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Structural versus behavioral remedies in the deregulation of electricity markets: An experimental investigation motivated by policy concerns

Silvester van Koten [a,b,*], Andreas Ortmann [c]

[a] Department of Institutional Economics, University of Economics, Prague, Czech Republic
[b] CERGE-EI, A joint workplace of Charles University and the Economics Institute of the Academy of Sciences of the Czech Republic, Politickych veznu 7, 111 21 Prague, Czech Republic
[c] Australian School of Business, University of New South Wales, Sydney, Australia

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ABSTRACT

We experimentally study the effects of introducing a forward market and of increasing the number of competitors in a quantity-setting market under strictly convex production costs. Our key interest is to better understand which of these two remedies is more effective at enhancing competition. Allaz and Vila (1993) theorized that forward markets can have a pro-competitive effect under linear production costs. Le Coq and Orzen (2006) and Brandts et al. (2008) investigated this and related issues experimentally. All three experiments (including ours) support the prediction by Allaz and Vila (1993) that introducing a forward market does indeed intensify competition. The results of the present study, however, differ from previous experimental results in that we find the forward market to be the more effective remedy. Brandts et al. (2008) increase the number of competitors by entry, which thus increases the aggregate stock of production assets and makes output cheaper. In contrast, we increase the number of competitors by divestiture, which leaves the aggregate stock of production assets constant. Our results address an important policy issue and provide tentative evidence on the competition-enhancing effect of forward markets, which can be considered a behavioral remedy.

1. Introduction

Mitigating market power in the EU markets is a central problem faced by policy makers and regulators.[1] The European Commission distinguishes two broad types of remedies to address market power, structural remedies and behavioral remedies.[2] Structural remedies, such as increasing competition by forced divestiture (Green, 2006), focus on the removal of the structural causes of market power. Behavioral remedies focus on preventing firms to be able to use their market power.

* Corresponding author at: Department of Institutional Economics, University of Economics, Prague, Czech Republic. Tel.: +420 776 125 053.
E-mail addresses: Silvester.VanKoten@cerge-ei.cz, slvstr@gmail.com (S. van Koten), a.ortmann@unsw.edu.au, aortmann@gmail.com (A. Ortmann).

[1] For example, the European Commission claims that EU electricity markets "… remain national in scope, and generally maintain the high level of concentration of the pre-liberalization period. This gives scope for exercising market power" (European Commission, 2007a, p. 7).

[2] The European Commission (2006, p. 2) defines structural remedies as "changes to the structure of an undertaking. The most obvious one is the divestiture of an existing business," and behavioral remedies as (p. 8) "a measure that obliges the concerned undertaking(s) to act in a specific way." Duso et al. (2011, p. 980) characterize behavioral remedies as measures that "… effectively tackle the market power concerns potentially raised by mergers without destroying efficiency-enhancing synergies."

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The European Commission (2003, Article 7(1)) prefers behavioral remedies to structural ones, stating: “Structural remedies can only be imposed either where there is no equally effective behavioral remedy or where any equally effective behavioral remedy would be more burdensome for the undertaking concerned than the structural remedy”. Implementing market designs that, by modifying the market environment, affect market participants' behavior indirectly can be thought of as a behavioral remedy although we are aware that this may be a misnomer.

Allaz and Vila (1993) make the theoretical case for the introduction of a forward market as a behavioral remedy that can mitigate market power by enhancing competition. Real forward markets may, however, differ from Allaz and Vila's (1993) analysis of the situation. For example, Allaz and Vila (1993) assume linear production costs; however, in many industries, such as the electricity generation industry, costs are strictly convex. Also, Allaz and Vila (1993) assume that competition is a one-shot game; however, firms are likely to interact repeatedly in the real world which is why Harvey and Hogan (2000) and Kamat and Oren (2004) question the competition-enhancing effect of forward markets. Empirical evidence on the competition-enhancing effect of forward markets is scant. Wolak (2001) and Van Eijkel and Moraga-Gonzalez (2010) find that forward trading may have increased aggregate output in the Australian electricity market and the Dutch gas market, respectively.

Le Coq and Orzen (2006) and Brandts et al. (2008) address the competition-enhancing effect of forward markets experimentally.[3,4] In line with the predictions of Allaz and Vila (1993), they find that introducing forward markets intensifies competition. This effect, however, appears weak relative to increasing the number of competitors in the market. Behavioral remedies may therefore be less effective than structural remedies (Duso et al., 2011). Indeed, while increasing the number of competitors is a suitable benchmark for testing the competition-enhancing properties of forward markets, we note that the relative weakness of the forward-market remedy has been shown experimentally only for industries with zero production cost (Le Coq and Orzen, 2006) and for industries with strictly convex costs for entry by new competitors (Brandts et al., 2008) rather than by divestiture.

In most capital-intensive industries, short-term costs are positive and strictly convex due to a limited stock of (expensive) production assets. For example, the marginal costs of production in the electricity generation industry have been characterized as “hockey-stick” shaped, i.e., marginal costs are flat but sharply increase when capacity constraints become binding (e.g., Newbery, 2002). Positive and strictly convex costs induce producers to make careful decisions, as they can incur considerable losses if they produce too much. The results of Le Coq and Orzen (2006) therefore cannot be generalized to industries with positive and strictly convex costs. Moreover, we argue that a suitable benchmark to study the effect of forward markets in capital-intensive industries is to increase the number of competitors by *divestiture* rather than by *entry* as in Brandts et al. (2008).[5]

In industries with strictly convex costs, increasing the number of competitors by entry has a stronger effect on output than by divestiture. Both remedies increase output due to more competitors (the competition-enhancing effect), but introducing a new competitor by entry also increases the industry's stock of aggregate production assets, a consequence of which is that any given aggregate level of output becomes cheaper to produce due to the strict convexity of the cost function (the asset effect). The resultant increase in aggregate output is therefore a combined effect of more competitors (the competition-enhancing effect) and more aggregate production assets (the asset effect).[6] As introducing a forward market requires no investment in new production assets, increasing competition by divestiture is a more suitable benchmark than increasing competition by entry.[7]

Moreover, divestiture has played an important role as a structural remedy in increasing competition in several markets. For example, the UK addressed market power in the late nineties by coaxing dominant electricity generators to divest plants.[8] The competition-enhancing effect of adding one more competitor through divestiture under Cournot competition between producers with symmetrical convex cost functions has been theoretically derived by Vergé (2010). He shows that increasing the number of competitors by divestiture decreases the resulting price,[9] but his results have, so far, not been tested experimentally.

