Structural versus Behavioral Remedies in the Deregulation of Electricity Markets: An Experimental Investigation Guided by Theory and Policy Concerns

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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. Our key interest was to better understand which of these two remedies enhances competition. Allaz and Vila (1993) theoretically showed that forward markets can have a pro-competitive effect. Le Coq and Orzen (2006) and Brandts, Pezanis-Christou and Schram (2008) experimentally investigated similar issues. 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 our experiment, the forward market is a more effective remedy than increasing the number of competitors. We argue that our results differ from Brandts et al.'s (2008) because they increased the number of competitors by entry, which thus increased the asset base and made production cheaper. In contrast, we increased the number of competitors by divestiture, which left the asset base constant. Our results address an important policy issue and provide tentative evidence on the competition-enhancing effect of forward markets, which are considered a behavioral remedy and are favored by the European Commission.

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1. Introduction

Mitigating market power is a central problem faced by policy makers and regulators. 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). The Commission uses two broad types of remedies to address market power, structural remedies and behavioral remedies,[2] such as divestiture (structural) and forward markets (behavioral). The European Commission prefers behavioral remedies to structural ones, stating: "Structural remedies should only be imposed either where there is no equally effective behavioural remedy or where any equally effective behavioural remedy would be more burdensome for the undertaking concerned than the structural remedy" (European Commission, 2006a, p.11).

Allaz and Vila (1993) theoretically show that forward markets can mitigate market power by enhancing competition. Real forward markets may, however, differ from Allaz and Vila's (1993) theoretical portrayal. For example, Allaz and Vila (1993) assume that competition is a one-shot game, however, firms are likely to interact repeatedly in the real world. Indeed this 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 supply in the Australian electricity market and the Dutch gas market, respectively. Le Coq and Orzen (2006) and Brandts, Pezanis-Christou, and Schram (2008) experimentally[3] address the competition-enhancing effect of forward markets.[4] In line with Allaz and Vila's (1993) predictions, they find that introducing forward markets intensifies competition. This effect, however, appears weak relative to increasing the number of competitors in the market. Therefore behavioral remedies may actually 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 instrument has only been shown

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[2] The European Commission (2006b, p. 6) 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, Gugler, and Yurtoglu (2011, p. 980) characterize behavioral remedies as measures that "… effectively tackle the market power concerns potentially raised by mergers without destroying efficiency enhancing synergies."

[3] Economics experiments are a form of empirical investigation that allows controlled testing of theoretically predicted effects (Rassenti, Smith and Wilson 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, Kujal and Rassenti (2009). The paper is currently unpublished, but we comment on it in footnote 33 (results section).

experimentally for industries with zero production cost (Le Coq and Orzen 2006) and for entry by new competitors (Brandts et al. (2008), rather than by divestiture.

In most industries, short-term costs are positive and convex due to a limited stock of (expensive) production assets. Indeed, many describe the marginal cost of producing in the electricity generation industry as "hockey-stick" shaped, i.e., marginal costs are flat but sharply increase when capacity constraints become binding (e.g., Newbery, 2002). Positive and convex costs imply producers must 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 convex costs.

We argue that a suitable benchmark to study the effect of forward markets in capital-intensive industries is to increase of the number of competitors by *divestiture* rather than by *entry,* as in Brandts et al. (2008).[5] Unlike introducing a new competitor through entry, which requires costly investment in new production assets, introducing a forward market or a new competitor through divestiture requires no investment in new production assets. Specifically, introducing a new competitor through entry increases the total set of assets in the industry, which means any given level of quantity is cheaper to produce due to the convex production function (the asset effect).[6] The resultant increase in production is thus a combined effect of more competitors (the competition-enhancing effect) and production assets (the asset effect).[7] The benchmark is therefore biased, as it unduly handicaps the competition-enhancing effects of forward markets (which do not affect the asset base). Divestiture, in contrast, has no asset effect, which allows us to cleanly compare the competition-enhancing effect of introducing a forward market to the competition-enhancing effect of adding more competitors through divestiture.

