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Abstract

We try to better understand the comparative advantages of structural and behavioral measures of deregulation in electricity markets, an eminent policy issue for which the experimental evidence is scant and problematic. In the present paper we investigate theoretically and experimentally the effects of the introduction of a forward market on competition in electricity markets. We compare 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, teasing apart number and asset effect, and studying numbers of competitors that reflect better 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 both the newly accessed and the old European Union member states. Introducing a forward market also increases efficiency. Our data furthermore suggest, in contrast to previous findings, that the effects of introducing a forward market is stronger than adding one more competitor both in markets with two, and particularly three, producers. Our data thus suggest that the behavioral measure of introducing a forward market is more effective than the structural measure of adding one more competitor by divestiture. Thus competition authorities should, in line with EU law, focus on the behavioral measure of introducing, or at least facilitating the emergence of, forward markets rather than on the structural measure of lowering market concentration by divestiture.

Keywords

Economics experiments, market power, competition, forward markets, EU electricity market.

1. Introduction[*]

Concentration in generator markets is a key 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 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 measures. For example, in 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.[1] The UK also experienced a considerable degree of new entry.[2] Belgium, France, Italy, Denmark, and the Netherlands are using, or used in the past, the auctioning of Virtual Power Plants[3] 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[4] - 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 also "softer" measures, 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).

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

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

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

4 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.

In addition to such structural measures, policy makers and regulators have shown interest in behavioral measures 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 measures 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, 2006).

Allaz and Vila (1993) make the theoretical case for the introduction of a forward market as a behavioral measure that increases competitive pressure. Specifically, they show that a forward market lowers the amount of market power producers can exert: 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. The contribution of Allaz and Villa (1993) is important since it has been argued that forward contracts are likely to decrease competition (Lévêque, 2006).

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 the introduction of a forward market with those of the best alternative measure: reducing market concentration by divestiture. We do so for numbers of competitors that reflect better the market concentration in the old European states than previous literature has done: We also use realistic cost configurations and tease apart number 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. The question whether the theoretical predictions of Allaz and Villa (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 divestment and the effects of introducing a forward market, and then compare whether the effects are stronger in the former case than in the latter.

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

Table 1: Treatment conditions

	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 condition is different from the one tested in LeCoq and Orzen (2006) in that producers here face quadratic marginal costs.

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

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

* The condition 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 (NMS-12)[5] and three producers for markets in the old EU Member States (EU-15)[6] seems a good approximation.[7]

Thus for the NMS-12 we 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 re 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

5 The New EU Member States (NMS-12) are states that acceded to the EU in or after 2004. With the exception of Cyprus and Malthus these are all post-communistic 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).

6 The old EU Member States (EU-15) are states that acceded to 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).

7 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).

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 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 stronger than the addition of a forward market.

Brandts et al. (2008) confound two effects in their study: a pure number effect and an asset effect. The pure number 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 market participant's production assets; the aggregate size of production assets in the market thus increases, which results in lower prices and a larger total number of units supplied. Thus, assuming efficient production, any given level of aggregate production (the production of all producers together) is produced cheaper 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 the study of Brandts et al. (2008).

We therefore focus on the effect of divestiture as a benchmark for the effect of a forward market, and thus eliminate the asset effect confound. This insulates the number effect. To allow for comparisons, we drew (to the extent possible) on Brandts et al. (2008) and LeCoq and Orzen (2006) to parameterize our experiment.

2.3 Demand and supply

As in Brandts et al. (2008), the demand schedule is $p(Q) = Max(0, 2000 - 27Q)$, $Q \geq 0$ .As also in Brandt 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 the treatments in our experiment.

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, M3 and M3F. Brandts et al. (2008) set the marginal cost of producing the ith unit for a producer equal to $mc_3(q) = 2x^2$, cumulative costs can thus be calculated as

$$c_3(q) = \sum_{x=1}^{q} 2x^2 = \tfrac{2}{3}x^3 + x^2 + \tfrac{1}{3}x .$$

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 halves and their 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:

$$\boldsymbol{c}_2[\boldsymbol{y}] = \frac{8\boldsymbol{y}^3}{27} + \frac{2\boldsymbol{y}^2}{3} + \frac{\boldsymbol{y}}{3}, \text{ and } \boldsymbol{c}_4[\boldsymbol{y}] = \frac{32}{27}\boldsymbol{y}^3 + \frac{4}{3}\boldsymbol{y}^2 + \frac{\boldsymbol{y}}{3}.$$ [8]

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. This is indeed the case: Table 2 summarizes the production costs for each generator in the market with two (M2), three (M3) and four (M4) generators, and highlights occurrences where the aggregate production in one market is equal to that in another market as bold and colored. 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.