[3] Economics experiments are a form of empirical investigation that allows controlled testing of theoretically predicted effects (Rassenti et al., 2002; Roth, 2002). They allow, in particular, low-cost robustness tests of various design and implementation characteristics, and of scenarios that are counterfactual to what currently exists.

[4] Another paper addressing forward markets is Ferreira et al. (2009). The paper is currently unpublished. We comment on it in footnote 29 (Results section).

[5] Since Le Coq and Orzen (2006) assume zero production cost, it does not matter whether the number of competitors is increased by entry or divestiture.

[6] While increasing the stock of production assets may have positive effects, the costs of creating these assets can be considerable. For example, building new power plants in the electricity industry is very costly. Introducing an equal-sized new competitor by entry in a market with three symmetrical competitors requires an increase in production assets by 33%. In a country such as the UK, an increase of that magnitude would correspond to an increase in electricity generation capacity of 27 GW and would cost – depending on whether the increase is realized by gas, coal or nuclear power plants – between 27 billion and 189 billion English pounds (MacDonald, 2010, p. 58; Ofgem, 2013, p. 10). Moreover, when competition is lacking, yet there is no shortage of electricity production capacity, entrance leads to a wasteful duplication of assets (Green, 1996).

[7] When marginal costs are not increasing, but constant, it can easily be demonstrated that an increase in competitors lowers the price under Cournot competition (e.g., see Varian, 2006, p. 494). In the case of constant marginal costs there is no difference in the methods of increasing the number of competitors: either by entry or by divestiture, both result in the same decrease in price.

[8] The two dominant electricity generators in the UK, National Power and PowerGen, altogether divested 6GW in 1996 and another 8GW in 1999, which resulted in lowered concentration (Green, 2006). Belgium, France, Italy, Denmark, and the Netherlands are using, or have used, the auctioning of Virtual Power Plants to lower market power (Willems, 2006).

We compare experimentally the competition-enhancing effect of a forward market to the benchmark of increasing the number of competitors by divestiture. We thus eliminate the asset effect confound and isolate the competition effect. To make the comparison meaningful, we draw on Brandts et al. (2008) and on Le Coq and Orzen (2006) to design, implement, and parameterize our experiment. In fact, we replicate key treatments from those studies, including a benchmark of increasing the number of competitors by entry. In the following section we discuss our experimental design (i.e., the basic parameterization, treatments, and underlying working hypotheses). In Section 3, we summarize the experimental procedures. In Section 4, we report the results focusing on aggregate output, efficiency, and production efficiency. In Section 5 we conclude.

2. Experimental design

As in Brandts et al. (2008) and Le Coq and Orzen (2006), we use Cournot competition with a linear demand function. For comparability, we use the same demand function and strictly convex cost function for a producer in a market with three competitors that Brandts et al. (2008) used.[10] Denoting the output of a single producer as q and the aggregate output of all (symmetrical) producers in a market with n producers as $Q=\sum_{i=1}^{n} q = n \cdot q$, we use the demand function $p[Q] = \text{Max}\,[0, 2000-27Q]$ and, in a market with three producers, the cost function $c_3[q] = \sum_{x=1}^{q} 2x^2$. In our other computations we use the generalized continuous version of this (integer-valued) cost function:

$$c_3[q] = \sum_{x=1}^{q} 2x^2 = (2/3)q^3 + q^2 + (1/3)q \tag{1}$$

A market with three competitors is a reasonable approximation for the EU electricity markets in the old EU member states. Since the new EU member states have more concentrated electricity markets, we also include a market with two competitors as a better approximation.[11] We refer to a market with two (three, four) competitors as M2 (M3, M4), and to a market with two (three) competitors and a forward market as M2F (M3F). We take the stock of aggregate production assets in M3 as the baseline, and derive the cost functions of M2 and M4 while keeping the stock of aggregate production assets fixed. Therefore, in contrast to Brandts et al. (2008), M4 (M2) is created from M3 by a divestiture (merger) followed by a reallocation of assets to restore symmetry.[12] In line with Brandts et al. (2008), we will refer to the market with four competitors created by entry as M4^{entry}.

