**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 of the introduction of a forward market – considered a behavioral remedy by the European Commission -- on competition in electricity markets. 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 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 some evidence for the position that behavioral remedies may be more effective than structural remedies. Competition authorities thus seem well advised, in line with EU law (European Commission, 2006a, p.11), to focus on introducing, or at least facilitating the emergence of, forward markets rather than on lowering market concentration by divestiture.

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## 1. Introduction

Concentration in generator markets remains 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[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, 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.[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

[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 the 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 hand, 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.

plants, and thus adding to the capacity of competing new entrants. Of interest are 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, they show that a forward market lowers the amount of market power producers can exert. The contribution of Allaz and Villa (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 Villa (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 equal to zero gives $0 = \frac{d\pi_i}{dq_i} \Leftrightarrow -p'[Q](q_i - f_i) = p[Q] - c'[q_i]$. 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

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[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 to us that a forward market also constitutes a structural remedy. We are agnostic on that issue; after all it’s just a label. We note that we follow the definitions of 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

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

equation) decreases in $f_i$, the number of units sold in the forward market. The more 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 Villa (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, no firm selling in the forward market cannot be a Nash-equilibrium. 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 fare (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.

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 remedy: reducing market concentration by divestiture. We do so for competitor numbers 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 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. 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 the effects.

We model the competition of generators in the spot and forward markets using the standard Cournot approach (see for example Borenstein & Bushnell, 1999; LeCoq & 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 & Ortmann, 2007, for a recent review). Wolak & 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 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 1summarizes 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: 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[10] and three producers for markets in the old EU Member States[11] seems a good approximation.[12]

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 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

[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 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).
[11] The old EU Member States are the 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).
[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).

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 competition effect[13] and an 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 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). Moreover, the welfare effects Brandts et al. (2008) reports are not conclusive, as they do not incorporate the 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 effect of 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.

### 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 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)

[13] Brandts et al. (2008) call this “the number effect”. We use “competition effect” as we believe it is a more descriptive term.

[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).

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, 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$^{\text{th}}$ 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 $\frac{1}{4}^{\text{th}}$ 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: $\boldsymbol{c}_2[\boldsymbol{y}] = \frac{8\boldsymbol{y}^3}{27} + \frac{2\boldsymbol{y}^2}{3} + \frac{\boldsymbol{y}}{3}$, and $\boldsymbol{c}_4[\boldsymbol{y}] = \frac{32}{27}\boldsymbol{y}^3 + \frac{4}{3}\boldsymbol{y}^2 + \frac{\boldsymbol{y}}{3}$.[15]

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 highlights occurrences where the aggregate production in one market is equal to that in another market as bold and colored. For example,

[15] 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 $\boldsymbol{n} \in ¥^{+}$, 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).

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:[16] 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** | | | | | |
| 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** |

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

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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.[17]

## 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 $\boldsymbol{c}_2[\boldsymbol{y}] = \frac{8\boldsymbol{y}^3}{27} + \frac{2\boldsymbol{y}^2}{3} + \frac{\boldsymbol{y}}{3}$, $c_3(q) = \sum_{x=1}^{q} 2x^2 = \frac{2}{3}x^3 + x^2 + \frac{1}{3}x$, and

[17] Using the not rounded numbers gives virtually identical theoretical predictions.

$c_4[y]=\frac{32}{27}y^3+\frac{4}{3}y^2+\frac{y}{3}$. 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.[18]

Table 3 shows the theoretical predictions. The prefix NE stands for Nash-equilibrium, Walras for the efficient solution, and JPM for Joint Profit Maximization (the monopoly solution). [19]

**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[20] | 15 | 11 | 25/26[21] | 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 |

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

[19] 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) 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.

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

[21] 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[22], 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 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 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).

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) |

[22] 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).

| 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) | |

### 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).[23] 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 producers and sellers only. They were not shown the demand schedule but were given on screen, and as 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 sell in the forward market. Producers sell units to traders. The units that producers sell are promises to produce and 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 communicate to them the cost of their selling decision in the forward market and the resulting profit.