Table 2:[9] 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					
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**					

---

8 With identical choices in the respective markets, the aggregate production in M3 and M4 is equal when it can be divided by both 3 and 4. Formally, when, for $\boldsymbol{n} \in \mathbb{N}^{+}$, the four producers in M4 each produce $3\boldsymbol{n}$ units, then their aggregate production is $4 \cdot 3\boldsymbol{n} = 12\boldsymbol{n}$; when the three producers in M3 each produce $4\boldsymbol{n}$ units, then their aggregate production is $3 \cdot 4\boldsymbol{n} = 12\boldsymbol{n}$. As a result, the aggregate costs must be the same in these cases. Thus

$4 \cdot \boldsymbol{c}_4[3 \cdot \boldsymbol{y}] = 3 \cdot \boldsymbol{c}_3[4 \cdot \boldsymbol{y}]$ and $\boldsymbol{c}_4[\boldsymbol{y}] = \frac{3}{4} \cdot \boldsymbol{c}_3[\frac{4}{3} \cdot \boldsymbol{y}] = \frac{32}{27}\boldsymbol{y}^3 + \frac{4}{3}\boldsymbol{y}^2 + \frac{\boldsymbol{y}}{3}$. In the same way, it follows that

$\boldsymbol{c}_2[\boldsymbol{y}] = \frac{3}{2} \cdot \boldsymbol{c}_3[\frac{2}{3} \cdot \boldsymbol{y}] = \frac{8\boldsymbol{y}^3}{27} + \frac{2\boldsymbol{y}^2}{3} + \frac{\boldsymbol{y}}{3}$. Notice that for marginal costs holds the equality:

$\boldsymbol{c}_2'[\frac{3}{2}\boldsymbol{y}] = \boldsymbol{c}_3'[\boldsymbol{y}] = \boldsymbol{c}_4'[\frac{3}{4}\boldsymbol{y}]$. Conforming to intuition, the marginal cost of a producer in M3 thus increases faster (slower) than in M2 (M4).

9 Numbers have been rounded to the nearest whole number.

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**

To help subjects focus on the decision task, we presented to our subjects 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 these rounding rules, some of the aggregate total costs in Table 2 are different. The discrepancy is small however; on average of 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.[10]

2.4 Theoretical Predictions and Hypotheses

Table 3 shows the theoretical predictions for our treatments M2, M2F, M3, M3F, and M4. The prefix NE stands for Nash-equilibrium, Walras for the efficient solution, and JPM for Joint Profit Maximization (the monopoly solution).[11]

Table 3: Theoretical predictions 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[12]	15	11	25/26[13]	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

10 Using the not rounded numbers gives virtually identical theoretical predictions,

11 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 identically 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) chose to broaden their equilibrium concept by considering partially mixed strategies (for the choice of additional units) and thus 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.

12 One generator produces 15 units, the other two 14 units.

13 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.[14] 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[15], we thus conjecture that the measures can be ranked as follows: q(M3F) > q(M4) > q(M3). Likewise, both measures 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 measures 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 Nash-equilibria makes it impossible to rank the measures. We conjecture that the measures can be ranked as follows: q(M2F) > q(M2), q(M3) > q(M2), and q(M2F) = q(M3). Moreover, the theoretical results 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 measures 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).

We also test for effects on production efficiency. 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.

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)	

[14] 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 XXX. 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 – it is 40 instead of 42. As a result the difference in total surplus is relatively high: 1.8%.

[15] 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).

2.5 Experimental procedures

The experimental sessions were conducted in October 2009, December 2009, and April 2010 in Prague at the Center of Economic Research and Graduate Education and Economic Institute (CERGE-EI).[16] Our subjects were students at the Charles University or at the University of Economics. A total of 198 students participated. The session with a forward market lasted about 2 hours, the sessions without a forward market lasted about 90 minutes. At the beginning of each session, the English instructions were read to the subjects by the experimenter (Van Koten).

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

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. A detailed comparison may be found in the Appendix.