To derive the cost functions for M2 and M4, we first derive the cost function for a market with one producer, using the premise of Perry and Porter (1985, p. 219) that "the new firm should have access to the combined productive capacity of both merger partners". Generally, we will use the notation $c_n[q]$ to refer to the cost function of a producer in a market with n competitors. If n sets of production assets of n producers would be merged into one single firm, then, as the cost function is convex, this single firm would minimize its costs by dividing output equally over the n sets of production assets. The total costs of the single firm would thus be $c_1[q] = n \cdot c_n[1/n \cdot q]$. Likewise, $c_1[q] = y \cdot c_y[1/y \cdot q]$, for any strictly positive integer y. The right-hand sides of these two equations thus must be equal. Setting these equal and rearranging results in

$$c_n[q] = (y/n) \cdot c_y[(n/y) \cdot q] \tag{2}$$

The general equation can now be obtained by substituting $y=3$ and applying (1):[13]

$$c_n[q] = (3/m).c_3[(n/3).q] = (2n^2/27)q^3 + (n/3)q^2 + (1/3)q \tag{3}$$

To obtain the cost functions for M2 and M4, we can substitute 2 and 4 for n[14]:

$$c_2[q] = (8/27)q^3 + (2/3)q^2 + (1/3)q \tag{4}$$

$$c_4[q] = (32/27)q^3 + (4/3)q^2 + (1/3)q \tag{5}$$

[9] Vergé (2010) focuses on the effect of merger and shows that a merger results in a higher price under the assumption that production costs are homogeneous of degree one in quantity and production assets. The cost functions in our experiment fulfill this assumption and divestiture thus is predicted to result in a lower price.

[10] Quadratic marginal costs are considered a reasonable approximation to the marginal costs of electricity generators (Green and Newbery, 1992; Borenstein et al., 2002).

[11] See Van Koten and Ortmann (2011, p. 5), and Van Koten and Ortmann (2008) for an overview of the EU member states and an explanation of how these numbers were determined.

[12] The treatments with the M3 and M3F markets are thus identical to the ones in Brandts et al. (2008), but not to those with the M4 market, as we created M4 by divestiture rather than entry.

[13] The general equation can be written as a function of the production assets of a producer in a market with n producers $c_n[q] \equiv c[q, k_n] = (2/27) \cdot q^3/k_n^2 + (1/3) \cdot q^2/k_n + (1/3) \cdot q$, where a producer's assets are given by $k_n = 1/n$ and the stock of aggregate assets in the market is normalized to 1. This cost function is homogeneous of degree one in output and production assets, $c[\alpha \cdot q, \alpha \cdot k_n] = \alpha \cdot c[q, k_n]$. Vergé (2010) shows that divestiture decreases the price under these conditions. See Online appendix for more details.

[14] To not unduly add to our subjects' cognitive load, we presented costs that were rounded. The numbers we obtained after this rounding procedure were also the numbers we used to calculate the theoretical predictions. As a result of these rounding rules, some of the rounded total costs are different, but the discrepancy is negligible. On average the absolute discrepancy is 0.12%. See Van Koten and Ortmann (2011), p. 10 for the precise rounding rules, and Table 1 in Online appendix for an overview of the aggregate cost levels for M2(F), M3(F) and M4.

Table 1
Treatments.

	2 competitors	3 competitors	4 competitors	
Without forward market	**M2**[a]	M3[b]	**M4**[c]	M4^{entry}[b]
With forward market	**M2F**[a]	M3F[b]	–	

[a] These treatments were not tested in Brandts et al. (2008). Their inclusion in this study is motivated by the more concentrated markets of the new EU member states as well as related treatments in Le Coq and Orzen (2006). More on this above (footnote 12) and below in Section 4.
[b] These treatments are identical to the ones tested in Brandts et al. (2008).
[c] This treatment is different from the one tested in Brandts et al. (2008), as the market has been created from the market with three competitors by divestiture, not by entry.

Table 2
Theoretical predictions.

	NE M2	**NE M2F (two Nash-equilibria)**		NE M3	**NE M3F**	NE M4	NE M4^{entry}[a]
q^f	–	2	11	–	5	–	
q	20	20	22	14/15[b]	15	11	12/13[c]
Q	40	40	44	43	45	44	49
p	920	920	812	839	785	812	677
Prod.S	31520	31520	28768	29537	27885	28768	27635
Cons.S	21060	21060	25542	24381	26730	25542	31752
Total S	52580	52580	54310	53918	54615	54310	59387

Explanation of column terms: NE stands for the Nash-equilibrium.
Explanation of row terms: q^f stands for the forward output of each producer, q for the total output of forward (if it is present) and spot market for each producer, Q for the total *aggregate* output of forward (if it is present) and spot market for all producers together, p for the price on the spot market, *Prod.S* for producer surplus, *Cons.S* for consumer surplus, *Total S* for total surplus.
[a] Note that, for NE M4^{entry}, our calculations result in some outcomes that are different than those Brandts et al. (2008) report. We find that the price is 677 rather than 704 and that producer surplus is 27 635 rather than 27 638. See Van Koten and Ortmann (2011, footnote 22), for an overview of the main (but inconsequential) differences.
[b] One generator produces 15 units, the other two 14 units each.
[c] One generator produces 13 units, the other three produce 12 units each.

A producer in M4^{entry} (a market with four competitors created by *entry* as done in Brandts et al. (2008)) has the same cost function as a producer in a market with three competitors, M3. The M4^{entry} cost function is thus lower and flatter than the one in M4 (a market with four competitors created by *divestiture*), as can be verified by comparing Eq. (5) with (1).

Table 1 summarizes our treatments and indicates how they compare with Brandts et al. (2008). Table 2 contains the Nash-equilibrium (NE) predictions for each treatment; recall that the subjects can choose only integer output values.[15] The theoretical predictions summarize, for the particular parameterizations chosen, the qualitative effect on aggregate output and welfare of introducing a forward market on the one hand and of adding one more competitor by divestiture on the other hand. Using $Q(x)$ to denote aggregate output in market structure x, the theoretical predictions (hypotheses) are summarized in Table 3.[16]

Hypothesis H1 predicts the effect of introducing a forward market on aggregate output. Introducing a forward market in M2 results in two welfare-rankable Nash-equilibria: one with output 40 (low) and one with output 44 (high). We have no prior, but if both Nash-equilibria are chosen with some positive probability, introducing a forward market will have a positive effect on aggregate output (H1a). Similarly, in M3, theory predicts that the forward market will have a positive effect on aggregate output (H1b). Hypothesis 2 predicts the effect of adding one more competitor by divestiture (the benchmark) on aggregate output. The remedy is hypothesized to increase aggregate output both in markets M2 (H2a) and M3 (H2b). Hypothesis 3 compares the predicted effect of the forward market relative to the benchmark. Since the output in M3 lies between the low and high Nash-equilibria of M2F, we cannot make a prediction whether adding a forward market or adding one more competitor by divestiture will have the larger effect. Therefore, by the principle of insufficient reason, we hypothesize that the outputs will be equal (H3a). In M3, theory predicts that the effect of the forward market will be larger than the benchmark (H3b). Hypothesis 4 predicts the effect of adding one more competitor by entry on aggregate output.

