STRUCTURAL VERSUS BEHAVIORAL REMEDIES IN THE DEREGULATION OF ELECTRICITY MARKETS: AN EXPERIMENTAL INVESTIGATION GUIDED BY THEORY AND POLICY CONCERNS

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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 try to better understand the comparative advantages of structural and behavioral remedies of deregulation in electricity markets, an eminent policy issue for which the experimental evidence is scant and problematic. Specifically, we investigate theoretically and experimentally the effects on competition of introducing a forward market — considered a behavioral remedy by the European Commission. We compare this scenario with the best alternative, the structural remedy of reducing concentration by adding one more competitor by divestiture. Our study contributes to the literature by introducing more realistic cost configurations, by teasing apart competition effect and asset effect, and by investigating competitor numbers that reflect the market concentration in the European electricity industries. Our experimental data suggest that introducing a forward market has a positive effect on the aggregate supply in markets with two or three major competitors, configurations typical for the newly accessed and the old European Union member states, respectively. Introducing a forward market also increases efficiency. In contrast to previous findings, our data furthermore suggest that the effect of introducing a forward market is stronger than adding one more competitor both in markets with two, and particularly three, producers. Our data thus provides evidence that behavioral remedies may be more effective than structural remedies. Our data suggest that competition authorities are well advised, in line with EU law (European Commission, 2006a, p.11), to focus on introducing, and facilitating the proper functioning of, forward markets rather than on lowering market concentration by divestiture.

Keywords: economics experiments, market power, competition, forward markets, EU electricity market.
JEL classification: C91, D61, L13, L43, L94, Q48.

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Abstrakt

Pokoušíme se lépe porozumět komparativním výhodám strukturálních a behaviorálních opatření deregulace na trzích s elektřinou, což je významná otázka při tvorbě veřejné politiky, pro niž existují limitovaná a problematická data. Teoreticky a experimentálně zkoumáme efekty, jež na konkurenci má zavedení termínového trhu – považovaného Evropskou komisí za behaviorální nápravu. Srovnáváme tento scénář s nejlepší alternativou, strukturálním opatřením, které snižuje koncentraci tím, že přidává dalšího konkurenta pomocí divestitury. Naše studie přispívá do existující literatury zavedením realističtějších konfigurací cen pomocí oddělení efektu konkurence od efektu jmění a pomocí prozkoumání počtů konkurentů, které odráží tržní koncentraci na evropských trzích s elektřinou. Naše experimentální data naznačují, že zavedení termínového trhu má pozitivní dopad na agregovanou nabídku na trzích s dvěma nebo třemi hlavními konkurenty, což jsou konfigurace typické pro nově přistoupivší, respektive staré členy Evropské unie. Zavedení termínového trhu také zvyšuje efektivitu. V protikladu k dřívějším zjištěním naše data dále naznačují, že efekt zavedení termínového trhu je silnější než přidání dalšího konkurenta na trzích s dvěma, a zejména třemi, producenty. Naše data tedy přinášejí důkazy, že behaviorální opatření mohou být efektivnější než opatření strukturální. Naše data naznačují, že úřady na ochranu soutěže by se v souladu s právem EU (Evropská komise, 2006a, str. 11) měly zaměřit na zavedení a podporu správného fungování termínových trhů místo toho, aby se zaměřovaly na snižování tržní koncentrace pomocí divestitur.

1. Introduction

Concentration in generator markets remains a major problem in the EU electricity markets. The European Commission (2007a, p.7), for example, concludes: "At the wholesale level, gas and 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." The European Commission suggests structural remedies[2] such as divestiture or asset swaps of power plants on a European scale (2007a, p.15), blocking mergers (2007a, p.12), auctioning large scale Virtual Power Plants (2007a, p.12), stimulating the entrance of new electricity generators (2007a, p.16), and increasing competition by enabling generators from abroad to sell electricity over cross-border transmission lines (2007a, p.8).

Several EU member states have experience with some of these structural remedies. For example, at the end of the nineties, the UK forced dominant electricity generators to divest plants; the two dominant electricity generators NationalPower and PowerGen together divested 6GW in 1996 and another 8GW in 1999, thus lowering concentration (Green, 2006). However, beginning in 2000, the UK experienced mergers which reversed that trend.[3] The UK also experienced a considerable degree of new entry.[4] Belgium, France, Italy, Denmark, and the Netherlands are using, or used in the past, the auctioning of Virtual Power Plants[5] to lower market power (Willems, 2006). Finally, several countries increased the capacity of cross-border transmission lines and harmonized their market regimes with neighboring countries to make it easier for generators to sell electricity over borders, thus increasing competition.

The encouragement of cross-border trading – while creating a larger, European, market – is likely to alleviate the concentration problem only marginally; many electricity companies have merged across borders, and have thus become players in neighboring countries (Matthes, Grashof, and Gores, 2007). Increasing competition is therefore done most efficiently - avoiding duplication of investment in generation assets[6] - by divestiture; enforcing big incumbent power companies to sell parts of their plants, and thus adding to the capacity of competing new entrants. Of interest are

[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."

[3] In 2002 one of the largest generators, PowerGen, merged with TXU Europe, thus adding 3GW to its capacity (Green, 2006).

[4] The policy of allowing distributors to sign long-term contracts with independent power producers promoted entry of new electricity producers, mainly with new Combined-Cycle-Gas-Turbine (CCGT) generation technology (Newbery, 2002).

[5] 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 hands, and the selling generator remains the owner of all its generation plants (Willems, 2006).

[6] Entry of new generators is generally not the most efficient solution to increase competition. When there is no need for new generation investment, entry, by adding excessive capacity, imposes deadweight losses on the market that can be larger than the gains of increased competition (Green, 1996). Divestiture is in such case the best alternative solution.

also “softer” remedies, such as discouraging incumbents to replace old plants and instead encouraging new entrants to build generation assets, as this is effectively a form of divestiture (no duplication of investment in generation assets).

In addition to such structural remedies, policy makers and regulators have shown interest in behavioral remedies[7] that prevent electricity generators, through the appropriate organization of electricity markets, to be able to use their market power. The wording of EU law suggests that behavioral remedies ought to be the default setting : “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) make the theoretical case for the introduction of a forward market as a behavioral remedy that increases competitive pressure.[8] Specifically, analyzing competition in a one-shot game set-up, they show that a forward market lowers the amount of market power producers can exert. The contribution of Allaz and Vila (1993) is important since it has been argued that forward contracts are likely to decrease competition (Lévêque, 2006). Willems et al. (2009), drawing on Allaz and Vila (1993), give the following brief explanation of the effect. In the spot market every producer maximizes his profit given by the profit function $\pi_i = p[q_i + q_{-i}](q_i - f_i) - c[q_i]$, where q_i stands for their own production, q_{-i} for the production of all other producers, and f_i for the number of units sold in the forward market. Differentiating this equation to q_i and setting it equal to zero yields $0 = \frac{d\pi_i}{dq_i} \Leftrightarrow -p'[Q](q_i - f_i) = p[Q] - c'[q_i]$. This equation can be rewritten[9] as $\frac{s_i}{E_p^Q}(1 - \frac{f_i}{q_i}) = \frac{p[Q] - c'[q_i]}{p[Q]}$, where s_i stands for the market share and E_p^Q for the price elasticity of demand. We can see from the formula that the markup (the right-hand side of the equation) decreases in f_i, the number of units sold in the forward market. The more

[7] The European Commission (2006b, p.8) defines a behavioral remedy as “a measure that obliges the concerned undertaking(s) to act in a specific way”.

[8] It has been suggested that a forward market also constitutes a structural remedy. We are agnostic on this definitional issue; after all it is just a label. We note that the EC which defines measures that nudge towards particular actions as behavioral remedies and measures that change the structure of a producer (such as divesture) as a structural remedy. In general, behavioral remedies are easier to implement than structural remedies.

[9] Multiplying the left side by $\frac{p[Q] \cdot q_i \cdot Q}{p[Q] \cdot q_i \cdot Q}$ gives $-p'[Q](q_i - f_i) \cdot \frac{p[Q] \cdot q_i \cdot Q}{p[Q] \cdot q_i \cdot Q} = p[Q] - c'[q_i]$. Rearranging gives

$$-p'[Q]\frac{Q}{p[Q]}\frac{q_i}{Q}\frac{(q_i - f_i)}{q_i} = \frac{p[Q] - c'[q_i]}{p[Q]}.$$

producers sell in the forward market, the closer the outcome in the spot market will be to the Walrasian outcome.

Welfare and consumer surplus thus increase in the number of units sold in the forward market. But do producers have incentives to sell units in the forward market? Allaz and Vila (1993) show that they do. Suppose that only one, privileged, firm could sell in the forward market. In that case this firm has a first mover's advantage. It can, by selling the right number of units in the forward market, reach the Stackelberg equilibrium, which has a higher profit for the privileged firm. Thus, it cannot be a Nash-equilibrium for any firm to sell in the forward market. Consequently, when all firms are entitled to sell in the forward market, they all end up worse off than when none of them had sold. This prisoner's-dilemma type result is standard textbook (e.g., Binmore 2007, chapter 10). Producers earn the highest profit if nobody sells in the forward market, but selling in the forward market is a strictly dominant action for each individual producer. Allaz and Vila (1993) model the competition as a one-shot game. The Nash-equilibrium of a one-shot game and that of a repeated game with predictable ending are theoretically (albeit not necessarily behaviorally) identical. This makes the Allaz and Vila model a fitting theoretical benchmark for an experiment with a fixed, or predictable, number of periods. Of course, in the real world there is no fixed ending of the game (and the Nash-equilibrium of the stage game is one of many equilibria) which might affect the interpretation of the external validity of our results.

In this paper we investigate theoretically and experimentally the effects on competition of introducing forward markets in electricity markets. For relevant parameterizations, we compare the results of introducing a forward market with those of the best alternative remedy: reducing market concentration by divestiture. We do so for competitor numbers that better reflect the market concentration in the old European states than previous literature has done: We also use realistic cost configurations and tease apart competition and asset effect.

We show that, theoretically and behaviorally, the effects of introducing a forward market might be larger than adding one more competitor in markets both with two and three producers. Previously, Brandts, Pezanis-Christou, and Schram (2008) came to the opposite conclusion for the case of three initial competitors.

Whether the theoretical predictions of Allaz and Vila (1993) will materialize in the reality of a dynamic setting such as the EU electricity market has clear policy implications. An affirmative answer would suggest that regulators formulate guidelines for, and promote, the design of effective forward markets.

In the following section we first discuss the experimental design (i.e., the basic parameterizations, treatments, underlying working hypotheses) and experimental procedures as well as related literature. In section 3 we report the results focusing on aggregate quantity, efficiency, and production efficiency. In section 4 we conclude. The appendices contain robustness tests and instructions.

2 Experimental design and procedures

2.1 Treatments

We identify the effects of adding one more competitor through divestiture on the one hand and the effects of introducing a forward market on the other, and then compare the effects.

We model the competition of generators in the spot and forward markets using the standard Cournot approach (see for example Borenstein and Bushnell, 1999; LeCoq and Orzen, 2006; Bushnell 2007; Newbery, 2009). The supply-function approach of Klemperer and Meyer (1989) has been argued to be a more accurate approach to model competition in electricity markets. The supply-function approach, however, is more complicated and predicts a wide continuum of equilibria which in turn brings about an equilibrium selection problem (see Devetag and Ortmann, 2007, for a recent review). Wolak and Patrick (2001) provide empirical evidence that dominant generators exert market power by declaring plants to be unavailable, thus shifting the supply curve and suggesting that the Cournot approach is an appropriate modeling choice. In addition, Willems et al. (2009) show that Cournot and supply-function approaches lead to comparable outcomes. In contrast, Green (2004) argues that the Cournot approach does not accurately characterize producer behavior in England and Wales between 1985 and 2000.

Klemperer and Meyer (1989) show that the Cournot equilibrium outcome is the equilibrium with the maximal exertion of market power in the range of supply-function equilibria and hence, arguably, the natural benchmark. Brandt et al. (2008) show that this is also true for configurations with a forward market. The Cournot approach is thus not only relevant and interesting, but can be understood as a necessary first step for additional studies using the supply-function approach.

Table 1 summarizes our treatments and indicates how they compare with earlier studies, namely LeCoq and Orzen (2006) and Brandts et al. (2008), about which more below.

Table 1: Treatments

	2 producers	3 producers	4 producers
Without Forward Market	**M2**#	M3*	**M4**†
With Forward Market	**M2F**#	M3F*	–
Without Forward Market, zero costs	M2zc§	–	–
With Forward Market, zero costs	M2Fzc§	–	–

\# The treatment is different from the one tested in LeCoq and Orzen (2006) in that our producers face quadratic marginal costs.

† The treatment is different from the one tested in Brandts et al. (2008) in that the market has been created from the market with 3 producers by divestiture, not by entry; producers thus have the same set of assets as those in the market with 3 producers.

§ The treatment is identical to the one tested in LeCoq and Orzen (2006).

* The treatment is identical to the one tested in Brandts et al. (2008).

A key characteristic is the number of producers in the electricity market. While there is some variance, assuming two producers for markets in the new EU member states[10] and three producers for markets in the old EU member states[11] seems a good approximation.[12]

For the NMS-12 we thus compare outcomes in markets with two producers and without a forward market (M2) with outcomes in such markets with a forward market (M2F). We also compare the difference in outcomes with the difference in outcomes of markets with two (M2) and three producers (M3), when for the latter we add one more producer by means of divestiture. In other words, we compare the differences of M2F – M2 and M3 – M2. The markets M2zc and M2Fzc are treatments to allow comparison of our results with the experimental results of LeCoq and Orzen (2006).

For the EU-15 we compare outcomes in markets with three producers and without a forward market (M3) with outcomes in such markets with a forward market (M3F). We also compare the difference in outcomes with the difference in outcomes of markets with three (M3) and four producers (M4), when for the latter we add one more producer by means of divestiture. In other words, we compare the differences of M3F – M3 and M4 – M3.