3.1 Aggregate Quantity

Figure 1 shows the evolution of total (aggregate) quantities sold per period, averaged over treatment groups. 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 circles, triangles or squares, the treatments with forward markets by filled circles or triangles.

All treatments start out rather low[17] but trade volume moves quickly into the direction of the Nash-equilibrium. Between rounds 8 and 12 behavior has stabilized.

[16] 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 the treatments M3F and M4, and in April 2010 three data points for M2zc, M2Fzc, M2F, M2, M3, and four data points for the treatments M3F and M4. The original game plan was to obtain four data points for all treatments also in December 2009. Excessive 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.

[17] 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

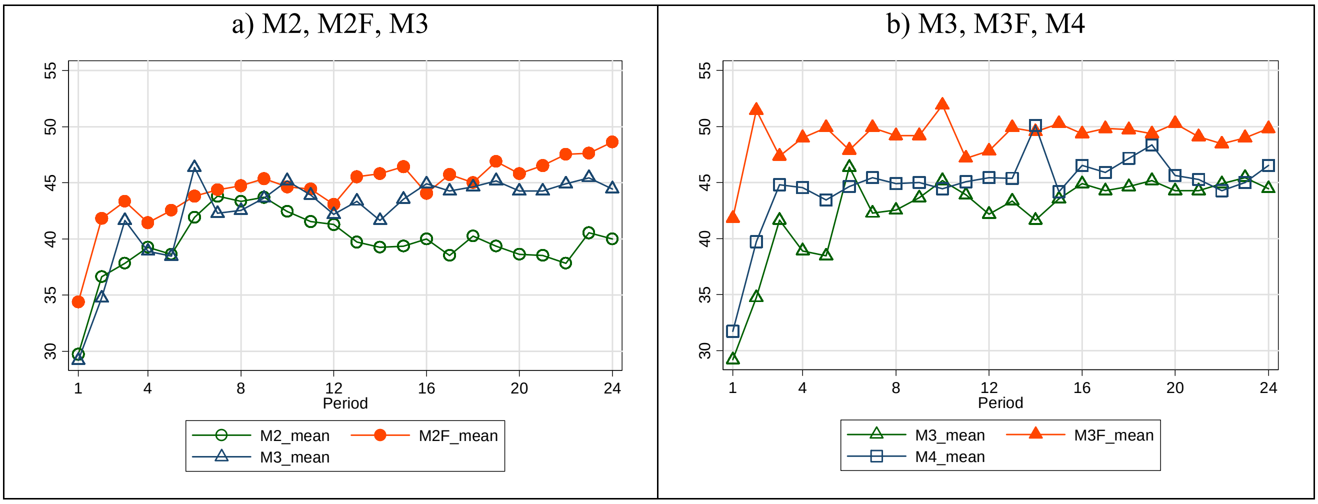

Table 5 shows the overall average aggregate production per treatment group, with the standard error in parenthesis.[18] The row below gives the size of the observed aggregated quantity relative to the Nash-equilibrium prediction in percentages.

Table 5: Production averages

	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%*[19]	*102.9%*	*110.1%*	*105.0%*
Number of observations	N=11	N=11	N=11	N=11	N=11
% of NE prediction - earlier studies[20]	*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)*

Notice 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-

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

[19] 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.

[20] 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 LeCoq and Orzen (2006) found (both p-values < 0.041). See the Appendix for a detailed exposition.

value=0.068). Of the treatments with a forward market, the production in M3F is significantly 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 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: Test results quantity hypotheses

	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.[21]

Hypothesis q.2: q(M3F) > q(M4) > q(M3).

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 with 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

[21] 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

production with 4%, and this effect is barely significant, p-value=0.105). We find that introducing a forward market increases the 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).

Hypothesis q.2: q(M2F) > q(M2), q(M3) > q(M2), q(M2F) = q(M3), and q(M2F) < q(M4).

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 with 18% in markets with two competitors and 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 with 12% and this increase is significant (q(M3) > q(M2), p-value= 0.006). Introducing a forward market increases aggregate production with 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.

Hypothesis q.3: 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.

In contrast with the theoretical predictions, the effect of introducing a forward market with two competitors does not increase competition significantly less than doubling the number of competitors. Our data rather indicate the opposite ordering; 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.[22]

3.2 Efficiency

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). 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.[23]

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[22] In the experiment of LeCoq and Orzen (2006) competitors incurred no costs in production, unlike in our experiments. This indicates that, in contradiction with theory, production costs might play a relevant role in the competitiveness of markets.