Increasing competition by divestiture is interesting theoretically and experimentally, as it has no asset effect. It is also interesting empirically, as it has played an important role 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. The two dominant electricity generators, NationalPower and PowerGen, altogether divested 6GW in 1996 and another 8GW in 1999, which resulted in lowered concentration (Green, 2006). Moreover, Belgium, France, Italy, Denmark, and the

[5] As Le Coq and Orzen (2006) assume zero production cost, it makes no difference in the predictions if the number of competitors is increased by entry or divestiture. We explain this in more detail in the Appendix.
[6] See the Appendix for a mathematical exposition of this point in a market with Cournot competition.
[7] While the increasing 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: When competition is lacking but there is no shortage of electricity production capacity, entrance leads to wasteful duplication of assets (Green 1996).

Netherlands are using, or have used the auctioning of Virtual Power Plants[8] to lower market power (Willems, 2006).

We compared the competition-enhancing effect of a forward market to the benchmark of increasing the number of competitors by divestiture. We thus eliminated the asset effect confound and isolated the competition effect. To make the comparison meaningful, we drew (to the extent possible) on Brandts et al. (2008) and on Le Coq and Orzen (2006) to design and parameterize our experiment. In the following section we first 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 quantity, 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: $p[Q] = Max[0, 2000 - 27Q]$ for $Q \geq 0$, and convex cost function for a firm in a market with 3 competitors:

$c_3[q] = \sum_{x=1}^{q} 2x^2 = (2/3)q^3 + q^2 + (1/3)q$ as Brandts et al. (2008).[9] A market with 3 competitors is a reasonable approximation for the old EU member states. Since the new EU member states have more concentrated markets, we also include a market with 2 competitors as a better approximation.[10] We refer to a market with 3 (2, 4) competitors as M3 (M2, M4), and to a market with 3 (2) competitors and a forward market as M3F (M2F). In contrast to Brandts et al. (2008), M4 (M2) is created from M3 by symmetric divestiture (reverse symmetric divestiture).[11]

When one competitor is added to a market with *n* producers by symmetric divestiture, each producer divests $1/(n+1)$ of their assets; these divested assets form a new independent producer. The

[8] When a generator sells a Virtual Power Plant, he sells part of his production capacity to other generators. This divestiture of generation capacity is called virtual as no production capacity changes hand, and the selling generator remains the owner of all its generation plants (Willems, 2006).

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

[10] 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.

[11] 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. To repeat, adding competitors by entry as in Brandts et al. (2008) includes an asset effect and thus provides a biased benchmark.

new market therefore has n+1 producers, who each have $n/(n+1)$ of the producers' asset base in the market with n producers. The cost function is transformed into[12]

$$c_{n+1}[q] = (n/(n+1)) \cdot c_n[((n+1)/(n)) \cdot q]. \quad (1)$$

Using (1) and $c_3[q]$, the given cost function of producers in M3, the producers' cost functions in M2 and M4 can be derived as $c_2[q] = (2/27)q^3 + (2/3)q^2 + (1/3)q$ and $c_4[q] = (22/27)q^3 + (4/3)q^2 + (1/2)q$, respectively.[13]

Table 1: Treatments

	2 producers	3 producers	4 producers
Without Forward Market	**M2#**	M3*	**M4†**
With Forward Market	**M2F#**	M3F*	–

\# These treatments were not tested in Brandts et al. (2008). They were 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 below in section 4 (results section).
* These treatments are identical to the ones tested in Brandts et al. (2008).
† This treatment is different from the one tested in Brandts et al. (2008), as the market has been created from the market with 3 producers by divestiture, not by entry.

Table 1 summarizes our treatments and indicates how they compare with Brandts et al. (2008). Table 2 contains the Nash equilibrium predictions for each treatment; recall that the subjects can choose only integer production values.[14] The prefix NE stands for Nash equilibrium, Walras for the efficient solution (the outcome that maximizes the total surplus),[15] and JPM for Joint Profit

[12] If all the assets of n producers would be merged into one single firm, then this single firm would minimize its costs by dividing production equally over the n plants. The total costs of the single firm would thus be $c_1[q] = n \cdot c_n[\frac{1}{n} \cdot q]$. Likewise, $c_1[q] = (n+1) \cdot c_{n+1}[((1/n+1)) \cdot q]$. As the total assets base is held constant, $c_1[q]$ is identical in both equations and thus the above formula can easily be derived.
[13] 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 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 page 9, Table 2 for an overview of the aggregate cost levels for M2(F), M3(F) and M4.
[14] See Van Koten and Ortmann (2011), page 11, footnote 20, for more details about the numerical procedure to determine the Nash equilibria.
[15] We define efficiency, following Brandts et al. (2008), as the joint consumer and producer surplus realized in the experiment divided by the maximum joint consumer and producer surplus (the Walrasian level of joint surplus).