2.2 Earlier experiments

LeCoq and Orzen (2006) conducted experiments in markets with two producers with and without a forward market and compared the outcomes with those in a market with four producers (with and without a forward market); importantly, their producers faced zero production costs. In line with earlier experiments, such as Huck et al. (2004), LeCoq and Orzen (2006) found that producers competed less (more) than predicted with two (four) producers. A forward market had a positive effect, but weaker than expected. Adding two more producers increased output significantly more than introducing a forward market.

LeCoq and Orzen (2006) consider the effects of a forward market in a market with two (and four) producers. While speaking possibly to the reality of electricity markets in the NMS-12 countries, the number of relevant competitors tends to be three for EU-15 countries. Moreover, the

[10] The new EU member states are the states that acceded to the EU in or after 2004. With the exception of Cyprus and Malta they are all post-communist countries: Bulgaria (BG), Cyprus (CY), the Czech Republic (CZ), Estonia (EST), Hungary (H), Lithuania (LT), Latvia (LV), Malta (M), Poland (PL), Romania (RO), Slovakia (SK), and Slovenia (SLO).

[11] The old EU member states are the states that joined the EU before 2004. These are: Austria (A), Belgium (B), England (UK), Germany (D), Denmark (DK), Spain (E), France (F), Finland (FIN), Greece (GR), Italy (I), Ireland (IRL), Luxembourg (L), the Netherlands (NL), Portugal (P), Sweden (S).

[12] The average Hirsch-Herfindahl Index (HHI) for the old (West European) EU members in 2006 was equal to 3786, which is close to the case where three symmetrical firms compete (HHI=3333). The new (Central and East European) EU members had in 2006 a HHI equal to 5558, which is closer to the case where two symmetrical firms compete (HHI=5000) (Van Koten and Ortmann, 2008).

assumption that producers have zero marginal costs is unrealistic for all scenarios. In our experiment, producers therefore face, more realistically (e.g., Newbery, 2002) and in line with Brandts et al. (2008), quadratic marginal costs.

Brandts et al. (2008) conducted experiments in markets with three producers with and without a forward market and compared the outcomes with those in a market with four producers (without a forward market). Producers had quadratic marginal costs. Brandts et al. (2008) find that a forward market significantly increases the quantity supplied, but that entry of a new generator increases the quantity supplied significantly more than the addition of a forward market.

Brandts et al. (2008) confound two effects in their study: the competition effect[13] and the asset effect. The competition effect is brought about by an additional market participant; this makes the market more competitive and results in lower prices and a larger total number of units supplied. The asset effect is brought about by the additional production assets that are built and paid by a new entrant. Because Brandts et al. (2008) consider the entrance of a new generator, their treatment combines the competition and the asset effect: entrance increases competition, but also the aggregate size of production assets in the market, which reduces the aggregate cost and thus gives an extra incentive to increase production. Thus, assuming efficient production, any given level of aggregate production (the production of all producers together) is produced more cheaply in the market with four producers than in the market with three producers. We conjecture that the asset effect confound led to an overestimation of the effects of adding one more competitor in their study. Moreover, the welfare effects Brandts et al. (2008) reports are not conclusive, as they do not incorporate the very high costs of the increase in the asset base (the cost of building extra production plants). [14]

We therefore focus on the effect of divestiture as a benchmark for the effects of introducing a forward market, thus eliminating the asset effect confound and insulating the competition effect. To allow for comparisons, we drew (to the extent possible) on Brandts et al. (2008) and on LeCoq and Orzen (2006) to parameterize our experiment.[15]

[13] Brandts et al. (2008) call this effect the "number effect".

[14] Building electricity generation is very costly, and when the problem is a lack of competition but not a shortage of electricity production capacity, entrance leads to a wasteful duplication of assets (Green, 1996).

[15]Another paper addressing forward markets is Ferreira, Kujal and Rassenti (2009). Ferreira et al. (2009) find that forward markets have a positive effect on the aggregate production for inexperienced subjects, but no - or a negative - effect with experienced subjects. Producers in their experiment face linear rather than (as in our set-up) quadratic marginal costs. Also, subjects had a mere 30 seconds to make a decision and no extra time to review the results, whereas the subjects in our study had 60 seconds to make a decision and another 60 seconds to review the result of that decision. Moreover, in the experiment of Ferreira et al. (2009) the treatments with experienced subjects were different from the treatments with inexperienced subjects in important details. For example, the experienced subjects did not have production costs and the demand function they faced was different. In addition, due to random matching, the experiment draws on very few independent data points (1 or 2).

We found the result that experience decreases the competitive effect of a forward market nonetheless interesting and, as a robustness test, ran additional sessions with experienced subjects. Our subjects were experienced in the sense that they had participated in the experiment earlier. Our experienced subjects were assigned to exactly the same

2.3 Demand and supply

As in Brandts et al. (2008), the demand schedule is $p(Q) = Max(0, 2000 - 27Q)$, $Q \geq 0$. Also as in Brandts et al. (2008), we chose to program the demand side rather than have it enacted by experimental participants. This might reduce demand uncertainty which in turn is likely to influence (the speed of) convergence in our market. We believe that this choice does not interact with treatment effects in a significant manner.

For some treatments we model generators as having quadratic marginal costs. Marginal costs of producing electricity usually have a hockey-stick shape, i.e., they are flat with a sharp increase when capacity constraints become binding (Newbery, 2002). We consider marginal quadratic costs to be a reasonable approximation to the real cost curves of electricity generators.

To be able to compare our results with those of Brandts et al. (2008), we also use the same specification of the costs for markets with three producers, abbreviated by M3 for the market without forward market and by M3F for the market with forward market. Brandts et al. (2008) set the marginal cost of producing the i^{th} unit for a producer equal to $mc_3(q) = 2x^2$, cumulative costs can thus be calculated as $c_3(q) = \sum_{x=1}^{q} 2x^2 = \frac{2}{3}x^3 + x^2 + \frac{1}{3}x$.

The market with four producers, M4, is created from the market with three producers, M3, by divestiture; each of the three producers divests $\frac{1}{4}^{th}$ of their assets, and these three sets of assets are used to create a fourth, identical producer. The markets with two producers, M2 and M2F, are created from the market with three producers, M3, by reversing the divestiture process (merger): one of the producers is split in half and its assets are merged to the two remaining producers to create two larger, identical, producers. With the cost function of a producer in M3 given, the cost functions of producers in M2 and M4 can be calculated: $\boldsymbol{c}_2[\boldsymbol{y}] = \frac{8\boldsymbol{y}^3}{27} + \frac{2\boldsymbol{y}^2}{3} + \frac{\boldsymbol{y}}{3}$, and $\boldsymbol{c}_4[\boldsymbol{y}] = \frac{32}{27}\boldsymbol{y}^3 + \frac{4}{3}\boldsymbol{y}^2 + \frac{\boldsymbol{y}}{3}$.[16]

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treatment as the one in which they had participated earlier (with the exception for experienced subjects in treatment M2, where some subjects had participated earlier in M3 or M4). Overall we do not find that experienced subjects have a lower aggregate production than inexperienced subjects. On the contrary, we find indications that 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). We report the detailed results as a robustness test in the Appendix.

[16] If all the assets in M3 would be merged into one single firm (M1), then this single firm would minimize its costs by dividing production equally over the three plants. The total costs of the firm in M1 would thus be $\boldsymbol{c}_1[\boldsymbol{y}] = 3 \cdot \boldsymbol{c}_3[\frac{\boldsymbol{y}}{3}]$ Likewise, if we started with M2 and merged the assets of the two firms into one single firm, then the cost function of the single firm in M1 would be given by $\boldsymbol{c}_1[\boldsymbol{y}] = 2 \cdot \boldsymbol{c}_2[\frac{\boldsymbol{y}}{2}]$. Now we can derive the cost function for a firm in M2: from $2 \cdot \boldsymbol{c}_2[\frac{\boldsymbol{y}}{2}] = \boldsymbol{c}_1[\boldsymbol{y}] = 3 \cdot \boldsymbol{c}_3[\frac{\boldsymbol{y}}{3}]$ follows that $\boldsymbol{c}_2[\boldsymbol{y}] = \frac{3}{2} \cdot \boldsymbol{c}_3[\frac{2}{3} \cdot \boldsymbol{y}] = \frac{8}{27}\boldsymbol{y}^3 + \frac{2}{3}\boldsymbol{y}^2 + \frac{1}{3}\boldsymbol{y}$. In the same manner we can derive

The electricity generation asset base is the same for all three markets (M2, M3, and M4). Therefore, when generators make identical choices and the aggregate production is equal over different markets, the aggregate costs must also be equal.

Table 2 summarizes the production costs for each generator in the market with two (M2), three (M3) and four (M4) generators, and identifies aggregate production in one market being equal to that in another market by bold numbers and shaded cells. For example, the aggregate production in M2 (M4) is equal to that in M3 when the total number of units can be divided both by two (four) and three.

To not unduly add to our subjects' cognitive load, we presented costs that were rounded according to the following rounding rules:

- All numbers smaller than 100 were rounded to the nearest integer number.
- When a number was larger than 100, it was rounded to the nearest 5-fold.
- When a number was larger than 1000, it was rounded to the nearest 10-fold.
- When a number was larger than 10000, it was rounded to the nearest 50-fold.

As a result of these rounding rules, some of the aggregate total costs in Table 2 are different. The discrepancy is small, however; on average the absolute discrepancies is 0.12%. For the "rounded numbers" version of Table 2, see Table A1 in the Appendix.

The numbers we obtained after this rounding procedure were also the numbers we use to calculate the theoretical predictions.[17]

Table 2:[18] Overview of aggregate cost of producing

Market with two producers (after merger)					**Market with three producers (original market)**					**Market with four producers (after divestment)**				
Each Producer			Aggregate		Each Producer			Aggregate		Each Producer			Aggregate	
Units produced by each producer	Marginal Costs	Total Costs	Total Production	**Total Costs**	Units produced by each producer	Marginal Costs	Total Costs	Total Production	**Total Costs**	Units produced by each producer	Marginal Costs	Total Costs	Total Production	**Total Costs**
N	MC	TC	2*N	**2* TC**	N	MC	TC	3*N	**3*TC**	N	MC	TC	4* N	**4*TC**
0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**
1	1	1	2	2	1	2	2	3	6					
2	5	6	4	**11**						1	3	3	4	**11**
3	9	15	6	**30**	2	8	10	6	**30**					
4	16	31	8	**62**						2	12	15	8	**62**
5	24	55	10	111	3	18	28	9	84					

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the cost function for a firm in M4: $c_4[y] = \frac{3}{4} \cdot c_3[\frac{4}{3} \cdot y] = \frac{32}{27} y^3 + \frac{4}{3} y^2 + \frac{1}{3} y$. Notice that for marginal costs holds the equality: $c_2'[\frac{3}{2} y] = c_3'[y] = c_4'[\frac{3}{4} y]$. Conforming to intuition, the marginal cost of a firm in M3 thus increases faster (slower) than in M2 (M4).

[17] Using the exact numbers gives virtually identical theoretical predictions.

[18] Numbers have been rounded to the nearest whole number.

6	35	90	12	**180**	4	32	60	12	**180**	3	30	45	12	**180**
7	47	137	14	273	5	50	110	15	330					
8	60	197	16	**394**						4	54	99	16	**394**
9	76	273	18	**546**	6	72	182	18	**546**					
10	93	366	20	**733**						5	84	183	20	**733**
11	113	479	22	957	7	98	280	21	840					
12	133	612	24	**1224**	8	128	408	24	**1224**	6	123	306	24	**1224**
13	156	768	26	1536	9	162	570	27	1710					
14	180	948	28	**1897**						7	168	474	28	**1897**
15	207	1155	30	**2310**	10	200	770	30	**2310**					
16	235	1390	32	**2779**						8	221	695	32	**2779**
17	264	1654	34	3308	11	242	1012	33	3036					
18	296	1950	36	**3900**	12	288	1300	36	**3900**	9	280	975	36	**3900**
19	329	2279	38	4559	13	338	1638	39	4914					
20	365	2644	40	**5287**						10	347	1322	40	**5287**
21	401	3045	42	**6090**	14	392	2030	42	**6090**					
22	440	3485	44	**6970**						11	420	1742	44	**6970**
23	480	3965	46	7931	15	450	2480	45	7440					
24	523	4488	48	**8976**	16	512	2992	48	**8976**	12	502	2244	48	**8976**
25	567	5055	50	10109	17	578	3570	51	10710					
26	612	5667	52	**11334**						13	590	2834	52	**11334**
27	660	6327	54	**12654**	18	648	4218	54	**12654**					
28	709	7036	56	**14073**						14	684	3518	56	**14073**
29	761	7797	58	15593	19	722	4940	57	14820					
30	813	8610	60	**17220**	20	800	5740	60	**17220**	15	787	4305	60	**17220**
31	868	9478	62	18956	21	882	6622	63	19866					
32	924	10402	64	**20805**						16	896	5201	64	**20805**
33	983	11385	66	**22770**	22	968	7590	66	**22770**					
34	1043	12428	68	**24855**						17	1013	6214	68	**24855**
35	1104	13532	70	27064	23	1058	8648	69	25944					
36	1168	14700	72	**29400**	24	1152	9800	72	**29400**	18	1136	7350	72	**29400**
37	1233	15933	74	31867	25	1250	11050	75	33150					
38	1301	17234	76	**34467**						19	1267	8617	76	**34467**
39	1369	18603	78	**37206**	26	1352	12402	78	**37206**					
40	1440	20043	80	**40086**						20	1405	10022	80	**40086**
41	1512	21555	82	43111	27	1458	13860	81	41580					
42	1587	23142	84	**46284**	28	1568	15428	84	**46284**	21	1549	11571	84	**46284**
43	1663	24805	86	49609	29	1682	17110	87	51330					
44	1740	26545	88	**53090**						22	1702	13273	88	**53090**
45	1820	28365	90	**56730**	30	1800	18910	90	**56730**					
46	1901	30266	92	**60533**						23	1860	15133	92	**60532**
47	1985	32251	94	**64501**	31	1922	20832	93	**62496**					
48	2069	34320	96	**68640**	32	2048	22880	96	**68640**	24	2027	17160	96	**68640**