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

Figure 2: Efficiency percentages

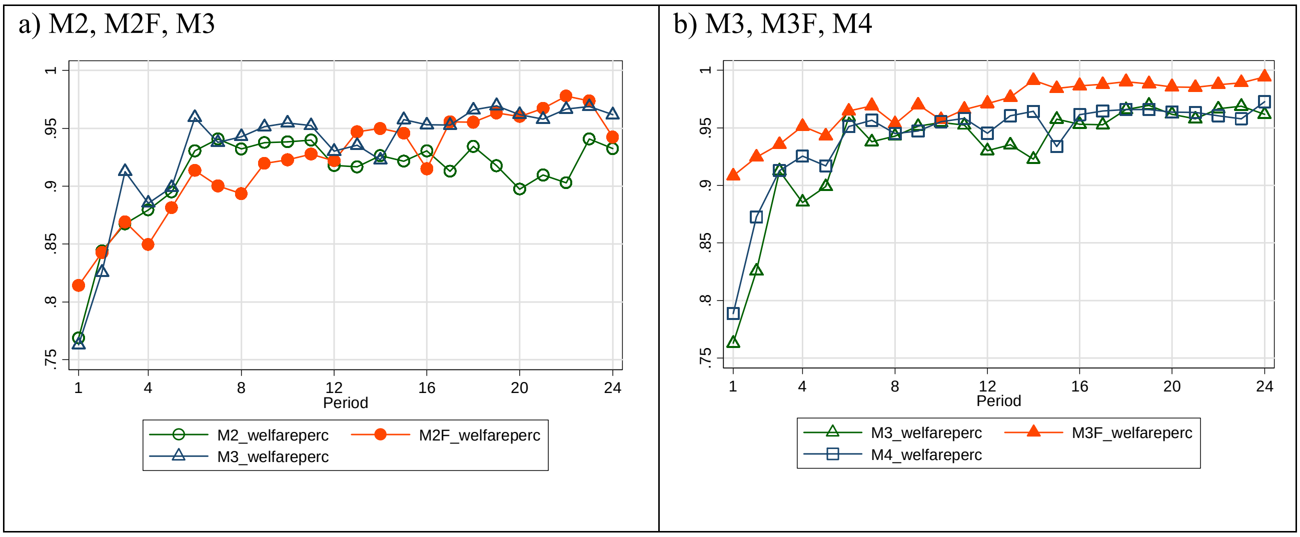

Table 7 shows the observed average efficiency level in the last 12 rounds, with the standard error in parenthesis. The row below gives the level of the observed average efficiency level relative to the Nash-equilibrium prediction in percentages. The efficiency levels are close to the Nash-equilibrium 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 in Brandts et al. (2008).

Table 7: Efficiency averages

	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%[24]	98.3%	100.5%	98.6%
	N=11	N=11	N=11	N=11	N=11
% of NE prediction - earlier studies[25]	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 8 presents the results of the F-tests and Jonckheere test.[26] Aggregate production in the market is the most important determinant of efficiency, as production inefficiency only has a minor influence. The results of the tests of hypotheses regarding efficiency thus closely follow those regarding aggregate production.

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24 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.

25 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).

26 The robustness tests, one-sided Wilcoxon rank-sum tests, confirmed our results at the same significance levels.

Table 8: Test results for HΩ.1, HΩ.2 and HΩ.3

	OLS regression, with correction for clustering on group level, followed by an one-sided F-test on equality of the coefficients			Jonckheere test
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

Hypothesis Ω.1: Ω (M3F) > Ω (M4) > 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 with 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).

Hypothesis Ω.2: 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 with 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).

Hypothesis Ω.3: 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 efficiently significantly less than doubling the number of competitors.