Maximization (the monopoly solution).[16] Following standard convention in experimental economics, we define the welfare percentage as the realized joint consumer and producer surplus in the experiment divided by the maximum joint consumer and producer surplus (the Walrasian level of joint surplus). Welfare is strongly affected by the level of aggregate production. Namely, since the level of production is predicted to be below the Walrasian level due to market concentration, any measure that increases aggregate production will most likely increase welfare. Welfare can also be affected by productive efficiency, defined as the aggregate production costs divided by the minimal aggregate production costs.[17] We expect that the effect of productive efficiency is minimal and roughly equal across our treatments.

Table 2: Theoretical predictions electricity markets

	NE M2	**NE M2F (two Nash-equilibria)**		NE M3	**NE M3F**	NE M4	Walras (M2, M2F)	Walras (M3, M3F)	Walras (M4)	JPM (M2, M2F)	JPM (M3)	JPM (M4)
q_{ti}^{f}	–	2	11	–	5	–	–	–	–	–	–	–
q_{ti}	20	20	22	14/15[18]	15	11	25/26[19]	17	13	16	11	8
q_t	40	40	44	43	45	44	51	51	52	32	33	32
p_t	920	920	812	839	785	812	623	623	596	1136	1109	1136
Prod.S	31520	31520	28768	29537	27885	28768	21053	21063	19672	33572	33567	33572
Cons.S	21060	21060	25542	24381	26730	25542	34425	34425	35802	13392	14256	13392
Total S	52580	52580	54310	53918	54615	54310	55478	55488	55474	46964	47823	46964
Welf.(%)	94.8	94.8	97.9	97.2	98.4	97.9	100	100	100	84.7	86.2	84.7

Explanation of column terms: NE stands for the Nash-equilibrium, Walras for the Walrasian (welfare optimizing) equilibrium, and JPM for joint profit maximization (collusion).
Explanation of row terms: q_{ti}^{f} stands for the forward production of each producer, q_{ti} for the total production of forward (if it is present) and spot market for each producer, q_t for the total *aggregate* production of forward (if it is present) and spot market for all producers together, p_t for the price, *Prod.S* for producer surplus, *Cons.S* for consumer surplus, *Total.S* for total surplus, *Welf.(%)* for efficiency in percentage.

The theoretical predictions show, for the particular parameterizations chosen, the qualitative effect of introducing a forward market and of adding one or more competitor by symmetric divestiture on

[16] The market outcomes for JPM (M3, M3F) , JPM (M4), NE (M3), NE (M3F), Walras (M3, M3F), and Walras (M4) in this experiment are identically to those in Brandts et al. (2008), and our predictions are almost identical to the ones reported in their paper. See Van Koten and Ortmann (2011), footnote 22 for on overview of the main (but inconsequential) differences.
[17] Due to the convexity of the cost functions, minimal production costs are attained when production is distributed as evenly as possible across producers.
[18] One generator produces 15 units, the other two 14 units.
[19] One generator produces 26 units, the other two 25 units.

aggregate production and welfare. Using q(x) to denote aggregate production in market structure x, we formulate hypotheses in Table 3**Error! Reference source not found.**.

Table 3: Hypotheses

H1	Effect of forward market	q(M2F) > q(M2) q(M3F) > q(M3)
H2	Effect of adding one competitor by symmetric divestiture (benchmark)	q(M3) > q(M2) q(M4) > q(M3)
H3	Effect of forward market relative to benchmark	q(M2F) = q(M3) q(M3F) > q(M4)

Hypothesis 1 predicts the effect of introducing a forward market on aggregate production. Introducing a forward market in M2 results in two welfare-rankable Nash equilibria: one with quantity 40 ("low") and one with quantity 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 quantity. Similarly, in M3, theory predicts that the forward market will have a positive effect on quantity. Hypothesis 2 predicts the effect of adding one more competitor by symmetric divestiture (the benchmark) on aggregate production. Both measures are hypothesized to increase aggregate production in markets M2 and M3. Hypothesis 3 compares the predicted effect of the forward market relative to the benchmark. Since the production in M3 is in between the low and high Nash equilibria of M2F, we cannot make a prediction. Therefore, by the principle of insufficient reason, we hypothesize that the effects will be equal. In M3, theory predicts that the effect of the forward market will be larger than the benchmark. As mentioned above, we expect the data on welfare to closely follow the patterns of those on the aggregate quantity.