2.4 Theoretical Predictions and Hypotheses

With demand given and the cost function defined, the profit function is given by $\pi_{i,MS} = p[q_i + q_{-i}](q_i - f_i) - c_{MS}[q_i]$ for each of the market sizes $MS \in (2,3,4)$, where the cost functions are defined as above by $\boldsymbol{c_2[y]} = \frac{8\boldsymbol{y}^3}{27} + \frac{2\boldsymbol{y}^2}{3} + \frac{\boldsymbol{y}}{3}$, $c_3(q) = \sum_{x=1}^{q} 2x^2 = \frac{2}{3}x^3 + x^2 + \frac{1}{3}x$, and

$c_4[y] = \frac{32}{27}y^3 + \frac{4}{3}y^2 + \frac{y}{3}$. We can now determine the Nash-equilibria for each of the treatments. Table 3 shows the theoretical predictions for our treatments M2, M2F, M3, M3F, and M4.[19] The prefix NE stands for Nash-equilibrium, Walras for the efficient solution (the outcome that maximizes the total surplus), [20] and JPM for Joint Profit Maximization (the monopoly solution). [21]

Table 3: Theoretical predictions for electricity markets

	NE M2	**NE M2F**		NE M3	**NE M3F**	NE M4	Walras (n=2)	Walras (n=3)	Walras (n=4)	JPM (n=2)	JPM (n=3)	JPM (n=4)
q_{ti}^f	–	2	11	–	5	–	–	–	–	–	–	–
q_{ti}	20	20	22	14/15[22]	15	11	25/26[23]	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
Eff. (%)	94.8	94.8	97.9	97.2	98.4	97.9	100	100	100	84.7	86..2	84.7

[19] The Nash equilibria have been numerically determined with Mathematica programs. The set of programs can be downloaded as a RAR file named "Nash-Equilibria with Forward Markets.RAR", at https://sites.google.com/site/slvstrnl/ElectricityMarketsExperiment. The predictions are based on the cost functions with numbers rounded according to the rounding procedure described above. Predictions based on the continuous cost functions are, except for the M2F condition, mostly identical: the chosen quantities are identical, and the difference in total surplus is lower than 0.02%. In the M2F condition the chosen quantities in the low Nash-equilibrium are lower when using the continuous functions – 40 instead of 42. As a result the difference in total surplus is relatively high: 1.8%.

[20] 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).

[21] The markets JPM (n=3) , JPM (n=4), NE C3.0, NE C3.2, Walras (n=3), Walras (n=4) and NE C4.0 in this experiment are identical to those in Brandts et al. (2008), and our predictions are almost identical to the ones reported in their paper. Key differences are: Using the functions without a rounding procedure, we find that for the Nash-equilibrium with three producers (M3) the price is equal to 839 rather than 866, as reported in Brandts et al. (2008). We find that for the Nash-equilibrium with four generators (M4), the price is equal to 677 rather than 704. Also, the producer surplus of M4 is equal to 27635 rather than 27638. For the welfare maximizing outcome with four generators, Walras (n=4), we find that all three generators produce 14 units and one of them 15 units, instead of all of the generators producing 14 units. Total welfare is therefore 60799 and not 60788. For the monopoly case with four generators, JPM (n=4), two generators produce 9 units and two 8 units, instead of all of them 8 units. As a result the producer surplus is higher, 34832 instead of 34728, the consumer surplus is lower, 15147 instead of 17010, and efficiency is lower, 82.2% instead of 85.1%.

For the Nash-equilibrium with three producers and a forward market (M3F), we find a unique symmetrical Nash-equilibrium in pure strategies where each producer sells 5 units in the forward market, and 10 additional units in the spot market. This is different from Brandts et al. (2008), who for the treatment with the forward market (M3F) consider partially mixed strategies (for the choice of additional units) and find an equilibrium where each producer sells 6 units in the forward market, and an additional 9 with probability .944 and 10 with probability 0.056. As we find a unique symmetric Nash-equilibrium in pure strategies, we do not follow Brandts et al. (2008) in broadening the equilibrium concept for one treatment case (no mixed strategies are considered for the other treatments). In any case, the total (expected) production by all three producers we find and the one reported by Brandts et al. (2008) are the same – 45 units.

[22] One generator produces 15 units, the other two 14 units.

[23] One generator produces 26 units, the other two 25 units.

The theoretical predictions give us, for the particular parameterizations chosen, an indication of the effect on aggregate production and efficiency of introducing a forward market or adding one more competitor. For markets with three producers, both introducing a forward market and adding one more competitor increases aggregate production, but introducing a forward market increases aggregate production more. For markets with two producers, adding one more competitor increases aggregate production. Introducing a forward market increases aggregate production only if the higher Nash-equilibrium is realized. In fact, aggregate production in that case is increased more than in the case of one more competitor. Using q(x) to denote aggregate production in market structure x[24], we thus conjecture that the remedies can be ranked as follows: q(M3F) > q(M4) > q(M3). Likewise, both remedies also increase efficiency, but introducing a forward market again is predicted to increase efficiency the most. Using Ω (x) to denote efficiency in market structure x, we thus conjecture that the remedies can be ranked as follows: Ω (M3F) > Ω (M4) > Ω (M3).

For markets with two producers, both introducing a forward market and adding one more competitor increases aggregate production, but the existence of two welfare-rankable Nash-equilibria makes it impossible to rank the remedies. We conjecture that the remedies can be ranked as follows: q(M2F) > q(M2), q(M3) > q(M2), and q(M2F) = q(M3). Moreover, the theoretical results, assuming the lower-ranked Nash-equilibrium will occur at least with some probability,[25] suggest that the effect of introducing a forward market is not as large as adding two more competitors; we thus conjecture q(M4) > q(M2F). Both remedies also increase efficiency but again they cannot be ranked. We conjecture that: Ω(M2F) > Ω(M2), Ω(M3) > Ω(M2), Ω(M2F) = Ω (M3), and Ω(4) > Ω(M2F).

Table 4: Hypotheses

Hq.1 (Quantity)	**HΩ.1 (Efficiency)**	**HΦ.1 (Production Efficiency)**
- q(M3F) > q(M4) > q(M3)	- Ω(M3F) > Ω(M4) > Ω(M3)	- Φ(M3F) = Φ(M3)
		- Φ(M4) < Φ(M3)

Hq.2 (Quantity)	**HΩ.2 (Efficiency)**	**HΦ.2 (Production Efficiency)**
- q(M2F) > q(M2)	- Ω(M2F) > Ω(M2)	- Φ(M2F) = Φ(M2)
- q(M3) > q(M2)	- Ω(M3) > Ω(M2)	- Φ(M3) < Φ(M2)
- q(M2F) = q(M3)	- Ω(M2F) = Ω(M3)	

Hq.3 (Quantity)	**HΩ.3 (Efficiency)**	
- q(M4) >q(M2F)	- Ω (M4) > q (M2F)	

[24] To facilitate comparisons with related literature, we use the same notation as Brandts et al. (2008). Also parts of our presentation have been inspired by Brandts et al. (2008).
[25] M2F has two Nash equilibria outcome for the aggregate production: a low one of 40 and a high one of 44. The high Nash equilibrium in M2F is equal to the Nash equilibrium in M4. The aggregate production in M2F can thus be expected to be lower than that in M4, as long as the lower Nash equilibrium of 40 occurs with at least some probability.

We also test for effects on production efficiency. We define production efficiency, following Brandts et al. (2008), as actual producer surplus divided by producer surplus had production taken place in the most efficient manner. As marginal costs are quadratic, production is fully efficient only if the aggregate production is evenly distributed over the producers. Like Brandts et al. (2008) we assume that more producers in a market should make it more difficult to achieve an even distribution, but that introducing a forward market should not have an effect. We thus conjecture Φ(M4) < Φ(M3) < Φ(M2), Φ(M3F) = Φ(M3), and Φ(M2F) = Φ(M2). Table 4 summarizes our hypotheses.

2.5 Experimental procedures

The experimental sessions were conducted in October 2009, December 2009, and April 2010 at CERGE-EI in Prague.[26] Our subjects were students at Charles University or at the University of Economics, both located in Prague. A total of 198 students participated. The sessions with a forward market lasted about 2 hours, the sessions without forward market lasted about 90 minutes. The subjects earned on average 382 Czech Koruna per hour including a show-up fee of 100 Korunas, meaning that subjects earned on average 640 Korunas.[27] The minimum earning was 330 and the maximum earning was 1080 Korunas, indicating that our experiment was well-incentivized on the margin. At the beginning of each session, the English instructions were read to subjects by the experimenter (Van Koten).

The market simulation was programmed in Z-Tree (Fischbacher, 2007).The demand schedule was pre-programmed. Participants took on the roles of producers and sellers. They were not shown the demand schedule but were given on screen, and as a printout, a payoff table.

In the treatments with a forward market every round has two periods: the first period for the forward market and the second period for the spot market. In the first period, producers decide how many units to produce and to sell in the forward market. Producers sell units to traders. The units that producers sell are promises to produce and to deliver units to traders in the second period (in the spot market). The units that are sold in the forward market are thus produced later, in the second period. To help producers see the effect of their actions on their profits, we communicated to them the cost of their selling decision in the forward market and the resulting profit.

[26] We obtained in October 2009 four data points for each treatment, in December 2009 four data points for M2zc, M2Fzc, M2F, M2, ,M3, and three data points for treatments M3F and M4, and in April 2010 three data points for M2zc, M2Fzc, M2F, M2, M3, and four data points for treatments M3F and M4. The original plan was to obtain four data points for all treatments also in December 2009. Unusual numbers of no-shows for treatments M3F and M4 derailed that plan. Several pilot sessions were run during the summer of 2009. None of the subjects in the pilot (mostly CERGE-EI students) participated in the regular sessions.

[27] This equaled about €26 (and about €36 at official purchasing power parity, and even more on student-specific purchasing power parity).

In the forward market two pre-programmed traders compete in prices for the total number of units that are offered.[28] We do not explicitly mention the existence of traders to the subjects. Because traders act rationally, their actions define a demand schedule, and we present this schedule to our producers.[29] The trader that offers the highest price per unit wins all units. When they offer the same price – which they do in equilibrium – a winner is drawn at random. As the pre-programmed traders are rational and compete in prices, they can predict the Nash-equilibrium spot price and offer this price for the units offered in the forward market. The pre-programmed traders do not observe the number of units offered by each producer, only the total number of units. They assume that the producer offers an equal number of units in the forward market.[30] Using this assumption, the traders are programmed to predict, conditional on the total number of units offered in the forward market, q^f, the Nash-equilibrium total production in the spot market: $q^{NE}(q^f)$.[31] By substituting the predicted total production in the spot market in the demand schedule, the traders predict the Nash-equilibrium price in the spot market: $p(q^{NE}(q^f))$. As traders offer the Nash-equilibrium price for all units, $p(q^{NE}(q^f))$ defines the demand schedule in the forward market. This forward market demand schedule is presented to producers in the first period of each round, so they can use this information when deciding how many units to offer for the forward market. At the end of the period, all producers are paid the number of units they produced in the forward market times the price per unit minus the production cost. Appendix A3 shows, conditional on the total production in the forward market (stage A), the predicted aggregate production and price in the spot market.

In the second period of each round, producers decide how many units to produce and sell in the spot market. The pre-programmed traders sell all the units they bought. The price per unit is 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 are paid the number of units they produced in the spot market times the price per unit minus the production cost.

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[28] In our experiment traders are not represented by experimental subjects, but they are, as in LeCoq and Orzen (2006), pre-programmed. 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 (Plott and Uhl, 1981). Brandts et al. (2008) use experimental subjects as traders and find indeed that a trader earns only a small portion (about 8%) of the profits that a producer earns.

[29] The full consolidated instructions can be downloaded at https://sites.google.com/site/slvstrnl/ElectricityMarketsExperiment.

[30] When the total of units sold forward is not divisible by the number of producers in the market, the trader assumes that the numbers of units sold forward by each producer are as close as possible. For example, when the total number of units sold forward is 14 in M3, the trader assumes that two producers sold 5 units and one producer 4 units. Violation of this assumption affects the prediction only minimally.

[31] This procedure is virtually identical to the one used in LeCoq and Orzen (2006).

3. Results

We have 11 statistically independent data points for all treatments (each data point below we call “a group” consisting of the aggregate of sellers in a particular treatment); since each participant took part in one experimental session, data points are also statistically independent across treatments. None of the participants went bankrupt. Each treatment consisted of 24 rounds. For our statistical tests, we use only the last 12 rounds of the data, as the experiment is complicated and we know – for example, from relatively easy auction experiments – that subjects need several rounds of trading to become familiar with the laboratory environment before they react to the embedded incentives (Hertwig and Ortmann, 2001). Following LeCoq and Orzen (2006), we test for disparity with the Nash-equilibrium predictions using two-sided Wilcoxon one-sample signed-rank tests (two-sided signed-rank tests), unless indicated otherwise. For comparison between the averages of the treatment in our experiment, we use, following Brandts et al. (2008), 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). The error terms are adjusted for clustered data by using the robust Huber/White/Sandwich estimator (Froot, 1989). To compare three ordered inequalities, we also run, following Brandts et al. (2008), a Jonckheere test, which makes no distributional assumptions. In addition, we ran robustness tests using, as did LeCoq and Orzen (2006), Wilcoxon rank-sum tests (rank-sum tests). These tests confirmed most of the results presented here. The results of these tests may be found in Appendix A2.

3.1. Aggregate Quantity

Figure 1 shows the evolution of total (aggregate) quantities sold per period, averaged over treatment groups. Treatments with two traders are represented by circles, with three traders by triangles, and with four traders 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 volume in all treatments starts out rather low[32] but trade volume moves quickly into the direction of the Nash-equilibrium. Between rounds 8 and 12 behavior has stabilized.