3.3 Production Efficiency

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.[27] Figure 2 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 2 traders are represented by circles, with 3 traders by triangles, and with 4 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

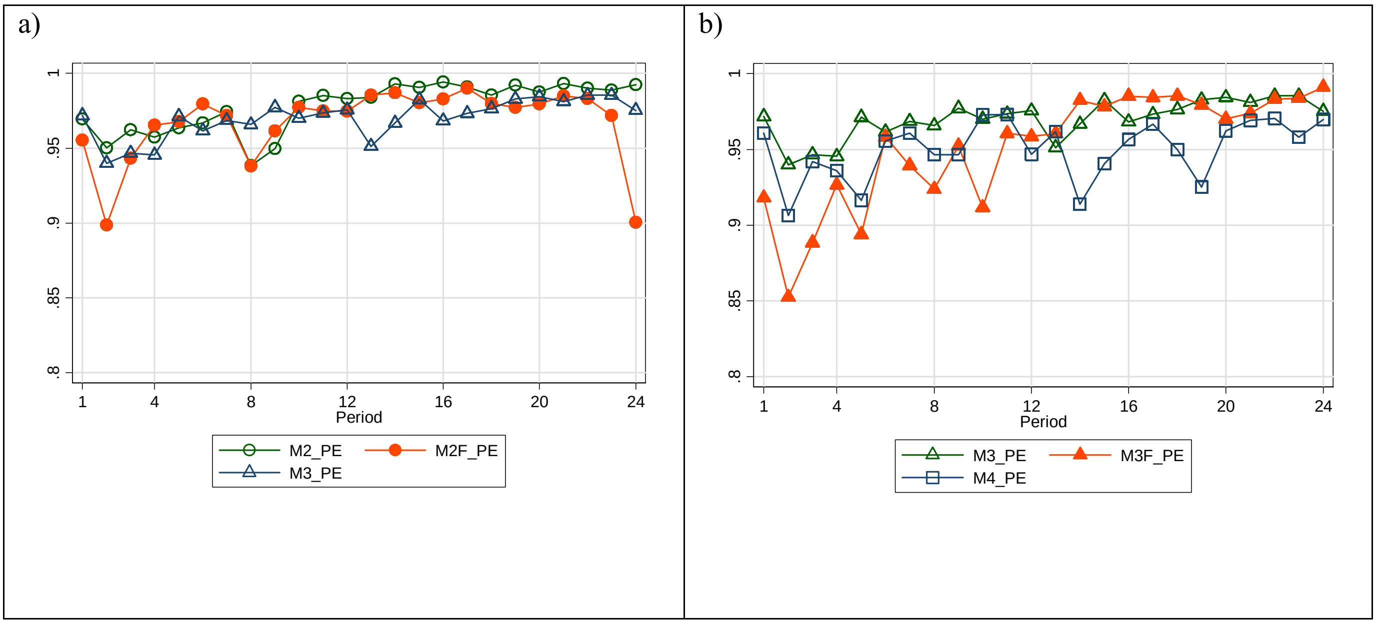

Table 9 shows the overall average of production efficiency in the last 12 rounds, with the standard error in parenthesis. The row below gives the size of the observed aggregated quantity relative to the

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

Nash-equilibrium prediction in percentages. Table 10 shows the test results of the hypotheses HΦ.1 and HΦ.2.[28]

Table 9: Production efficiency averages

	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: Test results for 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

Hypothesis Φ.1:

We find support for Hypothesis Φ.1:

- Φ(M4) ≥ Φ(M3) is REJECTED in favor of Φ(M4) < Φ(M3) , p-value=0.093.
- Φ(M3F) ≥ Φ(M3) is NOT rejected in favor of Φ(M3F) < Φ(M3) , p-value=0.666.

Adding one more competitor to M3 decreases the production efficiency with 2.4%, and this decrease is significant (Φ(M4) < Φ(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).

Hypothesis Φ.2: Φ(2F) < Φ(M2), and Φ(3F) < Φ(M3)
We find support for Hypothesis Φ.2:

- Φ(M3) ≥ Φ(M2) is REJECTED in favor of Φ(M3) < Φ(M2) , p-value=0.019.
- Φ(M2F) ≥ Φ(M2) is REJECTED in favor of Φ(M2F) < Φ(M2) , p-value=0.046.

Adding one more competitor to M2 decreases production efficiency with 1.4%.[29] Introducing a forward market to a market decreases production efficiency with 1.5%. Both decreases are significant.

3.4 Summary of results

Table 11 summarizes our theoretical and experimental results for the 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

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

[29] Running, in addition, a Jonkheere test rejects Φ(M4) ≤ Φ(M3) ≤ Φ(M2) in favor of Φ(M4) ≤ Φ(M3) ≤ Φ(M2)), with at least one of the inequalities being strict, p-value=0.0000.

aggregate production, while the effect of productive inefficiency is small and inconsequential (see section 3.3).

