, such that this interval is not empty.

Proof For $p_A^c = p_A^{mon}$ we must have $\frac{Q_A(c)+k}{k} \leq N_A \leq \frac{\max\left(\frac{Q_A\left(p_A^{mon}\right)}{k},1\right)}{(1-\delta)}$, while for p_B^c to be lower than monopoly price p_B^{mon} we must have $N_B > \frac{\max\left(\frac{Q_B\left(p_B^{mon}\right)}{k},1\right)}{(1-\delta)}$. If (8) holds, then $p_{ic}^c = p_{ic}^{mon}$, which by the previous Remark implies that interconnection has reduced welfare. The only thing to prove is that the set of parameters for which these prices are equilibrium prices is non-empty.

Assume $k < \min\left(Q_A\left(p_A^{mon}\right), Q_B\left(p_B^{mon}\right)\right)$. It has to be $\frac{Q_A(c)+k}{k} \leq N_A \leq \frac{Q_A\left(p_A^{mon}\right)}{k(1-\delta)}$ and $\frac{Q_B\left(p_B^{mon}\right)}{k(1-\delta)} < N_B < \frac{Q_B(c)}{k(1-\delta)}$. For there to be a set of values for which (8) holds true, one needs

$$\frac{Q\left(c\right)+k}{k} \leq \frac{Q_A\left(p_A^{mon}\right)}{k\left(1-\delta\right)}$$

which becomes

$$k \leq \frac{Q_A\left(p_A^{mon}\right)}{\left(1-\delta\right)} - Q\left(c\right)$$

which certainly holds for $p_A^c = p_A^{mon}$ to be true. Q.E.D. □

The implication of this result is that there is always a non empty set of parameters, such that if two markets are interconnected, firms may end up coordinating on the higher of the two previous prices. In this way, the high price country exports (very effective) collusion into the country where collusion was relatively less damaging.[15]

To provide an intuition for this result, notice that the outcome of the game depends on the relationship between aggregate capacity and market size.[16] In this environment, there may exist situations in which the two isolated markets sustain different outcomes. In market A aggregate capacity is smaller, and as a result monopoly pricing emerges. Notice that it may be the case that a small increase in the number of firms operating in market A does not affect this outcome: in other words, even with (a little) extra capacity, monopoly would prevail. Market B has a larger number of firms, with too much available capacity to be able to sustain collusion at monopoly price.

After integration, we may think of firms operating in the market B to split into two groups. One serves customers located in market B, and this group is composed of exactly the number of firms that allows the monopolistic outcome to prevail in this market. The other group serves customers in market A, thus providing this market with extra capacity, but not enough to thwart the emergence of the monopolistic outcome in the market A. We can view interconnection as a way to shift capacity from one group of customers to the other in order to "better" exploit the collusive potential offered by the dynamic game.

15 Observe that this result requires one of the two pre-integration prices to be set at the monopoly level. Monopoly price ensures that the market is able to absorb part of the excess capacity of the other market.

16 Given our assumption on symmetric capacity, heterogeneity in aggregate capacity is generated by changes in the number of firms.

A linear example Two crucial questions related to the set of parameters compatible with this result are the following: How large is the set of parameters? How plausible is it in actual episodes of interconnection? Let us generalize slightly our previous example in order to provide some insights into these issues.

Consider again two markets with linear demand functions, $p_r = a - b_r Q_r$, $r = A, B$. In market r, N_r firms operate. Firm i in market r has capacity k_r^i and produces with a constant marginal cost c. We relax the assumption of symmetric capacity across all firms, and we assume that in each market, $i = 1, 2, ..., N_r$ with $k_r^1 \geq k_r^2 \geq \cdots \geq k_r^{N_r}$. Total capacity in market r is K_r, with $K \equiv K_A + K_B$.

In line with the previous analysis, we assume that in each market no firm (including firm 1, the largest one) has a sufficient capacity to produce more than the monopoly output: $k_r^1 \leq Q_r^{mon} = \frac{a-c}{2b_r}$. We also assume that in each market condition (3) holds, which we may write as $\sum_{i=2}^{N_r} k_r^i > Q_r(c)$.