[32] It is likely that these trajectories are anchored by the examples in the instructions; in the examples we used low numbers to facilitate understanding of the basic relationships.

Figure 1 : Aggregate production

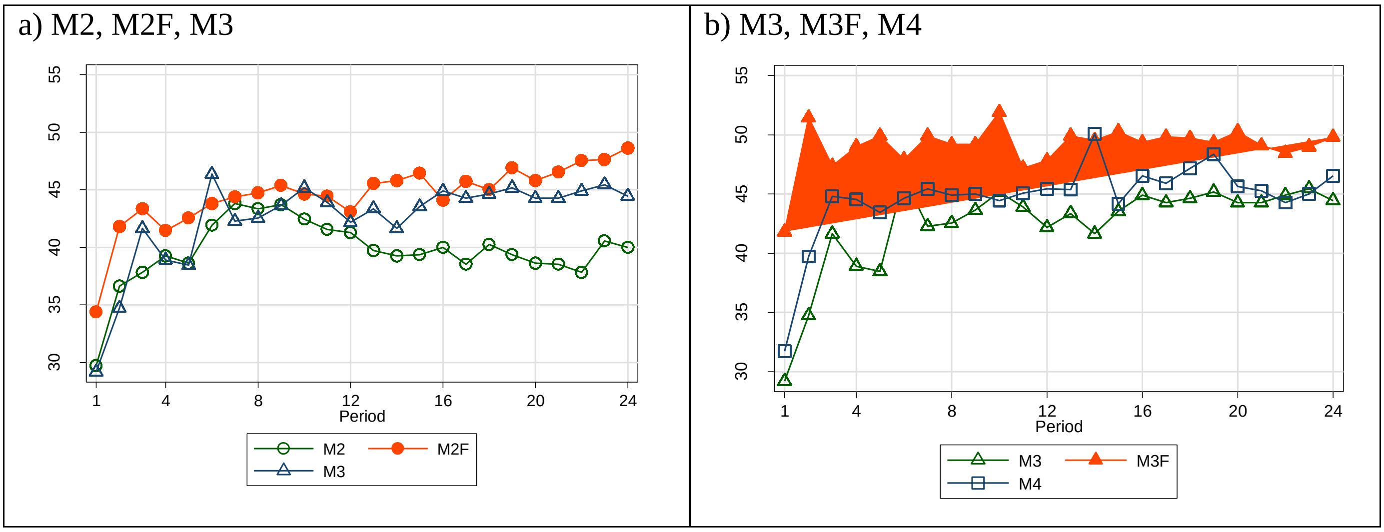

Table 5 shows the overall average aggregate production per treatment group, with the standard error in parenthesis.[33] The row below gives the size of the observed aggregated quantity relative to the Nash-equilibrium prediction in percentages.

Table 5: Production averages in the last 12 rounds

	M2	M2F	M3	M3F	M4
Average production	39.3 (1.52)	46.3 (2.06)	44.2 (1.22)	49.6 (0.61)	46.2 (0.98)
% of NE prediction	*98.7%*	*116 % / 105%*[34]	*102.9%*	*110.1%*	*105.0%*
Number of observations	N=11	N=11	N=11	N=11	N=11
% of NE prediction - earlier studies[35]	*93,2%, LeCoq and Orzen (2006)* *92,7%, Huck et al. (2004)*	*93,8%, LeCoq and Orzen (2006)*	*102.7%, Huck et al. (2004)* *98.9%, Brandts et al. (2008)*	*103.6%, Brandts et al. (2008)*	*113.7%, LeCoq and Orzen (2006)* *102.8%, Brandts et al. (2008)* *102.9%, Huck et al. (2004)*

Note that in the M2 and M2F conditions the standard error is relatively high. Of the treatments without forward markets, M2 and M3 are not significantly different from the Nash-equilibrium predictions (two-sided signed-rank test, both p-values > 0.32), while M4 is significantly larger (p-value=0.068). Of the treatments with a forward market, the production in M3F is significantly

[33] The standard error is computed based on the values of the averages for each group over the last 12 rounds.

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

[35] The averages by Huck et al. (2004) reported here are based on their meta-analysis of 19 experiments with Cournot competition. A Wilcoxon signed-rank test indicates that our results are not significantly different from their results (p-values for M2, M3 and M4 are 0.155, 0.657 and 0.534 respectively). Compared with Brandts et al. (2008), the production is significantly higher in condition M3F (p < 0.006) and not significantly different in the conditions M3 (p-value=0.213) and M4 (p-value=0.534). Compared with LeCoq and Orzen (2006), production is significantly higher in conditions M2F (p-value=0.010 for the low and p-value=0.033 for the high Nash-equilibrium) and M4 (p-value=0.010) and not significantly different in condition M2 (p-value= 0.182). For comparison, we also ran treatments with zero production costs, M2zc and M2Fzc. In these treatments the average production is 83% of the Nash-equilibrium prediction, which is significantly lower than what LeCoq and Orzen (2006) found (both p-values < 0.041). The results of these tests may be found in Appendix A2.

higher than the Nash-equilibrium (p-values = 0.004) and production in M2F is significantly higher than the low Nash-equilibrium (p-value=0.021), but is not significantly different from the high Nash-equilibrium (p-value=0.248).

Without a forward market, when the number of competitors is equal to two (three or four), production tends to be smaller (larger) than the Nash-equilibrium, which is in line with earlier findings (LeCoq and Orzen, 2006; Huck, Normann, and Oechssler, 2004). We see no evidence for long-lasting collusion; indeed the data suggest the opposite. A regression of aggregate production on the period of the experiment shows a significant upwards slope, suggesting that over time, as subjects become more experienced with the task, they become less likely to collude.

Table 6: Effects of one more competitor and forward market on quantities, Hq.1, Hq.2, and Hq.3

	OLS regression, with correction for clustering on group level, followed by an one-sided F-test on equality of the coefficients			Jonckheere test
Hq.1 - Markets with 3 producers	**q(M3F) > q(M3)*** (p<0.001)**	q(M4) > q(M3) (p=0.105)	**q(M3F) > q(M4)*** (p=0.002)**	q (M3F) ≥ q (M4) ≥ q (M3), with at least one of the inequalities being strict p-value = 0.0000
	N= 792	N= 924	N= 924	N= 1320
Hq.2 - Markets with 2 producers	**q(M2F) > q(M2)*** (p=0.003)**	**q(M3) > q(M2)** (p= 0.006)**	q(M2F) = q(M3) (p=0.374)	q (M2F) ≥ q (M3) ≥ q (M2), with at least one of the inequalities being strict*** p-value = 0.0000.
Number of observations	N= 528	N= 660	N= 660	N= 924
Hq.3	q(M4) > q(M2F) (p=0.521)			
	N= 792			

Table 6 presents the test for our hypothesis using F-tests based on an OLS regression and Jonckheere tests.[36]

[36] As a robustness test 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.

Results testing Hypothesis q.1: In markets with 3 competitors, introducing a forward market increases production, and the effect is stronger than adding one more competitor, q(M3F) > q(M3), and q(M3F) > q(M4).

We find partial support for Hypothesis q.1:

- q(M3F) ≤ q(M3) is REJECTED in favor of q(M3F) > q(M3), p-value<0.001.
- q(M4) ≤ q(M3) is NOT rejected in favor of Ω(M4) > q(M3) , p-value=0.105.
- q(M3F) ≤ q(M4) is REJECTED in favor of q(M3F) > q(M4) , p-value=0.002 .
- q(M3F) = q(M4) = q(M3) is REJECTED in favor of q (M3F) ≥ q (M4) ≥ q (M3), with at least one of the inequalities being strict.

Introducing a forward market increases aggregate production 12% in markets with three competitors (q(M3F) > q(M3), p-value < 0.001). This confirms earlier findings such as in Brandts et al. (2008). Adding one more competitor in markets with three competitors increases aggregate production by 4%, and this effect is barely significant (p-value=0.105). We find that introducing a forward market increases aggregate production by 7% more than increasing competition by adding one more competitor, and this difference is strongly significant (q(M3F) > q(M4), p-value=0.002).

Results testing Hypothesis q.2: In markets with 2 competitors, both introducing a forward market and adding one more competitor increases production, and the strength of the effects are of the same order, q(M2F) > q(M2), q(M3) > q(M2), and q(M2F) = q(M3).

We find support for Hypothesis q.2:

- q(M2F) ≤ q(M2) is REJECTED in favor of q(M2F) > q(M2), p-value= 0.003.
- q(M3) ≤ q(M2) is REJECTED in favor of q(M3) > q(M2) , p-value= 0.006.
- q(M2F) = q(M3) is NOT rejected in favor of q(M2F) ≠ q(M3) , p-value= 0.374.
- q(M2F) = q(M3) = q(M2) is REJECTED in favor of q (M2F) ≥ q (M3) ≥ q (M2), with at least one of the inequalities being strict, p-value= 0.0000.

In line with the theoretical predictions, introducing a forward market increases aggregate production by 18% in markets with two competitors. This increase is strongly significant (q(M2F) > q(M2), p-value= 0.003). Adding one more competitor in markets with two competitors increases aggregate production by 12%. This increase is significant (q(M3) > q(M2), p-value= 0.006). Introducing a forward market increases aggregate production by 5% more than adding one more competitor, but this effect is not significant (q(M2F)=q(M2), p-value= 0.344). A Jonckheere test rejects q.1 in favor of q (M2F) ≥ q (M3) ≥ q (M2), p-value= 0.0000), with at least one of the inequalities being strict.

Results testing Hypothesis q.3: Adding two more competitors does not increase production more than adding a forward market, q(M4) ≤ q(M2F).

We find no support for Hypothesis q.3:

- q(M4) ≤ q(M2F) is NOT rejected in favor of q(M4) > q(M2F), p-value= 0.521.

Doubling the number of competitors does not increase production significantly more than introducing a forward market. This is in contrast with the theoretical predictions. Our data indicate the opposite ordering instead; q(M2F) is 4% higher than q(M4). This is surprising as LeCoq and Orzen (2006) found that the production of two competitors *with* forward market is strictly lower than that of four competitors *without* a forward market. The main difference is that in our treatments producers have steeply increasing production costs, while in their treatments producers have zero costs. Our result thus suggests that production costs make it harder for producers to collude. Indeed, in our treatments with two producers with production costs, M2 and M2F, subjects produced more than the Nash-equilibrium, while in our treatment with two producers and zero costs, M2zc and M2Fzc, subjects produced fewer units than the Nash-equilibrium. See the Appendix for a detailed discussion of our results for M2zc and M2Fzc.

3.2. Efficiency

As mentioned above, 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). For the markets with a forward market, these measures are based on the outcomes in the forward and spot market together.

Figure 2 shows the evolution of efficiency per period, averaged over groups. Efficiency quickly converges and after period 8 its level is equal or higher than 90% for all treatments except M2. The highest efficiency levels in the last twelve periods are realized by treatments with forward markets, M2F and M3F.[37]

Figure 2: Efficiency percentages

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

[37] See the Appendix for graphs of efficiency levels per period for the individual treatment together with the Nash-equilibrium prediction.

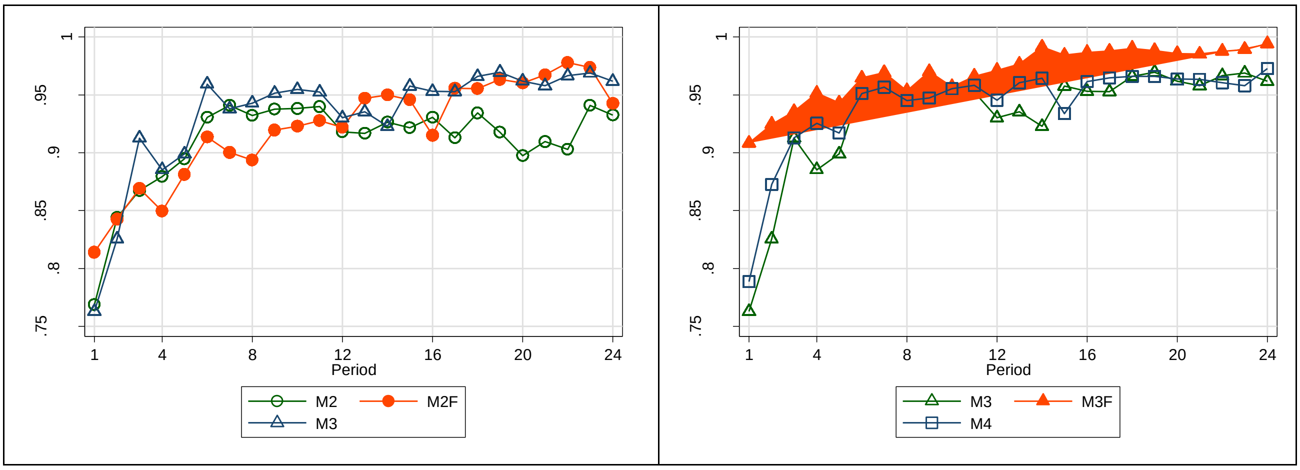

Table 7 shows the observed average efficiency level in the last 12 rounds, with the standard error in parenthesis. The row below gives the level of the observed average efficiency level relative to the Nash-equilibrium prediction in percentages. The efficiency levels are close to the Nash-equilibrium prediction; efficiency is significantly lower in M2 (p-value <0.068) and higher in M2F (p-value =0.083 in the low and 0.790 in the high Nash-equilibrium). This is mostly in line with earlier findings such as those in Brandts et al. (2008).

Table 7: Efficiency averages in the last 12 rounds

	M2	M2F	M3	M3F	M4
Average efficiency as % of Walras	92.0 (1.71)	95.5 (1.73)	95.6 (0.77)	98.7 (0.32)	96.1 (0.57)
% of NE prediction	97.2%	97.5%/ 100.7%[38]	98.3%	100.5%	98.6%
	N=11	N=11	N=11	N=11	N=11
% of NE prediction - earlier studies[39]	92.5%, LeCoq and Orzen (2006)	93,6%, LeCoq and Orzen (2006)	94.2%, Brandts et al. (2008)	96.7%, Brandts et al. (2008)	95.4%, Brandts et al. (2008) 109.3%, LeCoq and Orzen (2006)

Table 7 presents the results of the F-tests and Jonckheere test.[40] Aggregate production in the market is the most important determinant of efficiency, as production inefficiency has a minor influence only. The results of the tests of hypotheses regarding efficiency thus closely follow those regarding aggregate production.