[15] See Van Koten and Ortmann (2011), p. 11, footnote 20, for more details about the numerical procedure to determine the Nash-equilibria.
[16] We also analyze the effects on welfare and efficiency measures, but as welfare – defined as the realized joint consumer and producer surplus in the experiment divided by the maximum joint consumer and producer surplus – is strongly affected by the level of aggregate output, we expect welfare to follow the results for aggregate output closely. Welfare can also be affected by productive efficiency – defined as the aggregate production costs divided by the minimal aggregate production costs – but we expect that the effect on productive efficiency is minimal and roughly equal across our treatments. Our results confirm these expectations and we thus focus in this paper on the aggregate output. See Van Koten and Ortmann (2011) for details on the effect of our treatments on the welfare and productive efficiency measures.

Table 3
Hypotheses.

H1	Effect of forward market	(a) $Q(\text{M2F}) > Q(\text{M2})$ (b) $Q(\text{M3F}) > Q(\text{M3})$
H2	Effect of adding one competitor by divestiture (benchmark)	(a) $Q(\text{M3}) > Q(\text{M2})$ (b) $Q(\text{M4}) > Q(\text{M3})$
H3	Effect of forward market relative to benchmark	(a) $Q(\text{M2F}) = Q(\text{M3})$ (b) $Q(\text{M3F}) > Q(\text{M4})$
H4	Effect of adding one competitor by entry, relative to benchmark and relative to forward market	(a) $Q(\text{M4}^{\text{entry}}) > Q(\text{M3})$ (b) $Q(\text{M4}^{\text{entry}}) > Q(\text{M4})$ (c) $Q(\text{M4}^{\text{entry}}) > Q(\text{M3F})$

The effect is hypothesized to be strong not only relative to the aggregate output in market M3 (H4a), but also relative to the effect of adding one more competitor by divestiture, M4, (H4b) and to introducing a forward market, M3F (H4c).

3. Experimental procedures

The experimental sessions were conducted in October 2009, December 2009, and April 2010 at CERGE-EI in Prague.[17] The data for treatment M4$^{\text{entry}}$ (implemented in response to a referee request) together with additional data on M4, are from additional sessions conducted in January 2013. We conducted additional M4 sessions to test for comparability of procedures and subject pools. We compared the additional data on M4 with the original ones in the earlier sessions in 2009 and 2010 and found no statistically significant difference ($p=0.20$).[18] Subjects were students at Charles University or at the University of Economics, both located in Prague. A total of 286 students participated in the sessions for the treatments shown in Table 1.[19] To be conservative, we treat each set of producers (a group) per treatment as a single data point, resulting in 11 statistically independent observations for each of the six treatments reported here. The sessions with (without) a forward market lasted approximately 2 h (1.5 h). The subjects earned on average 382 Czech Koruna per hour, including a show-up fee of 100 Koruna. On average subjects earned 640 Koruna.[20] The minimum earning was 330 and the maximum earning was 1080 Koruna. Our experiment was therefore well incentivized on the margin. The same experimenter read the (English language) instructions to the subjects for all sessions.

The market simulation was programmed in Z-tree (Fischbacher, 2007). The demand schedule was pre-programmed, and subjects enacted the roles of producers. At the beginning of each session, groups of 2, 3 or 4 subjects were formed by random assignment. Group membership stayed fixed during the whole session. Subjects were not shown the mathematical formula for the demand schedule but were given an earnings table on the screen and as a printout. During the experiment, once subjects had submitted their choice for the (forward) spot market, the following outcomes were shown: the aggregate output sold, the resulting price per unit on the (forward) spot market, and their own profit, marginal cost, and cumulative cost. Subjects were not shown their competitors' profits, costs, or contributions to the aggregate quantity sold. In treatments with two subjects (i.e. M2 and M2F), subjects could, however, calculate the competitor's contribution.

Each treatment consisted of 24 rounds. Treatments with a forward market contained two periods per round: the first for the forward market and the second for the spot market. In the first period, producers chose how many units to produce and sell in the forward market. These units were produced and delivered to traders. In the forward market, two pre-programmed traders competed in prices for the total number of units that were offered.[21] Traders were programmed to act rationally. Their actions defined a demand schedule, which we presented to the producers.[22] Producers were shown this forward-market demand schedule in the first period of each round, which they could use to inform the number of units to offer in the forward market. At the end of the period, producers were paid the number of units they produced in the forward market times the price per unit, minus their production cost. In the second period of each round, producers chose the number of units to produce and sell in the spot market. The pre-programmed traders sold all the units they bought. The price per unit was determined by substituting the number of units sold by all producers in the forward and spot markets together for Q in the demand schedule $p[Q] = \text{Max}\,[0, 2000-27Q]$. All producers were paid the number of units they produced in the spot market times the price per unit, minus their production cost.

[17] See Van Koten and Ortmann (2011), p. 13, footnote 25, for details of the treatments.

[18] We used a two-sided Wilcoxon rank-sum (Mann–Whitney) test to compare the aggregate output averaged over the last 12 rounds for each independent observation.