3. Experimental procedures

The experimental sessions were conducted in October 2009, December 2009, and April 2010 in Prague at CERGE-EI.[20] Subjects were students at the Charles University or at the University of Economics, both located in Prague. A total of 198 students participated in the experiment. The sessions with (without) a forward market lasted approximately 2 hours (90 minutes). The subjects earned on average 382 Czech Koruna per hour, including a show-up fee of 100 Korunas. Subjects thus earned on

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

average 640 Korunas[21]. The minimum earning was 330 and the maximum earning was 1080 Korunas. 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 and sellers. They were not shown the demand schedule, but were given an earnings table on the screen and as a printout. During the experiment, once subjects submitted their choice for the (forward) spot market, they were shown the following outcomes: the aggregate quantity sold, the resulting price per unit on the (forward) spot market, and their own profit, marginal cost, and cumulative costs. 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), subject 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 second period (in the spot market).

In the forward market, two pre-programmed traders competed in prices for the total number of units that were offered.[22] Traders were programmed to act rationally. Their actions defined a demand schedule, which we presented to our producers.[23] 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 the 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 market together for Q in the demand schedule $p[Q] = Max[0, 2000 - 27Q]$. All producers were paid the number of units they produced in the spot market times the price per unit, minus the production cost.

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[21] This amount equaled about €26 (and about €36at official purchasing power parity, 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.

[22] 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 a producer earns.

[23] See Van Koten and Ortmann (2011), page 14, for details on the preprogrammed traders, and page 45, Appendix F, for the consolidated instructions.

4. Results

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

Following Le Coq and Orzen (2006), we test for deviations from the Nash-equilibrium predictions using two-sided Wilcoxon one-sample signed-rank tests (two-sided signed-rank tests), unless indicated otherwise. To be conservative, we treat each set of sellers ("a group") per treatment as a single data point. We therefore have 11 statistically independent data points for each of the five treatments reported here. Since each participant took part in one experimental session only, data points are independent across treatments. There was no bankruptcy in the experiment.

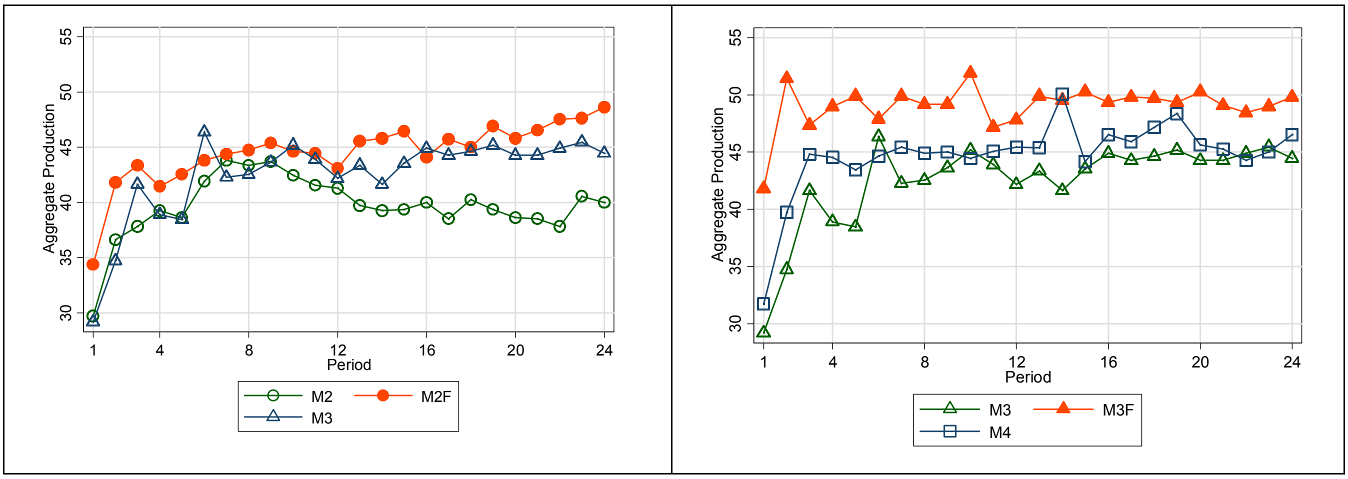
In line with Brandts et al. (2008), we test our hypotheses with F-tests based on an OLS regression of the dependent variable on the 5 treatment dummies, M2, M2F, M3, M3F, and M4, without a constant (F-tests): $AggregateSupply = \beta_1 \cdot M2 + \beta_2 \cdot M2F + \beta_3 \cdot M3 + \beta_4 \cdot M3F + \beta_5 \cdot M4 + \varepsilon$. The error terms are adjusted for clustering at the group level by using the robust Huber-White sandwich estimator (Froot, 1989).[25]