Table 8: Effects of one more competitor and forward market on efficiency, HΩ.1, HΩ.2 and HΩ.3

	OLS regression, with correction for clustering on	Jonckheere test

[38] The first number gives the percentage of efficiency relative to the high production Nash-equilibrium, the second number relative to the low production Nash-equilibrium.
[39] Using a Wilcoxon signed-rank test to compare with the results reported by Brandts et al. (2008) shows that in our results efficiency is significantly higher (p-values=0.003 for M3, M3F and M4). Compared with LeCoq and Orzen (2006), efficiency is significantly higher in condition M2F (p-value= 0.062 for the low Nash-equilibrium and p-value= 0.050 for the high Nash-equilibrium), significantly lower in condition M4 (p-value=0.003) and not significantly different in M2 (p-value= 0.131).
[40] The robustness tests, one-sided Wilcoxon rank-sum tests, confirmed our results at the same significance levels.

	group level, followed by a one-sided F-test on equality of the coefficients			
HΩ.1 - Markets with 3 producers	**Ω(M3F) > Ω(M3)*** (p< 0.001)**	Ω(M4) > Ω(M3) (p=0.293)	**Ω(M3F) > Ω(M4)*** (p< 0.001)**	**Ω (M3F) ≥ Ω (M4) ≥ Ω (M3), with at least one of the inequalities being strict p-value < 0.001.**
Number of observations	**N= 792**	N= 924	**N= 924**	**N= 1320**

HΩ.2 - Markets with 2 producers	**Ω(M2F) > Ω(M2)* (p=0.075)**	**Ω(M3) > Ω(M2)** (p=0.026)**	Ω(M2F) = Ω(M3) (p= 0.927)	**Ω (M2F) ≥ Ω (M3) ≥ Ω (M2), with at least one of the inequalities being strict*** p-value < 0.001.**
Number of observations	**N= 528**	**N= 660**	N= 660	**N= 924**

HΩ.3	Ω(M4) > Ω(M2F) (p=0.351)
Number of observations	N= 792

Results testing Hypothesis Ω.1: In markets with 3 competitors, introducing a forward market increases efficiency, and the effect is stronger than adding one more competitor, Ω (M3F) > Ω (M4), and Ω (M3F) > Ω (M3).

We find partial support for Hypothesis Ω.1:

- Ω(M3F) ≤ Ω(M3) is REJECTED in favor of Ω(M3F) > Ω(M3), p-value<0.001.
- Ω(M4) ≤ Ω(M3) is NOT rejected in favor of Ω(M4) > Ω(M3) , p-value=0.293.
- Ω(M3F) ≤ Ω(M4) is REJECTED in favor of Ω(M3F) > Ω(M4) , p-value<0.001.
- Ω(M3F) = Ω(M4) = Ω(M3) is REJECTED in favor of Ω (M3F) ≥ Ω (M4) ≥ Ω (M3), with at least one of the inequalities being strict, p-value<0.001.

Introducing a forward market in a market with three producers increases efficiency by 3.1% and this is strongly significant Ω (M3F) > Ω (M3), p-value < 0.001). Adding one more competitor increases efficiency with a mere 0.5%, and this is not significant (NOT Ω (M4) > Ω (M3), p-value = 0.293). The increase in efficiency from introducing a forward market is larger than that from adding one more competitor, and that effect is strongly significant (Ω (M3F) > Ω (M4), p-value < 0.001).

Results testing Hypothesis Ω.2: In markets with 2 competitors, both introducing a forward market and adding one more competitor increases efficiency, and the strength of the effects are of the same order, Ω (M2F) > Ω (M2), Ω (M2F) > Ω (M2), Ω (M2F) > Ω (M3).

We find support for Hypothesis Ω.2:

- Ω(M2F) ≤ Ω(M2) is REJECTED in favor of Ω(M2F) > Ω(M2), p-value=0.075.
- Ω(M3) ≤ Ω(M2) is REJECTED in favor of Ω(M3) > Ω(M2) , p-value=0.026.
- Ω(M2F) = Ω(M3) is NOT rejected in favor of Ω(M2F) ≠ Ω(M3) , p-value=0.927.

- Ω(M2F) = Ω(M3) = Ω(M2) is REJECTED in favor of Ω (M2F) ≥ Ω (M3) ≥ Ω (M2), with at least one of the inequalities being strict, p-value<0.001.

Introducing a forward market increases efficiency by 3.5% and this is significant (Ω (M2F) > Ω(M3), p-value = 0.075). Adding one more competitor increases efficiency with 1.1% and this is also significant (Ω (M3) > Ω(M2), p-value = 0.026). The increase in efficiency due to the introduction of a forward market is not significantly larger than that due to adding one more competitor (NOT (Ω(M3F) ≠ Ω(M4), p-value = 0.927).

Results testing Hypothesis Ω.3: Adding two more competitors does not increase efficiency more than introducing a forward market, Ω (M2F) ≤ Ω(M4).

We find no support for Hypothesis Ω.3:

- Ω (M4) ≤ Ω(M2F) is NOT rejected in favor of Ω (M4) > Ω(M2F), p-value=0.351.

The effect of introducing a forward market with two competitors does not increase efficiency significantly less than doubling the number of competitors.

3.3. Production Efficiency

As mentioned above, we define production efficiency, following Brandts et al. (2008), as the actual producer surplus divided by the producer surplus had production taken place in the most efficient manner.[41] Figure 3 shows the evolution of efficiency per period, averaged over groups. Efficiency quickly converges and after period 8 its level is mostly equal or higher than 90% for all treatments.

The treatments with two traders are represented by circles, with three traders by triangles, and with four traders by squares. The treatments without forward markets are represented by open rounds, triangles or squares, the treatments with forward markets by filled rounds or triangles. M3 is clearly lower than M2, and M2F is most of the time in the middle. M4 is clearly lower than M3 and M3F, while there is no visible difference between M3 and M3F.

Figure 3: Production Efficiency

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

[41] Given the quadratic marginal cost function this implies an as even as possible division of units over the producers.

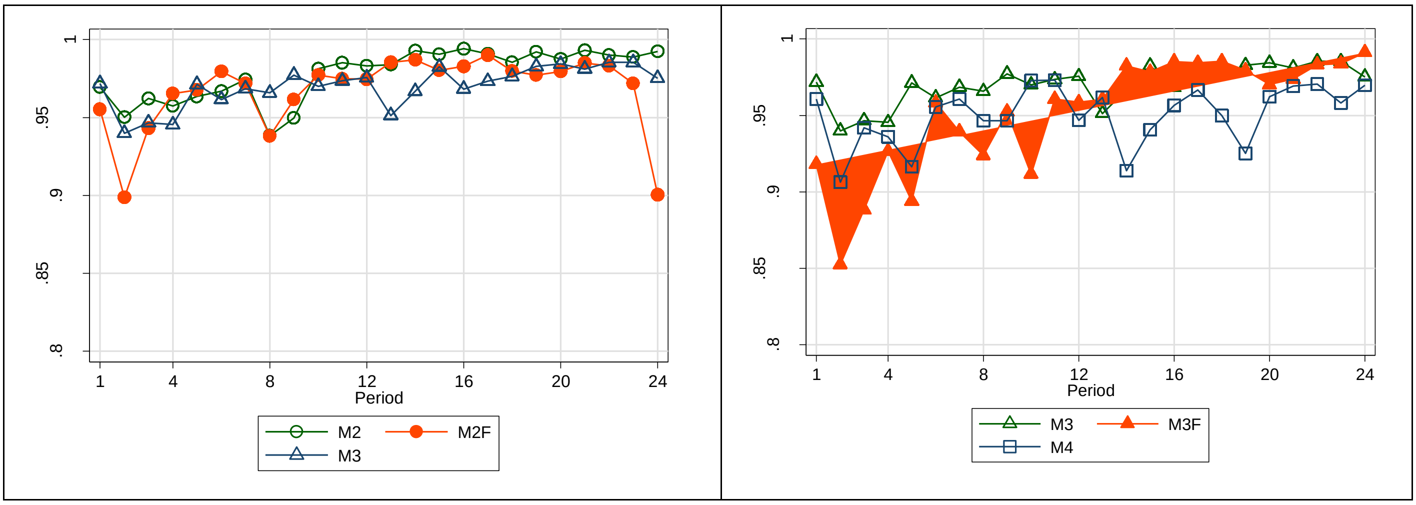

Table 9 shows the overall average of production efficiency in the last 12 rounds, with the standard error in parenthesis. The row below gives the size of the observed aggregated quantity relative to the Nash-equilibrium prediction in percentages.

Table 9: Production efficiency averages in the last 12 rounds

	M2	M2F	M3	M3F	M4
Average Production Efficiency	99.0 (0.35)	97.5 (0.81)	97.6 (0.59)	98.0 (0.69)	95.4 (1.63)
Number of observations	N=11	N=11	N=11	N=11	N=11

Table 10: Effects of one more competitor and forward market on productive efficiency, HΦ.1 and HΦ.2

	OLS regression, with correction for clustering on group level, followed by a one-sided F test	
HΦ.1 – Markets with 3 producers	**Φ(M4) < Φ(M3)* (p=0.093)**	Φ(M3F) < Φ(M3) (p= 0.666)
Number of observations	N= 1001	N= 858

HΦ.2– Markets with 2 producers	**Φ(M3) < Φ(M2)** (p=0.019)**	**Φ(M2F) < Φ(M2)** (p=0.046)**
Number of observations	N= 715	N= 572

Table 10 presents the test for our hypothesis using F-tests based on an OLS regression and Jonckheere tests. [42]

Results testing Hypothesis Φ.1: In markets with 3 competitors, introducing a forward market does not decrease productive efficiency, while adding one more competitor does, Φ(M4) < Φ(M3) and Φ(M3F) ≥ Φ(M3).

We find support for Hypothesis Φ.1:

- Φ(M4) ≥ Φ(M3) is REJECTED in favor of Φ(M4) < Φ(M3) , p-value=0.093.

[42] Robustness tests confirm our results, but show a weaker significance (p-value=0.100) for Φ(M4) < Φ(M3).

- $\Phi(M3F) \geq \Phi(M3)$ is NOT rejected in favor of $\Phi(M3F) < \Phi(M3)$, p-value=0.666.

Adding one more competitor to M3 decreases the production efficiency by 2.4%, and this decrease is significant ($\Phi(M4) < \Phi(M3)$, p-value=0.093). Introducing a forward market does not lower production efficiency; the data rather suggest the opposite as efficiency is higher in the market with a forward market than in the market without one (though not significantly so).

Results testing Hypothesis Φ.2: In markets with 2 competitors, introducing a forward market and adding one more competitor decrease productive efficiency, Φ(2F) < Φ(M2), and Φ(3F) < Φ(M3)

We find support for Hypothesis Φ.2:

- $\Phi(M3) \geq \Phi(M2)$ is REJECTED in favor of $\Phi(M3) < \Phi(M2)$, p-value=0.019.
- $\Phi(M2F) \geq \Phi(M2)$ is REJECTED in favor of $\Phi(M2F) < \Phi(M2)$, p-value=0.046.

Adding one more competitor to M2 decreases production efficiency by 1.4%.[43] Introducing a forward market to a market decreases production efficiency by 1.5%. Both decreases are significant.

3.4 Rationality in forward markets

Using the assumption of rational behavior, Allaz and Vila (1993) argue that the forward price will be equal to the spot price, which implies that traders make zero profits. We indeed see this in our data for the treatments with a forward market: M2F and M3F. We estimated the relative markup of the spot market over the forward market price, defined by the difference between the two, divided by the average price: $P_{S-F} = \frac{P_S - P_F}{\frac{1}{2}(P_S + P_F)}$. The average of P_{S-F} over the last 12 rounds is 0.001, which is not significantly larger than zero (p<0.97). This indicates that traders are making an insignificantly small profit. The total number of units producers offer on the forward market thus accurately predicts the total number of units they sell on the spot market, which indicates rational behavior.

3.5 Summary of results and comparison to earlier experiments

Table 11 summarizes our theoretical and experimental results for aggregate production, together with the key results of earlier experiments. We do not summarize the data on efficiency and productive inefficiency because the data on efficiency closely follow the patterns of the data on aggregate production, while the effect of productive inefficiency is small and inconsequential (see section 3.3).

[43] Running, in addition, a Jonckheere test rejects $\Phi(M4) \leq \Phi(M3) \leq \Phi(M2)$ in favor of $\Phi(M4) \leq \Phi(M3) \leq \Phi(M2)$), with at least one of the inequalities being strict, p-value=0.0000.

Table 11: Comparison of our results with those of earlier studies

		Theoretical predictions in our study	Results of earlier studies	Our study
Market with 2 competitors	One more competitor	+ 7.5%	-	+ 12.1% **
	FM	• Same (low Nash-equilibrium) • + 10% (high Nash-equilibrium)	+ 20.9% *** (LeCoq&Orzen, 2006)	+ 17.8% ***
	Largest increase by	• **One more Competitor**: 7.5% higher than FM (low Nash-equilibrium) • **Forward Market**: 2.3% higher than OMC (high Nash-equilibrium)	-	**Forward Market**: 4.7% higher than OMC (not significant)
Market with 3 competitors	One more competitor	+ 2.3%	+ 19.6% *** (Brandts et al., 2008)	+ 4.4% (not significant)
	FM	+ 4.7%	+ 9.5% ** (Brandts et al., 2008)	+ 12.0% ***
	Largest increase by	**Forward Market**: 2.3% higher than One more competitor	**One more Competitor**: 9.2% higher than FM** (Brandts et al., 2008)	**Forward Market**: 7.3% higher than OMC***

: Results contrast with earlier results
: Results contradict earlier results

Our results show that in markets with three competitors, in line with our theoretical prediction and with earlier experimental results (Brandts et al., 2008), introducing a forward market significantly increases aggregate production. Introducing a forward market increases aggregate production significantly more than adding one more competitor, which is in line with our theoretical prediction, but contradicts the findings of Brandts et al. (2008) (the contradictory findings are indicated by the shaded background in Table 11). 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 lack of significance is likely caused by the relatively small number of observations.