[19] The total of 286 students includes the subjects that participated in the additional sessions for M4 and M4$^{\text{entry}}$.

[20] This amount equals about €26 (and about €36 at official purchasing power parity then, and even more at a student-specific purchasing power parity). The earnings were thus salient and in line with standard remuneration practices in experimental economics.

[21] Le Coq and Orzen (2006) also employed pre-programmed traders. The manner in which traders are represented in the experiment should not significantly affect outcomes, as traders are middlemen (between producers in the forward market and end demand in the spot market). Earlier experimental evidence indicates that the presence of strategically acting middlemen generally does not alter allocations and that the profit of middlemen converges to zero quickly (Plott and Uhl, 1981). Brandts et al. (2008) use experimental subjects as traders and find that traders earn only a small fraction (about 8%) of the profits that producers earn.

[22] See Van Koten and Ortmann (2011, p. 14, for details on the pre-programmed traders, and p. 45), Appendix F, for the consolidated instructions.

4. Results

For our statistical tests, we use the last 12 (of 24) rounds of the data. Because the experiment is complicated, subjects need, as they do in relatively easy auction experiments (Hertwig and Ortmann, 2001), several rounds of trading to become familiar with the laboratory environment and before they react to the embedded incentives.[23]

Following Le Coq and Orzen (2006), we test for deviations from the Nash-equilibrium predictions using two-sided Wilcoxon one-sample signed-rank tests, unless indicated otherwise. Since each participant took part in one session only (for a robustness-check exception, see footnote 34), data points are independent across treatments. None of the subjects went bankrupt.

In line with Brandts et al. (2008), we test our hypotheses with F-tests based on an OLS regression of the dependent variable on the six treatment dummies, M2, M2F, M3, M3F, M4, and M4^{entry}, without a constant: $AggregateSupply = \beta_1 \cdot M2 + \beta_2 \cdot M2F + \beta_3 \cdot M3 + \beta_4 \cdot M3F + \beta_5 \cdot M4 + \beta_6 \cdot M4^{entry} + \varepsilon$. The error terms are adjusted for clustering at the group level by using the robust Huber–White sandwich estimator (Froot, 1989). Fig. 1 shows the evolution of total (aggregate) outputs sold per period, averaged over groups in each treatment. We report the data for the different treatments as a moving average to eliminate some of the round-specific noise: an output is given as the average over the output in the present period and the three previous periods. Obviously, this way of visualizing the data has no effect on the statistics that follow. Treatments with two competitors are represented by circles, with three competitors by triangles, and with four competitors by squares. The treatments without forward markets are represented by open circles, triangles or squares, the treatments with forward markets by filled circles or triangles. The trade volume in all treatments is initially low,[24] but then quickly converges to the Nash-equilibrium. Output stabilizes between rounds 8 and 12.

For the treatments without forward markets, the M2, M3 and M4^{entry} outputs are not significantly different from the Nash-equilibrium (NE) predictions (two-sided Wilcoxon one-sample signed-rank tests, all p-values > 0.18), whereas the M4 output is significantly higher (p-value$=0.068$). For the treatments with a forward market, output in M3F is significantly higher than the NE (p-value$=0.004$). Also, output in M2F is significantly higher than the low NE (p-value$=0.021$), but not significantly different from the high NE (p-value$=0.248$).

In line with earlier findings (e.g. Le Coq and Orzen, 2006; Huck et al. 2004), when the number of competitors is equal to two (three or four) and there is no forward market, output tends to be smaller (larger) than the NE. We see no evidence for stable collusion; indeed our data suggest the opposite. Namely, regressing aggregate output on the period of the experiment shows a significant upward slope, which suggests they become less likely to collude as subjects become more experienced with the task.

Table 4 shows the average aggregate output for the last 12 rounds per treatment group with the standard deviation in parentheses.[25] Row “% of NE prediction” shows average aggregate output per treatment group relative to the NE prediction (which is given in the row above). For comparison purposes, average aggregate output and % of NE prediction of Brandts et al. (2008) and Le Coq and Orzen (2006) are also shown in Table 4. Using a two-sided Wilcoxon rank-sum (Mann–Whitney) test to compare output in the market with four competitors in our experiment to the output in Brandts et al. (2008),[26] we find that the average aggregate output is not significantly different when we created the market by entry (our M4^{entry} versus their M4^{entry}: 50.4 versus 50.9, p-value$=0.96$), although it is significantly smaller when we created it by divestiture (our M4 versus their M4^{entry}: 46.2 versus 50.9, p-value$=0.06$). This suggests that the asset effect has a considerable influence. Our results replicate the findings of Brandts et al. (2008) for the treatments without forward markets, as two-sided Wilcoxon rank-sum (Mann–Whitney) tests show no significant differences in “% of NE prediction”: our M3 versus their M3 (103% versus 99%, p-value$=0.56$), our M4 versus their M4^{entry} (105% versus 104%, p-value$=0.89$) and, as mentioned before, our M4^{entry} versus their M4^{entry} (103% versus 104%, p-value $=0.96$). We find, however, a significantly higher average aggregate output in M3F than Brandts et al. (our 110% versus their 104%, p-value$=0.02$), suggesting a behavioral effect that further strengthens the competitive effect of a forward market.[27]

Using the percentage of the NE predictions measure, we observe a larger average aggregate output in markets with two competitors than Le Coq and Orzen (2006) report. This conforms to earlier theoretical and experimental evidence, which shows that increasingly steeper cost curves lead to more competitive outcomes (Davis and Reilly, 2003; Engel, 2007). As robustness tests, we conducted treatments without production costs, and found that the average aggregate output was significantly lower than in treatments with (strictly convex) production costs. A detailed analysis of these treatments can be

[23] However, including all 24 rounds, or only the last 10 rounds as Brandts et al. (2008) did, does not change our results qualitatively. In fact, all results remain significant.