In this setting, the monopoly price in both regional markets, as well as in the interconnected market, is $\frac{a+c}{2}$. Define as $\xi_r \equiv \frac{a-c}{2b_r} - (1-\delta) K_r$ the difference between the monopoly output and aggregate capacity in market r.[17] Similarly, in the interconnected market, $\xi_{ic} \equiv Q_{ic}^{mon} - (1-\delta)(K_A + K_B) = \frac{(a-c)(b_A+b_B)}{2b_A b_B} - (1-\delta) K$.[18] Observe that, since $Q_{ic}^{mon} = Q_A^{mon} + Q_B^{mon}$, then $\xi_{ic} = \xi_A + \xi_B$.

In order for interconnection to "export" collusion, the following condition[19] must hold:

$$\xi_A > 0, \xi_B < 0 \text{ and } \xi_{ic} = \xi_A + \xi_B \geq 0 \tag{9}$$

Observe that ξ_r increases when demand increases (i.e., when the monopoly output increases), and/or when the aggregate capacity decreases. From (9), one can see that our result requires both an asymmetric ξ_m across markets, and a high level of ξ_{ic}. If we start from a situation in which the result holds (where $\xi_A > 0$, $\xi_B < 0$ and $\xi_{ic} \geq 0$), a decrease in ξ_B, entailed by a fall in Q_B^{mon}, or by an increase in K_B, may have two effects.

First, it decreases the likelihood that our result (i.e., that collusion is exported from an individual market to the integrated environment) holds; indeed, one needs more room for new capacity in market A, (i.e., a higher ξ_A), to compensate for the decrease in ξ_B. Second, when this happens ($\xi_{ic} \geq 0$), the welfare reduction effect of interconnection is very significant.

On the contrary, when $\xi_A > 0$, $\xi_B < 0$ and ξ_{ic} is negative, but close to zero (thus, collusion at the monopoly price is not feasible in the interconnected market), an increase in either ξ_A or ξ_B, sufficient to bring ξ_{ic} in the positive realm, while preserving a negative ξ_B, extends the monopolistic collusion to the integrated market.

17 Observe that the equilibrium outcome is monopoly when $\xi_r > 0$, while it is between monopoly and competition if $\xi_r < 0$.

18 As a reminder, $N = N_A + N_B$

19 Without loss of generality, we assume that $\xi_A > \xi_B$; market A is thus the market with (relatively) smaller installed capacity.

More specifically, given the definition of ξ_m, the first part of condition (9) may be written $\frac{a-c}{2(1-\delta)} \in (b_A K_A; b_B K_B)$.

The larger the difference $b_B K_B - b_A K_A$, the larger the likelihood to observe our result. This difference may reflect heterogeneity in capacity or in market size (indexed by b_A and b_B). Whether heterogeneous capacity levels are due to cross-country differences in the past technological choices (plant sizes), or in the number of firms in the two markets, does not matter for our result.

As mentioned in Sect. 1.1, the electricity interconnection between Italy and France (in the years 2004-2005) provides a good example for parameter values that fit our results of export of monopolistic collusion. Reconsidering the example in the light of the notation introduced in this paragraph, according to our hypothesis, France (F) had $\xi_F < 0$ (its substantial capacity with respect to demand was hindering monopolistic collusion), Italy (I) had $\xi_I > 0$ (low capacity with respect to demand), and $\xi_{ic} = \xi_F + \xi_I \geq 0$ (Italy had enough "room" to host the French excess capacity, and this opportunity was exploited after integration).

The set of parameter values for which integration exports monopoly collusion and reduces welfare is limited. In other cases, interconnection may, on the contrary, enhance welfare (contrary to the results in Bernheim and Whinston 1990, but in line with the standard results in the international trade literature). Consider the same environment as above, but suppose that both ξ_A and ξ_B are negative (hence their sum is negative as well), and both markets are colluding at an intermediate price between monopoly and competition. Under such circumstances, the total quantity produced after interconnection is the same as the sum of the quantities produced in the two individual markets. However, in the integrated market, output is allocated to consumers with the highest marginal valuations, thereby generating a higher welfare.