In markets with two competitors, in line with earlier experimental results (LeCoq and Orzen, 2006), introducing a forward market significantly increases aggregate production. Our data suggest that this increase is larger than that of adding one more competitor: The difference is not significant but has a marginal significance in our robustness test. The lack of significance is also likely caused by the relatively small number of observations.

Our present study contributes to an understanding of the effects of forward markets and competition in electricity market settings. The following questions for future work suggest themselves: Is the effect of a forward market the same in an experiment with an indefinite time horizon? Demand uncertainty also introduces an insurance motive on the side of producers. Does the strategic effect of forward markets stay the same under demand uncertainty?

4. Conclusion

We have tried to better understand the comparative advantages of structural remedies and behavioral remedies of deregulation in electricity markets. We investigate theoretically and experimentally the effects of the introduction of a forward market on competition in electricity markets. We compared this scenario with the best alternative, reducing concentration by adding one more competitor by divestiture. Our work contributes to the literature by introducing more realistic cost configurations of steeply increasing marginal costs, teasing apart competition effect and asset effect, and studying numbers of competitors that better reflect the market concentration in the European states.

Our experimental results suggest that the behavioral remedy of introducing a forward market in concentrated markets with two or three competitors is an effective remedy for increasing the aggregate supply. This is in line with the empirical studies of Wolak (2001) and Van Eijkel and Moraga-Gonzalez (2010), who found empirical evidence that forward trading increased the aggregate supply in the Australian power market and in the Dutch gas market, respectively. Our experimental results also suggest that the effect of the behavioral remedy of introducing a forward market is larger than that of the structural remedy of adding one more competitor by divestiture. This is a policy relevant finding: competition authorities should, in line with EU law, focus on the behavioral remedy of introducing a forward market than on the structural remedy of lowering market concentration by divestiture.

At present, the EU has no single policy for the design of forward markets for electricity. Such a policy might improve 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 indicates that the design, or evolution, of such public forward exchanges 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). Observability of forward positions may not be optimal in markets with large volumes of over-the-counter trading. The EU could thus implement methods to increase the observability of the forward positions, for example by having the regulator publish aggregated and anonymized totals of forward positions.

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 stems most likely from the confound of competition effect and asset effect. In Brandts et al. (2008) adding one more competitor not only increases competition, but also increases the aggregate asset base, which reduces the aggregate cost and thus gives an extra incentive to increase production. This asset effect is likely influential, as producers have steeply increasing costs. The welfare effects Brandts et al. (2008) report are not conclusive, however, 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. As a result 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.

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6. Appendices

A1. Production costs

Table 12: Overview of aggregate cost of producing (rounded numbers)

Market with two producers (original market)					Market with three producers (after first divestment)					Market with four producers (after second divestment)				
Each Producer			Aggregate		Each Producer			Aggregate		Each Producer			Aggregate	
Units produced by each producer	Marginal Costs	Total Costs	Total Production	**Total Costs**	Units produced by each producer	Marginal Costs	Total Costs	Total Production	**Total Costs**	Units produced by each producer	Marginal Costs	Total Costs	Total Production	**Total Costs**
N	MC	TC	2*N	**2* TC**	N	MC	TC	3*N	**3*TC**	N	MC	TC	4* N	**4*TC**
0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**
1	1	1	2	2	1	2	2	3	6					
2	5	6	4	**12**						1	3	3	4	**12**
3	9	15	6	**30**	2	8	10	6	**30**					
4	16	31	8	**62**						2	12	15	8	**60**
5	24	55	10	110	3	18	28	9	84					
6	35	90	12	**180**	4	32	60	12	**180**	3	30	45	12	**180**
7	45	135	14	270	5	50	110	15	330					
8	60	195	16	**390**						4	55	100	16	**400**
9	80	275	18	**550**	6	70	180	18	**540**					
10	90	365	20	**730**						5	85	185	20	**740**
11	115	480	22	960	7	100	280	21	840					
12	130	610	24	**1220**	8	130	410	24	**1230**	6	120	305	24	**1220**
13	160	770	26	1540	9									
14	180	950	28	**1900**		160	570	27	1710	7	170	475	28	**1900**
15	210	1160	30	**2320**	10	200	770	30	**2310**					
16	230	1390	32	**2780**						8	220	695	32	**2780**
17	260	1650	34	3300	11	240	1010	33	3030					
18	300	1950	36	**3900**	12	290	1300	36	**3900**	9	280	975	36	**3900**
19	330	2280	38	4560	13	340	1640	39	4920					
20	360	2640	40	**5280**						10	345	1320	40	**5280**
21	410	3050	42	**6100**	14	390	2030	42	**6090**					
22	430	3480	44	**6960**						11	420	1740	44	**6960**
23	490	3970	46	7940	15	450	2480	45	7440					
24	520	4490	48	**8980**	16	510	2990	48	**8970**	12	500	2240	48	**8960**
25	560	5050	50	10100	17	580	3570	51	10710					
26	620	5670	52	**11340**						13	590	2830	52	**11320**
27	660	6330	54	**12660**	18	650	4220	54	**12660**					
28	710	7040	56	**14080**						14	690	3520	56	**14080**
29	760	7800	58	15600	19	720	4940	57	14820					
30	810	8610	60	**17220**	20	800	5740	60	**17220**	15	790	4310	60	**17240**
31	870	9480	62	18960	21	880	6620	63	19860					
32	920	10400	64	**20800**						16	890	5200	64	**20800**
33	1000	11400	66	**22800**	22	970	7590	66	**22770**					
34	1050	12450	68	**24900**						17	1010	6210	68	**24840**
35	1100	13550	70	27100	23	1060	8650	69	25950					
36	1150	14700	72	**29400**	24	1150	9800	72	**29400**	18	1140	7350	72	**29400**

37	1230	15930	74	31860	25	1250	11050	75	33150					
38	1320	17250	76	**34500**						19	1270	8620	76	**34480**
39	1350	18600	78	**37200**	26	1350	12400	78	**37200**					
40	1450	20050	80	**40100**						20	1380	10000	80	**40000**
41	1500	21550	82	43100	27	1450	13850	81	41550					
42	1600	23150	84	**46300**	28	1600	15450	84	**46350**	21	1550	11550	84	**46200**
43	1650	24800	86	49600	29	1650	17100	87	51300					
44	1750	26550	88	**53100**						22	1700	13250	88	**53000**
45	1800	28350	90	**56700**	30	1800	18900	90	**56700**					
46	1900	30250	92	**60500**						23	1900	15150	92	**60600**
47	2000	32250	94	**64500**	31	1950	20850	93	**62550**					
48	2050	34300	96	**68600**	32	2050	22900	96	**68700**	24	2000	17150	96	**68600**

A2. Robustness tests

A2.1 Alternate statistical tests

As robustness tests, we ran one-sided Wilcoxon rank-sum tests, as in LeCoq and Orzen (2006), for our hypotheses on quantity, efficiency and productive efficiency.

Table 13 shows the results of the robustness tests on quantity. Overall they confirm our findings in the main test with two exceptions. The relationship q(M4)>q(M3) is not significant anymore (p-value=0.154), but barely so. The relationship q(M2F)>q(M3) has a lower p-value and thus is significant (p-value= 0.086).

Table 13: Test results quantity hypotheses

	One-sided two-sample Wilcoxon rank-sum (Mann-Whitney) test		
Hq.1 - Markets with 3 producers	**q(M3F) > q(M3)*** (p< 0.001)**	q(M4) > q(M3) (p=0.154)	**q(M3F) > q(M4)*** (p=0.010)**
	N= 22	N= 22	N= 22

Hq.2 - Markets with 2 producers	**q(M2F) > q(M2)** (p= 0.01275)**	**q(M3) > q(M2)** (p=0.012)**	**q(M2F) > q(M3)* (p=0.070)**
Number of observations	N= 22	N= 22	N= 22

Hq.3	q(M4) > q(M2F) (p=0.794)
	N= 22

Table 14 shows the results of the robustness tests on efficiency. Overall they confirm our findings in the main test; all relationships have the same levels of significance (0.1, 0.05, or 0.01) as in the main test.

Table 14: Test results for HΩ.1, HΩ.2 and HΩ.3

	One-sided two-sample Wilcoxon rank-sum (Mann-Whitney) test		
HΩ.1 - Markets with 3 producers	**Ω(M3F) > Ω(M3)*** (p= 0.002)**	Ω(M4) > Ω(M3) (p= 0.311)	**Ω(M3F) > Ω(M4)*** (p< 0.001)**
Number of observations	N= 22	N= 22	N= 22

HΩ.2 - Markets with 2 producers	**Ω(M2F) > Ω(M2)* (p=0.079)**	**Ω(M3) > Ω(M2)** (p=0.039)**	Ω(M2F)> Ω(M3) (p= 0.7251)
Number of observations	N= 22	N= 22	N= 22

HΩ.3	Ω(M4) > Ω(M2F) (p=0.603)
Number of observations	N= 22

Table 15 shows the results of the robustness tests on production efficiency. Overall they confirm our findings in the main test with one exception: The relationship Φ(M4) < Φ(M3)* has a slightly higher p-value and thus is no longer significant (p-value= 0.100), but barely so.

Table 15: Test results for HΦ.1 and HΦ.2

	One-sided two-sample Wilcoxon rank-sum (Mann-Whitney) test	
HΦ.1 – Markets with 3 producers	Φ(M4) < Φ(M3) (p=0.100)	Φ(M3F) < Φ(M3) (p= 0.859)
Number of observations	N= 22	N= 22

HΦ.2– Markets with 2 producers	**Φ(M3) < Φ(M2)** (p=0.041)**	**Φ(M2F) < Φ(M2)* (p=0.079)**
Number of observations	N= 22	N= 22

Notably, the robustness tests confirm the results we found in the main tests, and suggest that introducing a forward market may also have a stronger effect on competition than adding one more competitor in markets with two competitors.

A2.2 Comparability data without costs

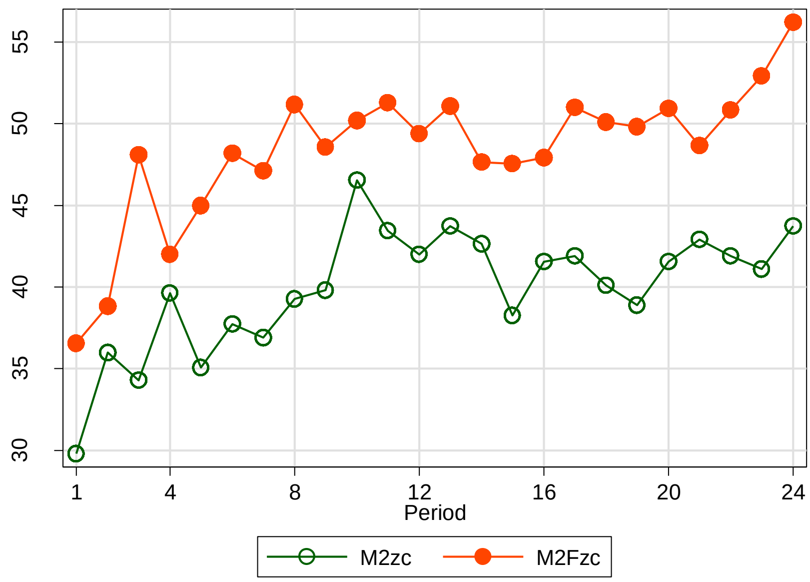
We ran treatments for markets with two producers without costs to allow comparisons with an earlier experiment on the effect of forward markets by LeCoq and Orzen (2006). Table 16 shows the theoretical predictions for these cases.

Table 16: Theoretical predictions for zero-cost markets

	NE M2-zc	NE **M2F-zc**	Walras-zc (n=2)	JPM-zc (n=2)
q_{ti}^{f}	–	16	–	–
q_{ti}	25	30	37	18/ 19[44]
q_t	50	60	74	37
p_t	650	380	2	1001
Prod. S.	32500	22800	148	37037
Cons. S.	33075	47790	72927	17982
Total S.	65575	70590	73075	55019
Eff. (%)	89.74	96.60	100	75.29

Figure 4 shows the evolution of total (aggregate) quantities sold per period, averaged over groups. The treatments without forward markets are represented by open circles, the treatments with forward markets by filled circles. As in all other treatments, the aggregate production starts out rather low, 45, then quickly jump up in the direction of the Nash-equilibrium. Between rounds 10 and 12 behavior has stabilized.

Figure 4: Average aggregate quantities sold per period



[44] One generator produces 18 units, the other 19 units.

[45] We believe this might be a primer effect of the instructions, which presented examples with rather low numbers to facilitate understanding of the basic relationships.

Averages by group

Table 17 shows that aggregate production tends to be significantly (p-values<0.093) smaller than the Nash-equilibrium, confirming the results of LeCoq and Orzen (2006).

Table 17: Production averages and comparison

Averages		
	M2zc	M2Fzc
Average production	41.6 (1.91)	50.3 9 (2.51)
% of NE prediction	79.9%	83.8%
Number of observations	N=11	N=11
% of NE prediction LeCoq and Orzen (2006)	*93,2%,*	*93,8%,*

Using a one-sided Wilcoxon rank-sum test we find that the increase in aggregate production due to a forward market is significant (p-value=0.014), confirming the results of LeCoq and Orzen (2006). A robustness tests confirms this finding.