[24] It is likely that these trajectories are anchored by the examples in the instructions in which we used low numbers to facilitate understanding of the basic relationships. Loss-averse behavior due to the initially considerable uncertainty could be another explanation.

[25] The standard error is computed based on the averages for each of the 11 independent groups over the last 12 rounds.

[26] The original group-level data of Brandts et al. (2008) can be found in Appendix 4 of the online document at www1.feb.uva.nl/creed/pdffiles/EJappendix2006.pdf.

[27] Subjects behave more competitively than NE predicts. Since the NE prediction for M3F is already more competitive than the prediction for adding one more competitor by divestiture (M4), this difference is increased by the behavior of our subjects. Our use of pre-programmed traders may be the cause of our stronger effect of the forward market compared with the results in Brandts et al. (2008). The use of pre-programmed traders reduces the variation in subject choice, and this may enable the forward market to exert a stronger, unhindered effect. Admittedly, this argument is speculative.

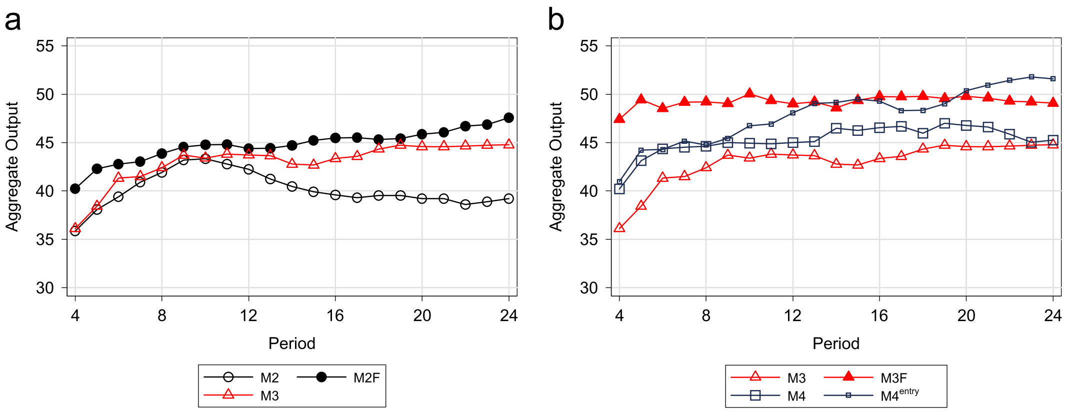

Fig. 1. Aggregate output (moving average over four periods).

Table 4
Average aggregate output (last 12 rounds).

	M2	M2F	M3	M3F	M4	M4^{entry}
Average aggregate output	39.3 (5.03)	46.3 (6.82)	44.2 (4.06)	49.6 (2.01)	46.2 (3.26)	50.4 (4.35)
Predicted output (NE)	40	40/44	43	45	44	49
% of NE prediction	99	116/105[a]	103	110	105	103
Number of independent observations	$N=11$	$N=11$	$N=11$	$N=11$	$N=11$	$N=11$
Results of Brandts et al. (2008) for comparison						
Average aggregate output			42.5(5.57)	46.6(2.91)		50.9(5.86)
% of NE prediction			99	104		104
Number of independent observations			$N=7$	$N=6$		$N=7$
Results of Le Coq and Orzen (2006) for comparison						
% of NE prediction	93	94			114	
Number of observations	$N=15$	$N=15$			$N=8$	

The shaded columns indicate the treatments that are identical to the ones tested in Brandts et al. (2008).
[a] The first (second) number in the cell, 116% (105%), gives the percentage of output relative to the low (high) output NE.

found in Van Koten and Ortmann (2011), Appendix B.2. Table 5 presents the results of the F-tests based on OLS regressions, clustered in groups.[28]

Our results show that in markets with two competitors, in line with earlier experimental results (Le Coq and Orzen, 2006), both introducing a forward market (H1a), and adding one more competitor by divestiture (H2a) significantly increase aggregate output. In markets with three competitors, introducing a forward market (H1b) and adding one more competitor (H2b) significantly increase aggregate output, which is in line with our theoretical prediction and earlier experimental results (Brandts et al., 2008).[29] Introducing a forward market increases aggregate output significantly more than adding one more competitor by divestiture (H3b), which confirms our theoretical prediction. Adding one more competitor also increases aggregate output in Brandts et al. (2008), but the effect is larger due to the asset effect which, as we have argued, makes production relatively cheaper in M4^{entry}. Indeed, our results show that adding one more competitor increases aggregate output significantly more when done by entry rather than by divestiture (H4b). Thus adding one more competitor by entry, in line with earlier experimental results (Brandts et al., 2008), also increases aggregate output significantly (H4a). However, adding one more competitor by entry does not increase aggregate output significantly more than does introducing a forward market (H4c).

[28] To test robustness, we also compared the averages for the groups using Wilcoxon rank-sum (Mann–Whitney) tests. The hypotheses accepted (rejected) are the same, except that $Q(M4)>Q(M3)$ is no longer supported (p-value $=0.15$). Running the OLS regression without the treatment on M4^{entry} does not change the significance level of any of the results in hypotheses H1, H2, and H3, except that $Q(M4)>Q(M3)$ is, strictly speaking, no longer supported at conventional levels as the p-value is now marginally larger than 0.1 (0.101).