Figure 1 shows the evolution of total (aggregate) quantities sold per period, averaged over groups in each treatment. Treatments with two producers are represented by circles, with three producers by triangles, and with four producers 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[26], but then quickly converges to the Nash-equilibrium. Production stabilizes between rounds 8 and 12.

Figure 1: Aggregate production

a) M2, M2F, M3	b) M3, M3F, M4

[24] Including all 24 rounds, or only the last 10 rounds as Brandts et al. (2008) did, does not change our results qualitatively and all results remain significant.
[25] In addition, we ran robustness tests using, as did Le Coq and Orzen (2006), Wilcoxon rank-sum tests (rank-sum tests). These tests confirmed most of the results presented here. The results of these tests can be found in Van Koten and Ortmann (2011), p.31, Appendix B.1.
[26] 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.



For the treatments without forward markets, the M2 and M3 quantities are not significantly different from the Nash-equilibrium predictions (two-sided signed rank test, both p-values > 0.32), whereas the M4 quantities are significantly larger (p-value = 0.068). For the treatments with a forward market, production in M3F is significantly higher than the Nash-equilibrium (p-value = 0.004). Also, production in M2F is significantly higher than the low Nash-equilibrium (p-value = 0.021), but not significantly different from the high Nash-equilibrium (p-value = 0.248).

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

Table 4 Average aggregate production (last 12 rounds)

	M2	M2F	M3	M3F	M4
Average aggregate production	39.3 (5.033)	46.3 (6.816)	44.2 (4.063)	49.6 (2.010)	46.2 (3.26)
Predicted quantity (NE)	40	40/44	43	45	44
% of NE prediction	98.7%	116 %/ 105%[27]	102.9%	110.1%	105.0%
Number of observations	N = 11	N = 11	N = 11	N = 11	N = 11
Results of Brandts et al. (2008) for comparison					

[27] The first number gives the percentage of output relative to the low production Nash-equilibrium, the second number relative to the high production Nash-equilibrium.

Average aggregate production			42.5 (5.57)	48.8 (2.41)	50.9 (5.86)
Predicted quantity (NE)			43	45	49
% of NE prediction			98.9%	103.6%	105.0%
Number of observations			N = 7	N = 6	N = 7
Results of Le Coq and Orzen (2006) for comparison					
% of NE prediction	93. 2%,	93.8%,			113.7%
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).

Table 4 shows the average aggregate production for the last 12 rounds per treatment group with the standard deviation in parentheses.[28] Row “% of NE prediction” shows average aggregate production per treatment group relative to the Nash-equilibrium prediction (which is given in the row above). For comparison purposes, average aggregate production and % of NE prediction of Brandts et al. (2008) and Le Coq and Orzen (2006) are also shown in Table 4. Average aggregate production in the market with four producers (M4) is significantly smaller than in Brandts et al. (2008) (46.2 versus 50.9, p-value = 0.06), which suggests the asset effect influenced their results. Our results replicate the findings of Brandts et al. (2008) for the treatments without forward markets, as Wilcoxon rank-sum tests show no significant differences in “% of NE prediction” across studies for M3 (102.9% versus 98.9%, p-value = 0. 56) and M4 (105.0% versus 105.0%, p-value = 0. 89). We thus find the same behavioral effects as Brandts et al. (2008): outcomes are close to the Nash equilibrium predictions for M3 and significantly more competitive for M4. We find, however, a significantly higher average aggregate production in M3F than Brandts et al. (110.1% versus 103.6%., p-value = 0.02), suggesting a behavioral effect that further strengthens the competitive effect of a forward market.[29]