4.1 A few open issues

It may be useful to discuss briefly some of our assumptions, and illustrate their impact on our results.

The assumption of exogenous capacity confines our analysis to the short run, as increasing capacity is a lengthy, costly, and difficult venture due to the interplay of various factors, including environmental concerns and the necessary compatibility of the extra capacity with the existing transmission system (the issue becomes particularly critical after liberalization, when the decisions on generation and on transmission capacity are taken separately). Furthermore, prior to liberalization, the incumbent's capacity was presumably not built in the anticipation of future competition. Thus, the available capacity right after liberalization can safely be regarded as an exogenous variable.

Therefore, we present here a short-run effect. If interconnection encourages entry,[20] it may well happen that prices decrease after an initial phase. The implication of our analysis can thus be regarded from a different perspective. An immediate increase in prices after interconnection should not be interpreted as an indicator that market open-

[20] The results when entry is allowed depend on the shape of the cost functions.

ing is “bad”. Indeed, the beneficial effects of interconnection may emerge only in the long-run, thanks to entry. In this sense, market opening and policies aimed at encouraging entry are not substitutes, in that market opening may be totally unsuccessful without further entry.

Moreover, in our model firms hold excess capacity. This is a typical feature of electricity markets: Electricity cannot be stored and its demand varies, so that a substantial reserve margin is almost always observed. In particular, at peak times capacity may only slightly exceed demand, while in base hours the bulk of capacity may remain idle. Notice that it may well happen that collusion is sustainable in some sub-markets (peak times) but less so in parts of the day where excess capacity is instead excessively large.[21]

As shown in the previous example, the assumption of symmetric capacity has been introduced for simplicity *only*. As long as each firm’s individual capacity is small enough, namely that (3) holds, and that each firm’s capacity is lower than the monopoly outcome, our results hold.[22]

5 Conclusions

In recent years, a strong policy orientation in favor of market integration and physical interconnection in network markets has emerged both in Europe and in the United States. However, some anecdotal evidence suggests that an increase in interconnection capacity may induce price increases. The received literature offers some possible explanations for the result. However, none of them appears to capture satisfactorily the peculiarities of network markets. Our paper offers an alternative explanation, based on a framework and a set of assumptions (capacity constraints and dynamic game) chosen to fit the electricity industry - both its structural properties, and its recent transition from a vertically integrated monopoly to a disintegrated liberalized industry.

Without integration, one market may be charaterised by a collusive (monopoly) price, while in the other one, capacity may be so large that such an outcome is impossible. However, when the markets are interconnected, the “excess” capacity in the second market may be diverted to the first one. Monopoly price might thus prevail in the integrated market, so that monopoly would be “exported” from the first market to the second one.

Although most of the analysis is carried out under the assumption of symmetric capacity, it is easy to see that nothing substantial would change, if we relaxed such an assumption by introducing the possibility of differences in firms’ capacities.[23] The

[21] Given the non- storability of electricity, national authorities have often opted for a definition of the electricity market(s) conditional on the parts of the day and thus on demand levels.

[22] With minor alterations to the model, the results could still hold for some parameter values even dispensing with the NEC conditions, and with the assumption that each firm’s capacity is lower than the monopoly outcome. For more details on this and other possible extensions of the present model, see Boffa (2006).