[29] We tested, as a robustness check, if the competitive-enhancing effect is robust when subjects are experienced. To test for the effect of experience, 63 subjects that were experienced in the sense that they had participated in the experiment earlier, participated in additional sessions in October 2010. (Of course, these data were not included in the statistical evaluation of the treatments in Table 1.) We became aware of the possibility of such an issue through the working paper by Ferreira, Kujal and Rassenti (2009) that started circulating while we were writing our paper. Ferreira et al. (2009) find that forward markets have a positive effect on the aggregate output with inexperienced subjects, but no – or a negative – effect with experienced subjects. We do not find that experienced subjects produce a lower aggregate output than inexperienced subjects. On the contrary, our experienced subjects produce a slightly higher output, which is in line with the experimental literature on the effect of experience on public good provision (Ledyard, 1995). For detailed results, see Van Koten and Ortmann (2011), p. 39, Appendix D.

Table 5
Effects of one more competitor and forward market.

H1	Effect of forward market	(a) **Q(M2F) > Q(M2)**	**Supported**	***(**p=0.003**)	N=528 (11)
		(b) **Q(M3F) > Q(M3)**	**Supported**	***(**p < 0.001**)	N=792 (11)
H2	Effect of adding one competitor by divestiture (benchmark)	(a) **Q(M3) > Q(M2)**	**Supported**	**(**p=0.005**)	N=660 (11)
		(b) **Q(M4) > Q(M3)**	**Supported**	* (**p=0.100**)	N=924 (11)
H3	Effect forward market relative to benchmark	(a) Q(M2F)=Q(M3)	Not rejected	(p=0.374)	N=660 (11)
		(b) **Q(M3F) > Q(M4)**	**Supported**	***(**p=0.002**)	N=924 (11)
H4	Effect of adding one competitor by entry, relative to benchmark and relative to forward market	(a) **$Q(M4^{entry}) > Q(M3)$**	**Supported**	***(**p < 0.001**)	N= 924 (11)
		(b) **$Q(M4^{entry}) > Q(M4)$**		***(**p=0.005**)	N=1056 (11)
		(c) $Q(M4^{entry}) > Q(M3F)$	**Supported**	(p=0.252)	N= 924 (11)
			Not supported		

We interpret a direction hypothesis to be "Supported" when our test successfully rejects the opposite postulate. We interpret a non-directional hypothesis (H3a) only to be "Not rejected" when our test fails to reject the postulate.
N: Number of observations (independent groups).
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Our findings show that without an asset effect, the competition-enhancing effect of introducing a forward market compares favorably to adding one more competitor through divestiture. Remarkably, especially in light of H4c, in markets with three competitors, the competition-enhancing effect of introducing a forward market does not compare negatively to the addition of one more competitor by entry, an alternative that not only increases the number of competitors, but also involves an increase in production assets.

5. Conclusion

We experimentally investigated the effects on competition of introducing a forward market. We compared the effects to those of the best alternative – reducing concentration by adding an additional competitor through divestiture. We find that introducing a forward market and adding an additional competitor by divestiture both increase competition, thus supporting the theoretical predictions of Allaz and Vila (1993) and Vergé (2010), respectively. Our results suggest that the behavioral remedy of introducing a forward market in concentrated markets with two or three competitors is an effective remedy for countering market power by increasing the aggregate output. This gives tentative support to the European Commission's preference for behavioral remedies such as the introduction of a forward market (European Commission, 2003). That introducing a forward market has a competition-enhancing effect is in line with the empirical studies of Wolak (2001) and Van Eijkel and Moraga-Gonzalez (2010), who found indications that forward trading increased aggregate output in the Australian electricity market and the Dutch gas market, respectively.

Our results are different from the findings of Brandts et al. (2008), who found in markets with three competitors a stronger effect for the structural remedy of adding one more competitor than for the behavioral remedy of introducing a forward market. Their result seems driven in part by a confounding of competition effect and asset effect. Brandts et al. (2008) add one more competitor by entry, which increases both competition and the stock of aggregate production assets. The aggregate cost of production is reduced and hence output is increased. The asset effect is influential, as producers face steeply increasing costs. Moreover, as a result the welfare effects Brandts et al. (2008) report are not conclusive, as they do not incorporate the costs of the increase in the production assets (the cost of building extra plants and production facilities). In our study, we control for the asset effect by adding one more competitor through divestiture. In addition, we find a stronger behavioral effect of introducing a forward market in a market with three competitors. As a result of these two differences, we find that the effect of the structural remedy of adding one more competitor is weaker and is now dominated by the effect of the behavioral remedy of introducing a forward market.

At present, the EU has no single policy towards the design of forward markets for electricity. Such a policy might improve competition by increasing the use of forward markets and the public observability of positions taken in the forward market, often referred to as "market transparency" (European Commission, 2007a, p. 127). In Spain and Greece, for example, forward trading is de facto forbidden or made impossible by design (European Commission, 2007a, p. 127, 2007b, p. 50). In contrast, in France the PowerNext exchange market allows for the trading of monthly, quarterly and yearly forward and future contracts. Our study suggests that forward markets could play a role in enhancing competition in concentrated markets and that the design, or evolution, of public forward exchanges such as in France (and many other developed markets) should indeed be encouraged. The public observability of forward positions is essential for the competition-increasing effect of Allaz and Vila (1993) to arise (Hughes and Kao, 1997; Van Eijkel and Moraga-Gonzalez, 2010). Energy markets are, however, not very transparent as most trading takes place on Over-The-Counter (OTC) markets over different trading platforms and a considerable proportion (around 10%) takes places bilaterally without intermediaries (European Commission, 2010, pp. 9–11). Forward trading positions are thus often not observable. Our results suggest that making the EU forward energy markets more transparent could contribute to a more competitive market.