Using the percentage of the Nash equilibrium predictions measure, we observed larger average aggregate production in markets with two producers than in Le Coq and Orzen (2006). This conforms to earlier theoretical and experimental evidence, which shows that increasingly steep cost curves lead to more competitive outcomes (Davis & Reilly, 2003; Engel 2007). As robustness tests, we conducted treatments without production costs, and found that the average aggregate production was significantly lower than in treatments with (convex) production costs. A detailed analysis can be found in Van Koten

[28] The standard error is computed based on the averages for each of the 11 independent groups over the last 12 rounds.
[29] Our use of pre-programmed traders may be the cause of our stronger effect of the forward market compared with Brandts et al. 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.

and Ortmann (2011, Appendix B.2). Table 5 presents the results of the F-tests based on OLS regressions, clustered on groups.[30]

Table 5: Effects of one more competitor and forward market

H1	Effect of forward market	**a) q(M2F) > q(M2)**	*****(p=0.003)**	N=528 (11)
		b) q(M3F) > q(M3)	*****(p<0.001)**	N=792 (11)
H2	Effect of adding one competitor by symmetric divestiture (benchmark)	**a) q(M3) > q(M2)**	**** (p=0.006)**	N=660 (11)
		b) q(M4) > q(M3)	(p=0.105)	N=924 (11)
H3	Effect forward market relative to benchmark	a) q(M2F) = q(M3)	(p=0.374)	N=660 (11)
		b) q(M3F) > q(M4)	*****(p=0.002)**	N=924 (11)

N: Number of observations (independent groups)

Results testing Hypothesis 1 (Effect of forward market)**:**

Introducing a forward market increases production.

We therefore find support for Hypothesis 1:

- q(M2F) ≤ q(M2) is REJECTED in favor of q(M2F) > q(M2), p-value = 0.003.[31]
- q(M3F) ≤ q(M3) is REJECTED in favor of q(M3F) > q(M3) , p-value < 0.001.

In line with theoretical predictions, introducing a forward market increases aggregate production by 12% (44.2 -> 49.6) in markets with three competitors and by 18% (39.3 -> 46.3) in markets with two competitors. The increases are strongly significant and are qualitatively in line with all previous experimental evidence.

Results testing Hypothesis 2 (Effect of benchmark - of adding one competitor by symmetric divestiture)**:**

In markets with 2 producers, the benchmark measure of adding one more competitor by divestiture increases, as predicted, production significantly. In markets with 3 producers, it also increases production, but there misses statistical significance at conventional levels albeit barely.

We find therefore find partial support for Hypothesis 2:

- q(M3) ≤ q(M2) is REJECTED in favor of q(M3) > q(M2), p-value = 0.006.
- q(M4) ≤ q(M3) is NOT REJECTED in favor of q(M4) > q(M3) , p-value = 0.105.

In line with theoretical predictions, adding one more competitor by divestiture increases production by 12% (39.3 -> 44.2) in markets with two competitors and by 5% (44.2 -> 46.2) in markets with three

[30] To test robustness, we also compared the averages for the groups using a two-sample Wilcoxon rank-sum (Mann-Whitney) test. The hypotheses accepted (rejected) are the same, except for Hypothesis 2.b (which becomes insignificant) and Hypothesis 3. c (which becomes significant). See the Appendix for a detailed analysis.

[31] Also in our robustness sessions for M2 and M2F, where producers had zero costs, the session with a forward market has significantly higher aggregate production that the one without a forward market (p<0.010).

competitors. The increase is strongly significant in markets with two producers. The result is in line with the finding of Huck et al. (2004) that a market with three producers is already relatively competitive (producing slightly more than the Nash equilibrium quantity), while a market with two producers is relatively collusive (producing slightly less than the Nash equilibrium quantity). The declining effects of larger numbers of competitors is of interest due to the typical market configuration in old and new member states, as discussed earlier.

Results testing Hypothesis 3:

Introducing a forward market increases production more than the benchmark in markets with 3 competitors, but not in markets with 2 competitors.