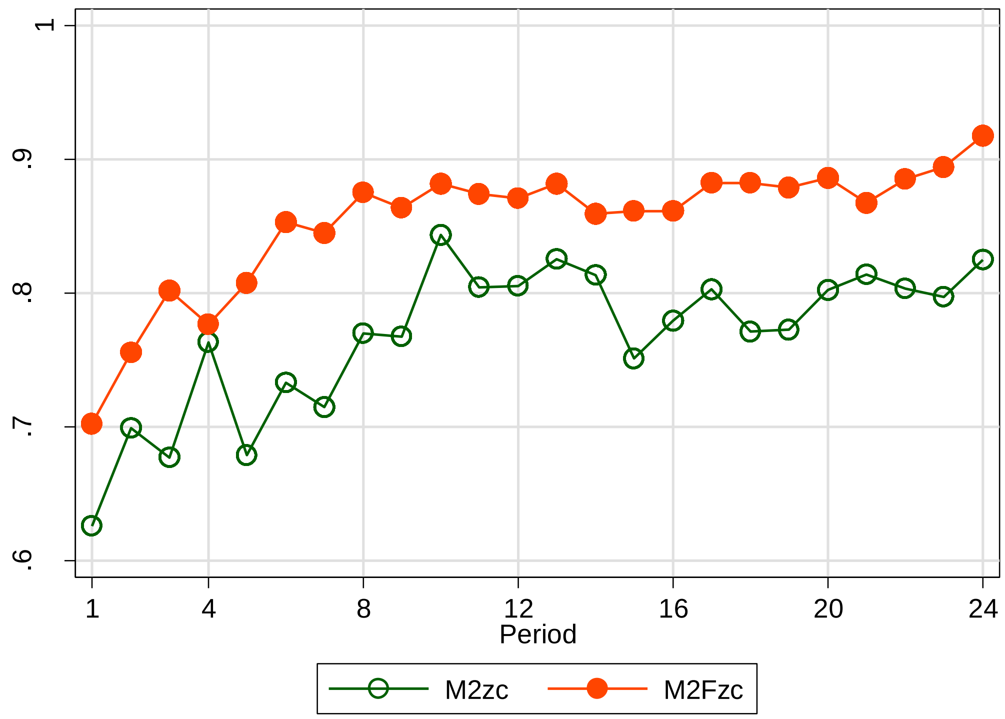
Table 18: Tests of effect of forward market

Main tests		
one-sided Wilcoxon rank-sum test		**M2Fzc> M2zc** (p=0.014)**
		N=11

Robustness tests		
OLS regression with correction for clustering on group level, followed by one-sided F test on equality of the coefficients		**M2Fzc> M2zc*** (p<0.010)**
		N= 572

Figure 5 shows the evolution of efficiency per period, averaged over groups. The treatments without forward markets are represented by open circles, the treatments with forward markets by filled circles. As producers have no production costs, production efficiency as defined in the main text is always 100%. Efficiency is thus determined by the aggregate production and the average efficiency in Figure 5 closely follows the aggregate average production (Figure 4).

Figure 5: Average efficiency per period



Efficiency is lower than the Nash-equilibrium prediction. A two-sided Wilcoxon one-sample signed-rank test indicates that these differences are significant (p-values<0.017).

Table 19: Efficiency averages and comparison

	M2zc	M2Fzc
Average efficiency as % of Walras	79.7 (2.10)	88.3 (2.37)
% of NE prediction	89.8%	90.7%
	N= 11	N= 11
one-sided Wilcoxon rank-sum test		**M2Fzc> M2zc***** **(p<0.010)**
		N= 16
OLS regression with correction for clustering on group level, followed by one-sided F test on equality of the coefficients		**M2Fzc> M2zc**** **(p=0.011)**
	N= 572	N= 572

A3. Sessions with experienced subjects

In October 2010 we ran sessions with subjects that had taken part in earlier sessions of the experiment. For each treatment we have 5 independent groups, except for M3F and M4, where we have 4 independent groups. For all treatments except M2 we assigned subjects to the exact same treatment they had participated in earlier. In the M2 treatments we had to rely on some subjects that had earlier participated in M3 or M4. Figure 6 shows the aggregate production for inexperienced subjects on the left and for experienced on the right. As can be seen, the basic pattern is the same.

The eyeball test reveals that the largest differences are in the first periods – experienced subjects produce visibly more.

We noted above that subjects start out producing rather low (below the average over all rounds) and that we believe that this is a primer effect. In the instructions we gave examples with low numbers to facilitate understanding. We believe this triggered our subjects to produce low amounts in the first few rounds. Experienced subjects seem less susceptible to this instructional framing effect. Figure 7 shows how much more experienced subjects produced than inexperienced ones on average over all treatments. Experienced subjects produce 20% more in the first round. After that the difference levels off to 10%, and from round 6 on the difference hovers close to zero.

Figure 6: Aggregate production per period

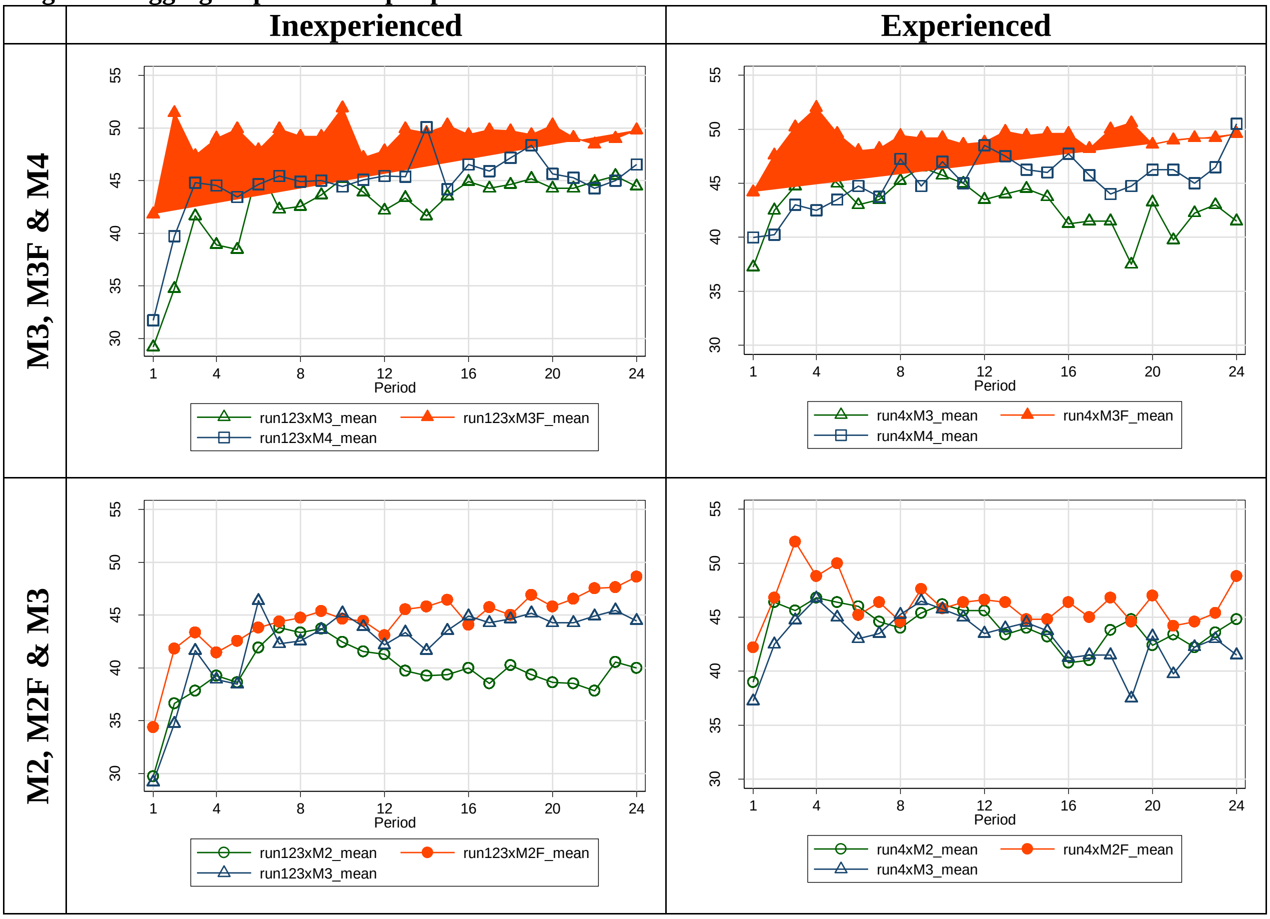
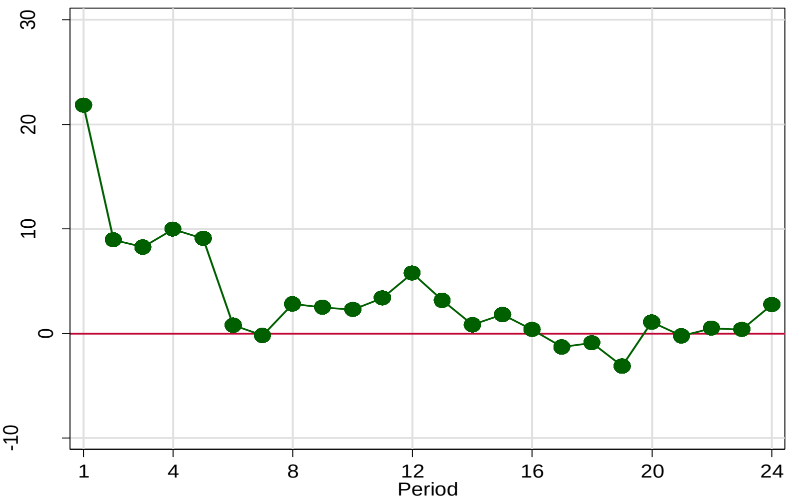


Figure 7: Percentage increase of aggregate production by experienced subjects



To test if the aggregate production of experienced subjects is different from that of inexperienced subjects, we run a regression of the aggregate production on the treatment dummies interacted with the experience dummy for the last 12 periods:

$$AggSupply = \begin{Bmatrix} InExp \cdot \left(\beta_{IE,M2} \cdot M2 + \beta_{IE,M2F} \cdot M2F + \beta_{IE,M3} \cdot M3 + \beta_{IE,M3F} \cdot M3F + \beta_{IE,M4} \cdot M4\right) + \\ Exp \cdot \left(\beta_{E,M2} \cdot M2 + \beta_{E,M2F} \cdot M2F + \beta_{E,M3} \cdot M3 + \beta_{E3F} \cdot M3F + \beta_{E,M4} \cdot M4\right) \ + \varepsilon \end{Bmatrix}$$

InExp (*Exp*) is the dummy for the inexperienced (experienced) subjects, and *M2*, *M2F*, *M3*, *M3F*, and *M4* are the dummies for the treatments. We then run 2-sided F-tests for the differences between $\beta_{IE,i}$ (inexperienced subjects) and $\beta_{E,i}$ (experienced subjects) for all treatments. Table 20 reports the results.

Table 20: Aggregate production for experienced versus inexperienced subjects

	M2	**M2F**	**M3**	**M3F**	**M4**
Inexperienced	39.34 (1.46)	46.31 (1.976)	44.24 (1.18)	49.55 (0.58)	46.20 (0.95)
Experienced	43.12 (1.53)	45.73 (2.40)	41.98 (1.57)	50.94 (0.16)	46.38 (0.93)
Difference	**+3.78**	-0.58	-2.26	**+1.39**	+0.18
Significance	**0.0781**	0.8533	0.2527	**0.025**	0.8937

Differences are significant for treatments M2 and M3F. In both these treatments experienced subjects produced more than inexperienced subjects. Another indication that experience leads to more production comes from regressing the aggregate production on the treatment dummies and a time variable to record how many months ago it is that the subject participated in the experiment. We conjecture that the more recently a subject has participated, the more influential his experience still is, and thus the more strongly might the effect of experience on the subject's decisions be. The time variable is indeed negative and significant ($p < 0.035$): subjects that participated 6 months ago produce on average 2.2 units more than subjects who participated 12 months ago.

Experience increasing aggregate production is in line with the experimental evidence for public provision games. This evidence indicates that private contributions to a public good fall with experience (Ledyard, 1995). The private contribution that producers could make in Cournot competition is to exercise restraint in selling units on the forward and spot markets. Such a restraint softens competition in the spot market which results in a higher overall profit. Experienced producers thus make lower "public contributions" by not restraining themselves.