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Appendix A. Supplementary materials

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References

Allaz, B., Vila, J.-L., 1993. Cournot competition, forward markets and efficiency. Journal of Economic Theory 59 (1), 1–16.
Borenstein, S., Bushnell, J., Wolak, F., 2002. Measuring market inefficiencies in California's restructured wholesale electricity market. American Economic Review 92 (5), 1376–1405.
Brandts, J., Pezanis-Christou, P., Schram, A., 2008. Competition with forward contracts: a laboratory analysis motivated by electricity market design. The Economic Journal 118, 192–214.
Davis, D.D., Reilly, R.J., 2003. Cost structures and Nash play in repeated Cournot games. Experimental Economics 6, 209–226.
Duso, T., Gugler, K., Yurtoglu, B.B., 2011. How effective is European merger control? European Economic Review 55, 980–1006.
Engel, C., 2007. How much collusion? A meta-analysis of oligopoly experiments. Journal of Competition Law and Economics 3 (4), 491–549.
European Commission, 2003. Council Regulation (EC) No 1/2003 of 16 December 2002 on the Implementation of the Rules on Competition Laid Down in Articles 81 and 82 of the Treaty. Official Journal L 1, 04.01.2003, 1–25.
European Commission, 2006. Roundtable on Remedies and Sanctions in Abuse of Dominance Cases. DAF/COMP/WD(2006)34.
European Commission, 2007a. DG Competition Report on Energy Sector Inquiry. SEC(2006) 1724.
European Commission, 2007b. Prospects for the Internal Gas and Electricity Market. COM(2006) 841 Final.
European Commission, 2010, Accompanying document to the proposal for a regulation of the European Parliament and of the Council on Energy Market Integrity and Transparency. COM(2010) 726 final.
Ferreira, J. L., Kujal, P., Rassenti, S., 2009. The Strategic Motive to Sell Forward: Experimental Evidence. Economics Working Papers we092616, Universidad Carlos III, Departamento de Economía.
Fischbacher, U., 2007. Z-Tree: Zurich toolbox for ready-made economic experiments. Experimental Economics, 10; 171–178.
Froot, K.A., 1989. Consistent covariance matrix estimation with cross-sectional dependence and heteroskedasticity in financial data. Journal of Financial Quantitative Analysis. 24, 301–312.
Green, R., 1996. Increasing competition in the British electricity spot market. The Journal of Industrial Economics 44 (2), 205–216.
Green, R., 2006. Market power mitigation in the UK power market. Utilities Policy 14, 76–89.
Green, R., Newbery, D., 1992. Competition in the British electricity spot market. Journal of Political Economy 100 (5), 929–953.
Harvey, S.M., Hogan, W.W., 2000. California Electricity Prices and Forward Market Hedging. Mimeo, John F. Kennedy School of Government, Harvard University.
Hertwig, R., Ortmann, A., 2001. Experimental practices in economics: a methodological challenge for psychologists? Behavioral and Brain Sciences 24, 383–451.
Huck, S., Normann, H.-T., Oechssler, J., 2004. Two are few and four are many: number effects in experimental oligopoly. Journal of Economic Behavior and Organization 53 (4), 435–446.
Hughes, J.S., Kao, J.L., 1997. Strategic forward contracting and observability. International Journal of Industrial Organization 16, 121–133.
Kamat, R., Oren, S.S., 2004. Two-settlement systems for electricity markets under network uncertainty and market power. Journal of Regulatory Economics 25, 5–37.
Le Coq, C., Orzen, H., 2006. Do forward markets enhance competition? Experimental evidence. Journal of Economic Behavior and Organization 61 (3), 415–431.
Ledyard, O., 1995. Public goods: a survey of experimental research. In: Kagel, J.H., Roth, A.E. (Eds.), Handbook of Experimental Economics, Princeton University Press, Princeton, pp. 111–194.
MacDonald ,2010. UK Electricity Generation Costs Update.
Newbery, D., 2002. Problems of liberalising the electricity industry. European Economic Review 46 (4–5), 919–927.
Ofgem, 2013. Electricity Capacity Assessment Report 2013. Reference: 105/13.
Perry, M.K., Porter, R.H., 1985. Oligopoly and the incentive for horizontal merger. The American Economic Review 75 (1), 219–227.
Plott, C.R., Uhl, J.T., 1981. Competitive equilibrium with middlemen: an empirical study. Southern Economic Journal 47 (4), 1063–1071.
Rassenti, S., Smith, V., Wilson, B., 2002. Using experiments to inform the privatization/deregulation movement in electricity. The Cato Journal 21 (3), 515–544.

Roth, Alvin E., 2002. The economist as engineer: game theory, experimentation, and computation as tools for design economics. Econometrica 70, 1341–1378.
Van Eijkel, R. and Moraga-Gonzalez, J.L. 2010. Do firms sell forward for strategic reasons? An application to the wholesale market for natural gas. IESE Business School Working Paper No. 864.
Van Koten, S., Ortmann, A., 2008. The unbundling regime for electricity utilities in the EU: a case of legislative and regulatory capture? Energy Economics 30 (6), 3128–3140.
Van Koten, S., Ortmann, A. 2011. Structural Versus Behavioral Remedies in the Deregulation of Electricity Markets: An Experimental Investigation Guided by Theory and Policy Concerns. Available at 〈http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1835482〉.
Varian, H.R., 2006. Intermediate Microeconomics. W.W. Norton & Company, New York.
Vergé, T., 2010. Horizontal mergers, structural remedies, and consumer welfare in a cournot oligopoly with assets. Journal of Industrial Economics 58 (4), 723–741.
Willems, B. 2006. Virtual Divestitures, Will They Make a Difference? Available at www.bertwillems.com.
Wolak, F.A., 2001. An empirical analysis of the impact of hedge contracts on bidding behavior in a competitive electricity market. International Economic Journal 14, 1–39.