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	• **OMC**: 7.5% higher than FM (low Nash-equilibrium) • **FM**: 2.3% higher than OMC (high Nash-equilibrium)	-	**FM**: 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	**FM**: 2.3% higher than One more competitor	**OMC**: 9.2% higher than FM** (Brandts et al., 2008)	**FM**: 7.3% higher than OMC***

OMC: One More Competitor
FM: Forward Market
: 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 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 which contradicts the findings of Brandts et al. (2008) (the contradictory findings are indicated by the red background in Tabel 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.

4. Conclusion

We have tried to better understand the comparative advantages of structural measures and behavioral measures 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, teasing apart number and asset effect, and studying numbers of competitors that reflect better the market concentration in the old European states.

Our experimental results suggest not only that the behavioral measure of introducing a forward market in concentrated markets with two or three competitors is an effective measure for increasing the aggregate supply, but also that this effect is larger than that of the structural measure of adding one more competitor by divestment. This is a policy relevant discovery: competition authorities should, in line with the EU law rather focus on the behavioral measure of introducing a forward market than on the structural measure of lowering market concentration by divestiture.

At present, the EU has no single policy towards the design of forward markets for electricity.

Such a policy might improve on the effectiveness of forward markets in the EU, as design is an important factor for the thickness of forward markets in EU countries (European Commission, 2007a, p.127). In Spain, for example, forward trading is de facto forbidden by design (European Commission, 2007a, p.127). In Greece forward trading has been made virtually impossible by design, as it has made trading in the pool mandatory (European Commission, 2007b, p.50). In contrast, in France the PowerNext exchange market allows for the trading of forward and future contracts of months, quarters, and years ahead. Our study indicates that the design or evolution of such public forward exchanges as in France (and many other developed markets) should be encouraged, especially as the public observabillity of forward position is essential for the competition-increasing effect of Allaz and Villa (1993) to arise (Hughes and Jennifer, 1997).

Our results contradict the findings of Brandts et al. (2008). Brandts et al. (2008) found a stronger effect for the structural measure of adding one more competitor than for the behavioral measure 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. In our study we control for this asset effect by adding one more competitor by divestiture. As a result the effect of the structural measure of adding one more competitor has is weaker and is now dominated by the effect of the behavioral measure of introducing a forward market

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6. Appendix

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 result 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 result 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 result 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 have also a stronger effect on competition than adding one more competitor in markets with two competitors.

A2.2 Comparability data without costs

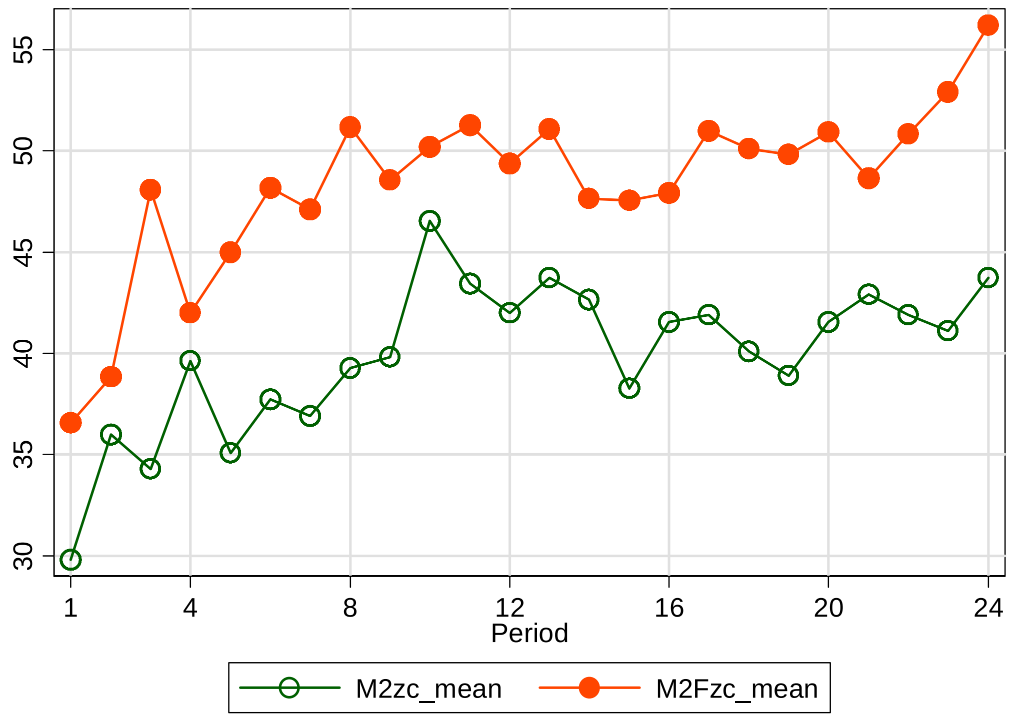
We ran treatments for markets with two producers without costs to allow comparisons with an earlier experiment on the effect of forward markets by LeCoq and Orzen (2006). Table 16 shows the theoretical predictions for these cases.