A4. Predictions of the spot market price by our automated traders

M2F-zc: Total Production Stage A, Predicted Total Production and Resulting (Spot) Price

Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price	Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price	Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price
0	49.4	667	**33**	71.4	73	**66**	93.4	0
1	50.0	649	**34**	72.0	55	**67**	94.0	0
2	50.7	631	**35**	72.7	37	**68**	94.7	0
3	51.4	613	**36**	73.4	19	**69**	95.4	0
4	52.0	595	**37**	74.0	1	**70**	96.0	0
5	52.7	577	**38**	74.7	0	**71**	96.7	0
6	53.4	559	**39**	75.4	0	**72**	97.4	0
7	54.0	541	**40**	76.0	0	**73**	98.0	0
8	54.7	523	**41**	76.7	0	**74**	98.7	0
9	55.4	505	**42**	77.4	0	**75**	99.4	0
10	56.0	487	**43**	78.0	0	**76**	100.0	0
11	56.7	469	**44**	78.7	0	**77**	100.7	0
12	57.4	451	**45**	79.4	0	**78**	101.4	0
13	58.0	433	**46**	80.0	0	**79**	102.0	0
14	58.7	415	**47**	80.7	0	**80**	102.7	0
15	59.4	397	**48**	81.4	0	**81**	103.4	0
16	60.0	379	**49**	82.0	0	**82**	104.0	0
17	60.7	361	**50**	82.7	0	**83**	104.7	0
18	61.4	343	**51**	83.4	0	**84**	105.4	0
19	62.0	325	**52**	84.0	0	**85**	106.0	0
20	62.7	307	**53**	84.7	0	**86**	106.7	0
21	63.4	289	**54**	85.4	0	**87**	107.4	0
22	64.0	271	**55**	86.0	0	**88**	108.0	0
23	64.7	253	**56**	86.7	0	**89**	108.7	0
24	65.4	235	**57**	87.4	0	**90**	109.4	0
25	66.0	217	**58**	88.0	0	**91**	110.0	0
26	66.7	199	**59**	88.7	0	**92**	110.7	0
27	67.4	181	**60**	89.4	0	**93**	111.4	0
28	68.0	163	**61**	90.0	0	**94**	112.0	0
29	68.7	145	**62**	90.7	0	**95**	112.7	0
30	69.4	127	**63**	91.4	0	**96**	113.4	0
31	70.0	109	**64**	92.0	0			
32	70.7	91	**65**	92.7	0			

M2F: Total Production Stage A, Predicted Total Production and Resulting (Spot) Price

Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price	Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price	Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price
0	40.0	921	**33**	47.3	723	**66**	66.0	218
1	40.2	915	**34**	47.5	717	**67**	67.0	191
2	40.4	909	**35**	47.7	711	**68**	68.0	164
3	40.6	903	**36**	48.0	705	**69**	69.0	137
4	40.9	897	**37**	48.2	699	**70**	70.0	110
5	41.1	890	**38**	48.4	693	**71**	71.0	83
6	41.3	884	**39**	48.6	688	**72**	72.0	56
7	41.6	878	**40**	48.8	682	**73**	73.0	29
8	41.8	872	**41**	49.0	676	**74**	74.0	2
9	42.0	866	**42**	49.3	670	**75**	75.0	0
10	42.2	860	**43**	49.5	664	**76**	76.0	0
11	42.5	854	**44**	49.7	659	**77**	77.0	0
12	42.7	848	**45**	49.9	653	**78**	78.0	0
13	42.9	842	**46**	50.1	647	**79**	79.0	0
14	43.1	836	**47**	50.3	641	**80**	80.0	0
15	43.3	830	**48**	50.5	636	**81**	81.0	0
16	43.6	824	**49**	50.7	630	**82**	82.0	0
17	43.8	818	**50**	51.0	624	**83**	83.0	0
18	44.0	812	**51**	51.2	619	**84**	84.0	0
19	44.2	806	**52**	52.0	596	**85**	85.0	0
20	44.5	800	**53**	53.0	569	**86**	86.0	0
21	44.7	794	**54**	54.0	542	**87**	87.0	0
22	44.9	788	**55**	55.0	515	**88**	88.0	0
23	45.1	782	**56**	56.0	488	**89**	89.0	0
24	45.3	776	**57**	57.0	461	**90**	90.0	0
25	45.6	770	**58**	58.0	434	**91**	91.0	0
26	45.8	764	**59**	59.0	407	**92**	92.0	0
27	46.0	758	**60**	60.0	380	**93**	93.0	0
28	46.2	752	**61**	61.0	353	**94**	94.0	0
29	46.4	746	**62**	62.0	326	**95**	95.0	0
30	46.7	740	**63**	63.0	299	**96**	96.0	0
31	46.9	734	**64**	64.0	272			
32	47.1	728	**65**	65.0	245			

M3F: Total Production Stage A, Predicted Total Production and Resulting (Spot) Price

Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price
0	43.2	833
1	43.4	829
2	43.5	824
3	43.7	820
4	43.9	816
5	44.0	811
6	44.2	807
7	44.3	803
8	44.5	799
9	44.7	794
10	44.8	790
11	45.0	786
12	45.1	781
13	45.3	777
14	45.5	773
15	45.6	769
16	45.8	764
17	45.9	760
18	46.1	756
19	46.2	752
20	46.4	747
21	46.6	743
22	46.7	739
23	46.9	735
24	47.0	730
25	47.2	726
26	47.3	722
27	47.5	718
28	47.6	713
29	47.8	709
30	48.0	705
31	48.1	701
32	48.3	697

Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price
33	48.4	693
34	48.6	688
35	48.7	684
36	48.9	680
37	49.0	676
38	49.2	672
39	49.3	668
40	49.5	663
41	49.7	659
42	49.8	655
43	50.0	651
44	50.1	647
45	50.3	643
46	50.4	639
47	50.6	635
48	50.7	630
49	50.9	626
50	51.0	622
51	51.2	618
52	52.0	596
53	53.0	569
54	54.0	542
55	55.0	515
56	56.0	488
57	57.0	461
58	58.0	434
59	59.0	407
60	60.0	380
61	61.0	353
62	62.0	326
63	63.0	299
64	64.0	272
65	65.0	245

Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price
66	66.0	218
67	67.0	191
68	68.0	164
69	69.0	137
70	70.0	110
71	71.0	83
72	72.0	56
73	73.0	29
74	74.0	2
75	75.0	0
76	76.0	0
77	77.0	0
78	78.0	0
79	79.0	0
80	80.0	0
81	81.0	0
82	82.0	0
83	83.0	0
84	84.0	0
85	85.0	0
86	86.0	0
87	87.0	0
88	88.0	0
89	89.0	0
90	90.0	0
91	91.0	0
92	92.0	0
93	93.0	0
94	94.0	0
95	95.0	0
96	96.0	0

A5. Sheets given to the subjects
(M2, M2zc, M3, M4)

Total Production and Resulting Price

Production	Price/Unit	Production	Price/Unit	Production	Price/Unit
0	2000	33	1109	66	218
1	1973	34	1082	67	191
2	1946	35	1055	68	164
3	1919	36	1028	69	137
4	1892	37	1001	70	110
5	1865	38	974	71	83
6	1838	39	947	72	56
7	1811	40	920	73	29
8	1784	41	893	74	2
9	1757	42	866	75	0
10	1730	43	839	76	0
11	1703	44	812	77	0
12	1676	45	785	78	0
13	1649	46	758	79	0
14	1622	47	731	80	0
15	1595	48	704	81	0
16	1568	49	677	82	0
17	1541	50	650	83	0
18	1514	51	623	84	0
19	1487	52	596	85	0
20	1460	53	569	86	0
21	1433	54	542	87	0
22	1406	55	515	88	0
23	1379	56	488	89	0
24	1352	57	461	90	0
25	1325	58	434	91	0
26	1298	59	407	92	0
27	1271	60	380	93	0
28	1244	61	353	94	0
29	1217	62	326	95	0
30	1190	63	299	96	0
31	1163	64	272		
32	1136	65	245		

(M2F, M2Fzc, M3F)

Aggregate Production and Resulting Price in STAGE B

Aggregate number of Units in Stage A+ B	Resulting Price in STAGE B	Aggregate number of Units in Stage A+ B	Resulting Price in STAGE B	Aggregate number of Units in SPOT Market	Resulting Price in STAGE B
0	2000	33	1109	66	218
1	1973	34	1082	67	191
2	1946	35	1055	68	164
3	1919	36	1028	69	137
4	1892	37	1001	70	110
5	1865	38	974	71	83
6	1838	39	947	72	56
7	1811	40	920	73	29
8	1784	41	893	74	2
9	1757	42	866	75	0
10	1730	43	839	76	0
11	1703	44	812	77	0
12	1676	45	785	78	0
13	1649	46	758	79	0
14	1622	47	731	80	0
15	1595	48	704	81	0
16	1568	49	677	82	0
17	1541	50	650	83	0
18	1514	51	623	84	0
19	1487	52	596	85	0
20	1460	53	569	86	0
21	1433	54	542	87	0
22	1406	55	515	88	0
23	1379	56	488	89	0
24	1352	57	461	90	0
25	1325	58	434	91	0
26	1298	59	407	92	0
27	1271	60	380	93	0
28	1244	61	353	94	0
29	1217	62	326	95	0
30	1190	63	299	96	0
31	1163	64	272		
32	1136	65	245		

(M3F)

Total Production STAGE A and Resulting Price in STAGE A

Total production STAGE A	Price STAGE A	Total production STAGE A	Price STAGE A	Total production STAGE A	Price STAGE A
0	833	**33**	693	**66**	218
1	829	**34**	688	**67**	191
2	824	**35**	684	**68**	164
3	820	**36**	680	**69**	137
4	816	**37**	676	**70**	110
5	811	**38**	672	**71**	83
6	807	**39**	668	**72**	56
7	803	**40**	663	**73**	29
8	799	**41**	659	**74**	2
9	794	**42**	655	**75**	0
10	790	**43**	651	**76**	0
11	786	**44**	647	**77**	0
12	781	**45**	643	**78**	0
13	777	**46**	639	**79**	0
14	773	**47**	635	**80**	0
15	769	**48**	630	**81**	0
16	764	**49**	626	**82**	0
17	760	**50**	622	**83**	0
18	756	**51**	618	**84**	0
19	752	**52**	596	**85**	0
20	747	**53**	569	**86**	0
21	743	**54**	542	**87**	0
22	739	**55**	515	**88**	0
23	735	**56**	488	**89**	0
24	730	**57**	461	**90**	0
25	726	**58**	434	**91**	0
26	722	**59**	407	**92**	0
27	718	**60**	380	**93**	0
28	713	**61**	353	**94**	0
29	709	**62**	326	**95**	0
30	705	**63**	299	**96**	0
31	701	**64**	272		
32	697	**65**	245		

(M2F)

Total Production STAGE A and Resulting Price in STAGE A

Total production STAGE A	Price/unit STAGE A	Total production STAGE A	Price/unit STAGE A	Total production STAGE A	Price/unit STAGE A
0	921	**33**	723	**66**	218
1	915	**34**	717	**67**	191
2	909	**35**	711	**68**	164
3	903	**36**	705	**69**	137
4	897	**37**	699	**70**	110
5	890	**38**	693	**71**	83
6	884	**39**	688	**72**	56
7	878	**40**	682	**73**	29
8	872	**41**	676	**74**	2
9	866	**42**	670	**75**	0
10	860	**43**	664	**76**	0
11	854	**44**	659	**77**	0
12	848	**45**	653	**78**	0
13	842	**46**	647	**79**	0
14	836	**47**	641	**80**	0
15	830	**48**	636	**81**	0
16	824	**49**	630	**82**	0
17	818	**50**	624	**83**	0
18	812	**51**	619	**84**	0
19	806	**52**	596	**85**	0
20	800	**53**	569	**86**	0
21	794	**54**	542	**87**	0
22	788	**55**	515	**88**	0
23	782	**56**	488	**89**	0
24	776	**57**	461	**90**	0
25	770	**58**	434	**91**	0
26	764	**59**	407	**92**	0
27	758	**60**	380	**93**	0
28	752	**61**	353	**94**	0
29	746	**62**	326	**95**	0
30	740	**63**	299	**96**	0
31	734	**64**	272		
32	728	**65**	245		

(M2Fzc)

Total Production STAGE A and Resulting Price in STAGE A

Total production STAGE A	Price/unit STAGE A	Total production STAGE A	Price/unit STAGE A	Total production STAGE A	Price/unit STAGE A
0	667	33	73	66	0
1	649	34	55	67	0
2	631	35	37	68	0
3	613	36	19	69	0
4	595	37	1	70	0
5	577	38	0	71	0
6	559	39	0	72	0
7	541	40	0	73	0
8	523	41	0	74	0
9	505	42	0	75	0
10	487	43	0	76	0
11	469	44	0	77	0
12	451	45	0	78	0
13	433	46	0	79	0
14	415	47	0	80	0
15	397	48	0	81	0
16	379	49	0	82	0
17	361	50	0	83	0
18	343	51	0	84	0
19	325	52	0	85	0
20	307	53	0	86	0
21	289	54	0	87	0
22	271	55	0	88	0
23	253	56	0	89	0
24	235	57	0	90	0
25	217	58	0	91	0
26	199	59	0	92	0
27	181	60	0	93	0
28	163	61	0	94	0
29	145	62	0	95	0
30	127	63	0	96	0
31	109	64	0		
32	91	65	0		

(M2, M2F)

Production Costs

Units Produced	Marginal Costs	Total Costs		Units produced	Marginal Costs	Total Costs
1	1	1		**25**	560	5050
2	5	6		**26**	620	5670
3	9	15		**27**	660	6330
4	16	31		**28**	710	7040
5	24	55		**29**	760	7800
6	35	90		**30**	810	8610
7	45	135		**31**	870	9480
8	60	195		**32**	920	10400
9	80	275		**33**	1000	11400
10	90	365		**34**	1050	12450
11	115	480		**35**	1100	13550
12	130	610		**36**	1150	14700
13	160	770		**37**	1230	15930
14	180	950		**38**	1320	17250
15	210	1160		**39**	1350	18600
16	230	1390		**40**	1450	20050
17	260	1650		**41**	1500	21550
18	300	1950		**42**	1600	23150
19	330	2280		**43**	1650	24800
20	360	2640		**44**	1750	26550
21	410	3050		**45**	1800	28350
22	430	3480		**46**	1900	30250
23	490	3970		**47**	2000	32250
24	520	4490		**48**	2050	34300

(M3, M3F)

Production Costs

Units Produced	Marginal Costs	Total Costs
0	0	0
1	2	2
2	8	10
3	18	28
4	32	60
5	50	110
6	70	180
7	100	280
8	130	410
9	160	570
10	200	770
11	240	1010
12	290	1300
13	340	1640
14	390	2030
15	450	2480
16	510	2990
17	580	3570
18	650	4220
19	720	4940
20	800	5740
21	880	6620
22	970	7590
23	1060	8650
24	1150	9800
25	1250	11050
26	1350	12400
27	1450	13850
28	1600	15450
29	1650	17100
30	1800	18900
31	1950	20850
32	2050	22900

(M4)

Production Costs

Units produced	Marginal Costs	Total Costs
0	0	0
1	3	3
2	12	15
3	30	45
4	55	100
5	85	185
6	120	305
7	170	475
8	220	695
9	280	975
10	345	1320
11	420	1740
12	500	2240
13	590	2830
14	690	3520
15	790	4310
16	890	5200
17	1010	6210
18	1140	7350
19	1270	8620
20	1380	10000
21	1550	11550
22	1700	13250
23	1900	15150
24	2000	17150

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