We therefore find partial support for Hypothesis 3:

- q(M2F) = q(M3) is NOT REJECTED in favor of q(M2F) ≠ q(M3), p-value = 0.374.
- q(M3F) ≤ q(M4) is REJECTED in favor of q(M3F) > q(M4) , p-value = 0.002.

Introducing a forward market increases aggregate production more than adding one more competitor by divestiture. The difference is 5% in markets with two competitors (44.2 -> 46.3) and 7% in markets with three competitors (46.2 -> 49.6), the latter as predicted. The difference is statistically significant only in the market with three competitors.

Running the same tests for welfare confirms our expectation that the welfare percentage closely follows the patterns of aggregate production. As expected, the effect of productive inefficiency turns out to be small and inconsequential.[32]. We also observed that prices in the forward market were rational in the sense that they predicted prices in the spot market well: the average difference between the spot and forward market was equal to 0.001 (0.01) over the last 12 rounds, which is not significantly different from zero (p < 0.93).

Table 6 summarizes our theoretical and experimental results for the aggregate production, together with the key results of earlier experiments.

Table 6 Comparison of our results with those of earlier studies

	Theoretical predictions in our study	Results of earlier studies	Empirical results of our study
Market with 2 competitors			
One more competitor (OMC)	+ 7.5%	-	**+ 12.1% ** (39.3 -> 44.2)**
Forward Market	+ 5%#	**+ 20.9% *****	**+ 17.8% *****

[32] See Van Koten and Ortmann (2011) for details on the effect of our treatments on the welfare and productive inefficiency measures.

(FM)		**(Le Coq & Orzen, 2006)**	**(39.3 -> 46.3)**
Largest increase by	OMC, by 8% (low NE) FM, by 2% (high NE)	-	FM, by 4.7% (44.2 -> 46.3) (not significant)

Market with 3 competitors

One more competitor (OMC)	+ 2.3%	**+ 19.6%***** **(Brandts et al., 2008)**	+ 4.5% (44.2 -> 46.2) (not significant)
Forward Market (FM)	+ 4.7%	**+ 9.5%**** **(Brandts et al., 2008)**	**+ 12.0% ***** (44.2 -> 49.6)
Largest increase by	**FM, by** 2.3%	**OMC, by 9.2% **** **(Brandts et al., 2008)**	**FM, by 7.3% ***** (46.2 -> 49.6)

•••• Results contrast with earlier results.
▬ Results contradict earlier results.

Our results show that in markets with three competitors, introducing a forward market significantly increases aggregate production, which is in line with our theoretical prediction and earlier experimental results (Brandts et al., 2008).[33] Introducing a forward market increases aggregate production significantly more than adding one more competitor, which confirms our theoretical prediction, but contradicts the findings of Brandts et al. (2008) (the contradictory findings are indicated by a bold frame in

Table 6). In line with our theoretical prediction, adding one more competitor increases aggregate production. The increase is, however, not significant, which is in contrast with the findings of Brandts et al. (2008). The larger, significant effect in Brandts et al. (2008) is probably due to the asset effect, which – as we have argued – makes production relatively cheaper. Our findings show that without an asset effect, the competition-enhancing effect of introducing an additional competitor to the market is minor in a market with three competitors. In markets with two competitors, in line with earlier experimental results (Le Coq and Orzen, 2006), introducing a forward market significantly increases aggregate production. We could not replicate the finding of Brandts et al. (2008) that this increase would be smaller than that of adding one more competitor. Our data suggests the opposite.

[33] We tested, as a robustness test, if the competitive-enhancing effect is robust when subjects are experienced. We became aware of the possibility of such an issue through a working paper of 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 production with inexperienced subjects, but no – or a negative – effect with experienced subjects. We do not find that experienced subjects have a lower aggregate production than inexperienced subjects. On the contrary, our experienced subjects supply a slightly higher production which is in line with the experimental literature on the effect of experience on public good provision (Ledyard, 1995). For the detailed results, see our Van Koten and Ortmann (2011), p. 39, Appendix D.

6. Conclusion

We experimentally investigated the effects of introducing a forward market on competition. We compared the effect to the best alternative - reducing concentration by adding an additional competitor by divestiture. Our results suggest 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 production. This gives tentative support to the European Commission's preference for behavioral remedies, such as the introduction of a forward market (European Commission, 2006a, p.11). The result 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 supply in the Australian electricity market and the Dutch gas market, respectively.