Table 16: Theoretical predictions no-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[30]
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 rounds, the treatments with forward markets by filled rounds. Like all other treatments, the aggregate productions starts out rather low,31 and then quickly jump up in the direction of the Nash-equilibrium. Between round 10 and 12 behavior stabilizes.

Figure 4: Average aggregate quantities sold per period



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

[31] 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 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)[32]	*91%*	*95%*

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 results of LeCoq and Orzen (2006). A robustness tests confirms this finding.

Table 18: Tests

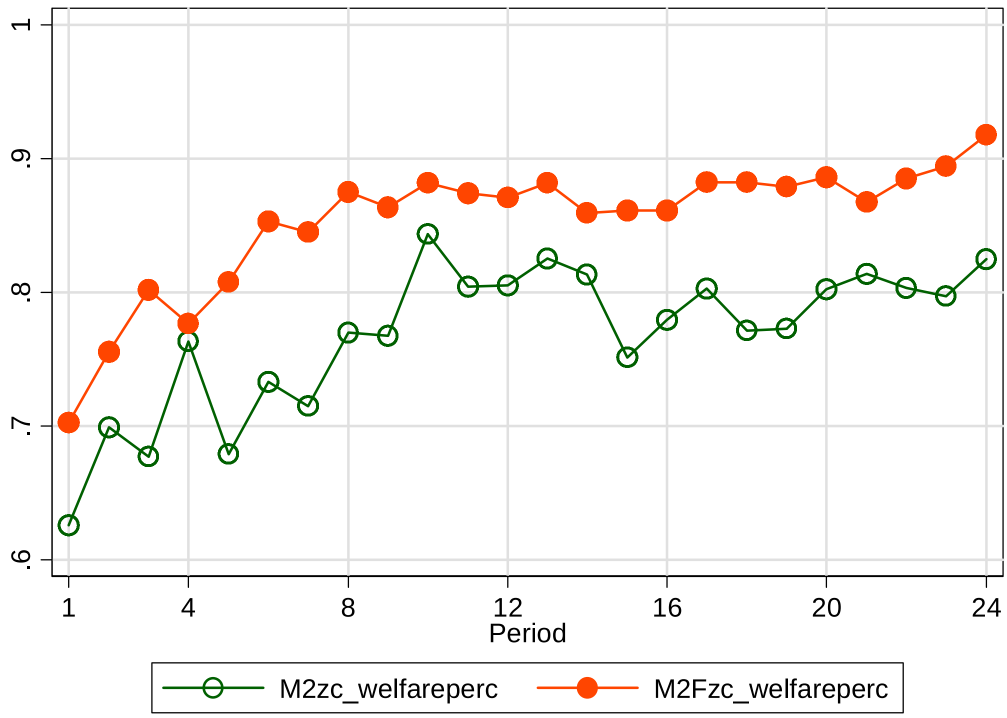
Main tests		
one-sided Wilcoxon rank-sum test		**M2Fzc> M2zc** (p=0.014)**
		N=11

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 rounds, the treatments with forward markets by filled rounds. 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 4 thus closely follows the aggregate average production (Figure 4).

[32] The averages by Huck et al. (2004) are based on a meta-analysis of 19 experiments with Cournot competition. A Wilcoxon signed-rank test indicates that our results are not significantly different from their results (all p-values > 0.327). The percentage of the Nash-equilibrium prediction we found in condition M3F is significantly higher than the percentage Brandts et al. (2008) found (p<0.0425).