[23] If, in a context of asymmetric capacity, no firm’s capacity exceeds the monopoly output of each market, the results of the paper extend in a straightforward way; otherwise, a more complicated analysis is required.

paper has focused on capacity constraints, and not on increasing cost functions both for expositional simplicity, and to fit a specific feature of the electricity markets. However, as increasing cost functions possess most of the qualitative properties of capacity constraints, most of the results hold even in the case of continuously increasing cost functions.[24]

Moreover, given our interest in showing that the effect of market integration on welfare is not unambiguous, we have only provided sufficient conditions for welfare reduction (due to the diffusion of collusion after market integration). The fact that there is always a set of parameters that may satisfy such conditions is a striking feature of our result. A further step might consist in a more precise assessment of the welfare effects of interconnection according to different parameter values of demand, cost, discount factor, and capacity (both individual and aggregate), reflecting different pre-interconnection market structures. Such classification may provide valuable information to policy makers facing interconnection prospects.

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6 Appendix

Proof of Proposition 1 A collusive agreement in market r is sustainable if and only if $\frac{q^i(p_r^c)(p_r^c-c)}{(1-\delta)} \geq \left(p_r^c - c\right) \min\left(k, Q_r\left(p_r^c\right)\right)$, i.e. $q^i\left(p_r^c\right) \geq (1-\delta) \min\left(k, N_r q^i\left(p_r^c\right)\right)$.

Assume first

$$\min\left(k, N_r q^i\left(p_r^c\right)\right) = k \tag{10}$$

i.e., no firm has sufficient capacity to produce the whole collusive equilibrium output. Under this assumption, a collusive agreement requires $q^i\left(p_r^c\right) \geq (1-\delta)\,k$, and the equilibrium price that maximizes aggregate profit is then p_r^c if $k \leq Q_r\left(p_r^c\right)$ where:

$$p_r^c \begin{cases} p_r^{mon} & \text{if } (1-\delta)\,N_r k \leq Q_r\left(p_r^{mon}\right) & \text{and } k \leq Q_r\left(p_r^{mon}\right) \\ p_r\left((1-\delta)\,N_r k\right) & \text{if } Q_r\left(p_r^{mon}\right) \leq (1-\delta)\,N_r k \leq Q_r(c) & \text{and } k \leq (1-\delta)\,N_r k \Rightarrow N_r \geq \frac{1}{(1-\delta)} \\ c & \text{if } Q_r(c) \leq (1-\delta)\,N_r k & \text{and } k \leq (1-\delta)\,N_r k \Rightarrow N_r \geq \frac{1}{(1-\delta)} \end{cases} \tag{11}$$

Assume now $\min\left(k, N_r q^i\left(p_r^c\right)\right) = N_r q^i\left(p_r^c\right)$, i.e., each individual firm has sufficient capacity to produce the entire collusive equilibrium outcome. In such case, we revert back to the standard IR constraint for collusion when firms have unlimited capacity, which entails:

[24] For a review of, among others, tacit collusion with increasing cost function, see Ivaldi et al. (2003).

$$p_r^c = \begin{cases} \in \left[c, p_r^{mon}\right] & \text{if } N_r \le \frac{1}{(1-\delta)} \\ c & \text{if } N_r \ge \frac{1}{(1-\delta)} \end{cases} \tag{12}$$

Combining (11) and (12), one obtains the aggregate profit maximizing equilibrium of the supergame. We start by conditions under which a cartel coordinating on monopoly price can be sustained:

$$p_r^c = p_r^{mon} \text{ if i. OR ii. } \text{ OR iii. } \text{ holds : } \begin{array}{lll} \text{i.} & N_r \le \frac{1}{(1-\delta)} & \text{and } k \le Q_r\left(p_r^{mon}\right) \\ \text{ii.} & N_r \le \frac{Q_r\left(p_r^{mon}\right)}{(1-\delta)k} & \text{and } N_r \ge \frac{1}{(1-\delta)} \\ \text{iii.} & N_r \le \frac{1}{(1-\delta)} & \text{and } k \ge Q_r\left(p_r^{mon}\right) \end{array} \tag{13}$$

This may be rewritten as:

$$p_r^c = p_r^{mon} \text{ if i. OR ii. holds : } \begin{cases} \text{i. } N_r \le \frac{1}{(1-\delta)} \\ \text{ii. } \frac{1}{(1-\delta)} \le N_r \le \frac{Q_r\left(p_r^{mon}\right)}{(1-\delta)k} \end{cases}$$

$$p_r^c = p_r^{mon} \text{ if } N_r \le \frac{\max\left(\frac{Q_r\left(p_r^{mon}\right)}{k}, 1\right)}{(1-\delta)}$$