Our results contradict the findings of Brandts et al. (2008), who found 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 confounding the competition effect and the asset effect. Brandts et al. (2008) add one more competitor by entry, which increases competition and increases the aggregate asset base. This reduces the aggregate cost and thus increases the incentive to raise production. This asset effect is likely influential, as producers have steeply increasing costs. The welfare effects these authors report are not conclusive, as they do not incorporate the costs of the increase in the asset base (the cost of building extra production plants). In our study, we control for the asset effect by adding one more competitor by divestiture. In addition, we find a stronger behavioral effect of introducing a forward market in a market with three producers. 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 on the effectiveness of forward markets in the EU, as design is an important factor for the thickness of forward markets in EU countries (European Commission, 2007a, p.127). In Spain, for example, forward trading is de facto forbidden by design (European Commission, 2007a, p.127). In Greece forward trading has been made virtually impossible by design, as it has made trading in the pool mandatory (European Commission, 2007b, p.50). In contrast, in France the PowerNext exchange market allows for the trading of forward and future contracts of months, quarters, and years ahead. Our study suggests that forward markets could play a role in enhancing competition in concentrated markets and thus suggests that the design, or evolution, of public forward exchanges such as in France (and many other developed markets) should indeed be encouraged. Moreover, 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 completely transparent as most trading takes place at Over-The-Counter (OTC) markets over different trading platforms and a considerable proportion (around 10%) takes places bilaterally without intermediaries (European Commission, 2010, 9-11). Forward trading positions may thus often not be observable. Our results thus suggest that making the EU forward energy markets more transparent could contribute to a more competitive market.

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Appendix

When one competitor is added to a market with n producers by symmetric divestiture, the cost function is transformed into

$$c_{n+1}[q] = (n/(n+1)) \cdot c_n[((n+1)/(n)) \cdot q].^{34} \quad (1)$$

With convex costs, the divestment causes the marginal cost to increase:

$$c'_{n+1}[q] = c'_n[((n+1)/n) \cdot q] > c'_n[q]. \quad (2)$$

In a market with Cournot competition, each of the n producer maximizes: $\pi_i[q_i] = q_i \cdot p[Q] - c_n[q_i]$. The first order condition for profit maximizing is $p[Q] - c'_n[q_i] = q_i \cdot -p'[Q]$. Focusing on symmetrical equilibria for producers with identical cost functions, this can be rewritten as

$$p[Q] = (Q/n) \cdot -p'[Q] + c'_n[Q/n], \quad (3)$$

where $c''_n[q] \geq 0$ and $P'[Q] < 0$.

Adding competitors by entry increases n and thus lowers the right hand side of (3). Thus, to preserve equivalence, the left hand side must decrease, which implies that the aggregate quantity Q increases. The entry of new competitors therefore increases the aggregate production. However, as argued above, this involves also a costly investment in production assets by the entrant, outlays that are not necessary for the introduction of a forward market.

Adding competitors by divestment increases n and lowers the right hand side of (3), but less so than in the case of entry, as (2) indicates that the marginal cost function of each producer, $c'_n[\cdot]$, increases. The increase in the aggregate production, Q, needed to keep the equivalence of (3), is thus smaller. The competition-enhancing effect of adding more competitors will thus be lower with divestiture than with entry. There is no such difference in effect between entry and divestiture when marginal costs are constant as this implies that the marginal cost term in (3), $c'_n[Q/n]$, is equal to zero. As Le Coq and Orzen (2006) assume zero production costs, their benchmark of adding competitors can be interpreted as the result of either entrance or of entry. For the setup of Brandts et al. (2008), assuming convex costs, entry and divestiture have differential effects.

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[34] If all the assets of n producers would be merged into one single firm, then this single firm would minimize its costs by dividing production equally over the n plants. The total costs of the single firm would thus be $c_1[q] = n \cdot c_n[\frac{1}{n} \cdot q]$. Likewise, $c_1[q] = (n+1) \cdot c_{n+1}[((1/n+1)) \cdot q]$. As the total assets base is held constant, $c_1[q]$ is identical in both equations and thus the above formula follows.