Figure 5: Average efficiency per period



Efficiency is lower than the Nash-equilibrium prediction. A two-sided Wilcoxon one-sample signed-rank tests 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. 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
0	40.0	921
1	40.2	915
2	40.4	909
3	40.6	903
4	40.9	897
5	41.1	890
6	41.3	884
7	41.6	878
8	41.8	872
9	42.0	866
10	42.2	860
11	42.5	854
12	42.7	848
13	42.9	842
14	43.1	836
15	43.3	830
16	43.6	824
17	43.8	818
18	44.0	812
19	44.2	806
20	44.5	800
21	44.7	794
22	44.9	788
23	45.1	782
24	45.3	776
25	45.6	770
26	45.8	764
27	46.0	758
28	46.2	752
29	46.4	746
30	46.7	740
31	46.9	734
32	47.1	728

Total Production Stage A	Predicted (NE) Aggregate Production	Predicted (NE) price
33	47.3	723
34	47.5	717
35	47.7	711
36	48.0	705
37	48.2	699
38	48.4	693
39	48.6	688
40	48.8	682
41	49.0	676
42	49.3	670
43	49.5	664
44	49.7	659
45	49.9	653
46	50.1	647
47	50.3	641
48	50.5	636
49	50.7	630
50	51.0	624
51	51.2	619
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

M3F: 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	43.2	833	33	48.4	693	66	66.0	218
1	43.4	829	34	48.6	688	67	67.0	191
2	43.5	824	35	48.7	684	68	68.0	164
3	43.7	820	36	48.9	680	69	69.0	137
4	43.9	816	37	49.0	676	70	70.0	110
5	44.0	811	38	49.2	672	71	71.0	83
6	44.2	807	39	49.3	668	72	72.0	56
7	44.3	803	40	49.5	663	73	73.0	29
8	44.5	799	41	49.7	659	74	74.0	2
9	44.7	794	42	49.8	655	75	75.0	0
10	44.8	790	43	50.0	651	76	76.0	0
11	45.0	786	44	50.1	647	77	77.0	0
12	45.1	781	45	50.3	643	78	78.0	0
13	45.3	777	46	50.4	639	79	79.0	0
14	45.5	773	47	50.6	635	80	80.0	0
15	45.6	769	48	50.7	630	81	81.0	0
16	45.8	764	49	50.9	626	82	82.0	0
17	45.9	760	50	51.0	622	83	83.0	0
18	46.1	756	51	51.2	618	84	84.0	0
19	46.2	752	52	52.0	596	85	85.0	0
20	46.4	747	53	53.0	569	86	86.0	0
21	46.6	743	54	54.0	542	87	87.0	0
22	46.7	739	55	55.0	515	88	88.0	0
23	46.9	735	56	56.0	488	89	89.0	0
24	47.0	730	57	57.0	461	90	90.0	0
25	47.2	726	58	58.0	434	91	91.0	0
26	47.3	722	59	59.0	407	92	92.0	0
27	47.5	718	60	60.0	380	93	93.0	0
28	47.6	713	61	61.0	353	94	94.0	0
29	47.8	709	62	62.0	326	95	95.0	0
30	48.0	705	63	63.0	299	96	96.0	0
31	48.1	701	64	64.0	272			
32	48.3	697	65	65.0	245			

A4. 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
0	2000
1	1973
2	1946
3	1919
4	1892
5	1865
6	1838
7	1811
8	1784
9	1757
10	1730
11	1703
12	1676
13	1649
14	1622
15	1595
16	1568
17	1541
18	1514
19	1487
20	1460
21	1433
22	1406
23	1379
24	1352
25	1325
26	1298
27	1271
28	1244
29	1217
30	1190
31	1163
32	1136

Aggregate number of Units in Stage A+ B	Resulting Price in STAGE B
33	1109
34	1082
35	1055
36	1028
37	1001
38	974
39	947
40	920
41	893
42	866
43	839
44	812
45	785
46	758
47	731
48	704
49	677
50	650
51	623
52	596
53	569
54	542
55	515
56	488
57	461
58	434
59	407
60	380
61	353
62	326
63	299
64	272
65	245

Aggregate number of Units in SPOT Market	Resulting Price in STAGE B
66	218
67	191
68	164
69	137
70	110
71	83
72	56
73	29
74	2
75	0
76	0
77	0
78	0
79	0
80	0
81	0
82	0
83	0
84	0
85	0
86	0
87	0
88	0
89	0
90	0
91	0
92	0
93	0
94	0
95	0
96	0

(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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