Now, by combining (11) and (12), we examine conditions under which an intermediate price between monopoly and competition emerges as the aggregate profit maximizing supergame equilibrium: $p_r^c = p_r\left((1-\delta) N_r k\right)$ if $\frac{Q_r\left(p_r^{mon}\right)}{(1-\delta)k} \le N_r \le \frac{Q_r(c)}{(1-\delta)k}$ and $N_r \ge \frac{1}{(1-\delta)}$.

This may be rewritten as:[25]

$$p_r^c = p_r\left((1-\delta) N_r k\right) \text{ if } \frac{\max\left(1, \frac{Q_r\left(p_r^{mon}\right)}{k}\right)}{(1-\delta)} \le N_r \le \frac{\max\left(1, \frac{Q_r(c)}{k}\right)}{(1-\delta)\, k} \tag{14}$$

Finally, again by combining (11) and (12), we check under what conditions collusion cannot be sustained, and competitive price is prevailing:

$$p_r^c = c \text{ if i. OR ii. holds : } \begin{cases} \text{i. } \frac{Q_r(c)}{k(1-\delta)} \le N_r \text{ and } \frac{1}{(1-\delta)} \le N_r \\ \text{ii. } N_r \ge \frac{1}{(1-\delta)} \text{ and } \frac{1}{(1-\delta)} \ge N_r \end{cases} \tag{15}$$

Rewriting (15), we obtain:

$$p_r^c = c \text{ if } N_r \ge \frac{\max\left(\frac{Q_r(c)}{k}, 1\right)}{(1-\delta)}$$

□

[25] Notice that the collusion at an intermediate price with $\delta \ge \frac{N_r-1}{N_r}$ *and* $k \ge Q_r^c$, in spite of being an equilibrium, is never part of an aggregate profit maximizing equilibrium. Indeed, when $\delta \ge \frac{N_r-1}{N_r}$ and $k \ge Q_r^c$ firms can sustain a cartel at a monopoly price, and this maximizes their profit.

Proof of Proposition 2 Suppose the contrary; i.e., that $p_{ic}^c > \max\left(p_A^c, p_B^c\right)$. For that to be true, $p_{ic}^c > c$, hence either $p_{ic}^c = p_{ic}^{mon}$ or $p_{ic}^{mon} > p_{ic}^c > c$. Assume first $p_{ic}^c = p_{ic}^{mon}$. Then, it has to be that $p_A^c, p_B^c < p_{ic}^{mon} = p_A^{mon} = p_B^{mon}$.[26]

$p_A^c, p_B^c < p_{ic}^{mon} = p_A^{mon} = p_B^{mon}$ requires:

$$N_r > \frac{\max\left(\frac{Q_r\left(p_r^{mon}\right)}{k}, 1\right)}{(1-\delta)}, \; r = A, B \tag{16}$$

while $p_{ic}^c = p_{ic}^{mon}$ requires

$$N \leq \frac{\max\left(\frac{(Q_A+Q_B)\left(p_{ic}^{mon}\right)}{k}, 1\right)}{(1-\delta)} \tag{17}$$

By (16), it follows that $N = N_A + N_B > \frac{\max\left(\frac{Q_A\left(p_A^{mon}\right)}{k},1\right)}{(1-\delta)} + \frac{\max\left(\frac{Q_B\left(p_B^{mon}\right)}{k},1\right)}{(1-\delta)} \geq \frac{\max\left(\frac{(Q_A+Q_B)\left(p_{ic}^{mon}\right)}{k},1\right)}{(1-\delta)}$, since $(Q_A + Q_B)\left(p_{ic}^{mon}\right) \leq Q_A\left(p_A^{mon}\right) + Q_B\left(p_B^{mon}\right)$, by assumption. Hence, $N > \frac{\max\left(\frac{(Q_A+Q_B)\left(p_{ic}^{mon}\right)}{k},1\right)}{(1-\delta)}$, in contradiction with (17).

Assume now $p_{ic}^{mon} > p_{ic}^c > c$. The requirement that $p_{ic}^c > \max\left(p_A^c, p_B^c\right)$ entails $p_{ic}^c > \left(p_A^c, p_B^c\right)$.

$p_{ic}^{mon} > p_{ic}^c > c$ requires

$$p_{ic}^c = p\left(Nk(1-\delta)\right) \text{ if } \frac{\max\left(\frac{(Q_A+Q_B)\left(p_{ic}^{mon}\right)}{k}, 1\right)}{(1-\delta)} < N \leq \frac{\max\left(\frac{(Q_A+Q_B)(c)}{k}, 1\right)}{(1-\delta)k}$$

while $p_{ic}^c > \left(p_A^c, p_B^c\right)$ requires

$$p_A^c = \begin{cases} p\left(N_A k(1-\delta)\right) & \text{if } \frac{\max\left(\frac{Q_A\left(p_A^{mon}\right)}{k},1\right)}{(1-\delta)} \leq N_A \leq \frac{\max\left(\frac{Q_A(c)}{k},1\right)}{(1-\delta)} \\ c & \text{if } N_A \geq \frac{\max\left(\frac{Q_A(c)}{k},1\right)}{(1-\delta)} \end{cases}$$

$$p_B^c \begin{cases} p\left(N_B k(1-\delta)\right) & \text{if } \frac{\max\left(\frac{Q_B\left(p_B^{mon}\right)}{k},1\right)}{(1-\delta)} \leq N_B \leq \frac{\max\left(\frac{Q_B(c)}{k},1\right)}{(1-\delta)} \\ c & \text{if } N_B \geq \frac{\max\left(\frac{Q_B(c)}{k},1\right)}{(1-\delta)} \end{cases}$$

[26] Notice that, given our assumption on equal reservation prices in markets A and B (and as a consequence in the interconnected market), $p_A^{mon} = p_B^{mon} = p_{ic}^{mon}$

Assuming $\frac{\max\left(\frac{Q_A\left(p_A^{mon}\right)}{k},1\right)}{(1-\delta)} \leq N_A \leq \frac{\max\left(\frac{Q_A(c)}{k},1\right)}{(1-\delta)}$ and $\frac{\max\left(\frac{Q_B\left(p_B^{mon}\right)}{k},1\right)}{(1-\delta)} \leq N_B \leq \frac{\max\left(\frac{Q_B(c)}{k},1\right)}{(1-\delta)}$, then $Q_{ic}^c = (N_A + N_B)\,k\,(1-\delta) = q_A\left(p_A^c\right) + q_B\left(p_B^c\right) = N_A k\,(1-\delta) + N_B k\,(1-\delta)$.

Hence, if $p_A^c = p_B^c$, then $p_{ic}^c = p_A^c = p_B^c$; if $p_A^c \neq p_B^c$, then p_{ic}^c is at an intermediate level between p_A^c and p_B^c, so $p_{ic}^c \leq \max\left\{p_A^c;\, p_B^c\right\}$. This is a contradiction with $p_{ic}^c > \max\left\{p_A^c;\, p_B^c\right\}$. If we assume that the supergame equilibrium entails the competitive outcome in one of the markets (say, without loss of generality, market A), then $N_A \geq \frac{\max\left(\frac{Q_A(c)}{k},1\right)}{(1-\delta)}$. Hence, $Q_{ic}^c = (N_A + N_B)\,k\,(1-\delta) \leq N_B k\,(1-\delta) + Q_A(c)$.

In this case, one of the separate markets (say, without loss of generality, A) has $p_A^c = c$. Since $p_{ic}^c > c$, then it has to be that $p_{ic}^c < p_B^c$. This is a contradiction with $p_{ic}^c > \max\left\{p_A^c;\, p_B^c\right\}$. □

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