In the forward market two pre-programmed traders compete in prices for the total number of units that are offered. (We do not present the existence of traders to our subjects, who act as producers in the experiment. Because traders act rational, their actions define a demand schedule, and we present this

[23] 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. 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.

schedule to our subjects )[24]. 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 each producer offers an equal number of units (or as equal as possible) in the forward market. Using this assumption,[25] the traders predict, conditional on the total number of units offered in the forward market, $q^f$, the Nash-equilibrium total production in the spot market: $q^{NE}(q^f)$.[26] 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 determenid 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.

## 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

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

[25] Violation of this assumption affects the prediction only minimally.

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

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[27] but trade volume moves quickly into the direction of the Nash-equilibrium. Between rounds 8 and 12 behavior has stabilized.

[27] 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**

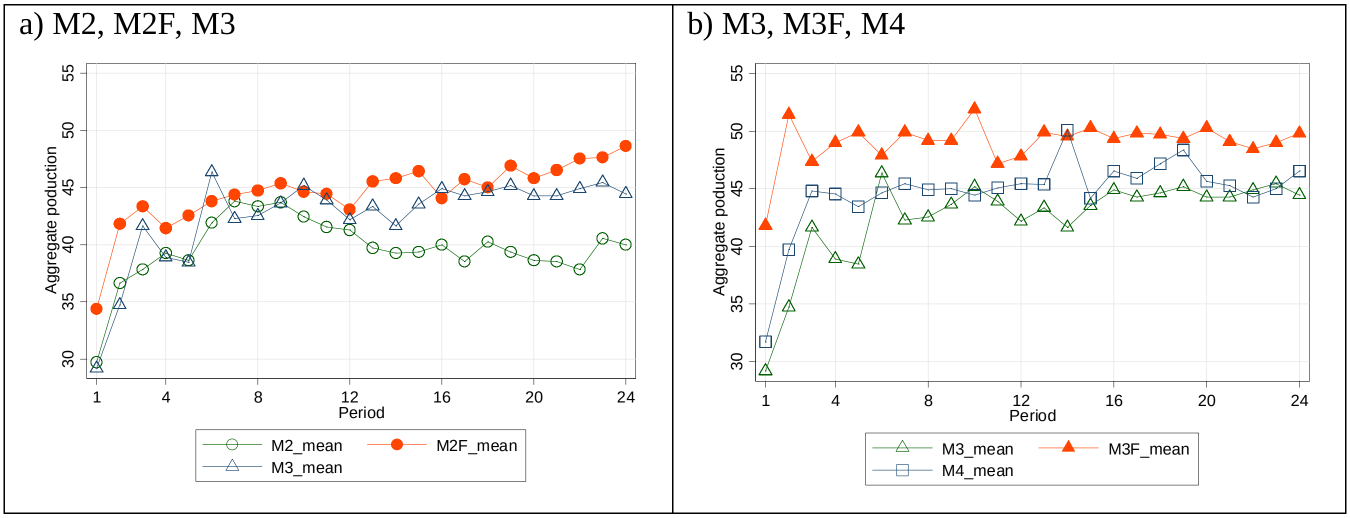


Table 5 shows the overall average aggregate production per treatment group, with the standard error in parenthesis.[28] The row below gives the size of the observed aggregated quantity relative to the Nash-equilibrium prediction in percentages.

**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%*[29] | *102.9%* | *110.1%* | *105.0%* |
| Number of observations | N=11 | N=11 | N=11 | N=11 | N=11 |
| *% of NE prediction - earlier studies*[30] | *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)* |

[28] The standard error is computed based on the values of the averages for each group over the last 12 rounds.
[29] 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.
[30] 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). The results of these tests may be found in Appendix A2.

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-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 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.[31]

**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 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).

**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.

[31] 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.

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.

**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 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.[32]

### 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). For the markets with a forward market, these measures are based on the outcomes in the forward and spot market together. Figure 2 show 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.[33]

**Figure 2: Efficiency percentages**

[32] 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.

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

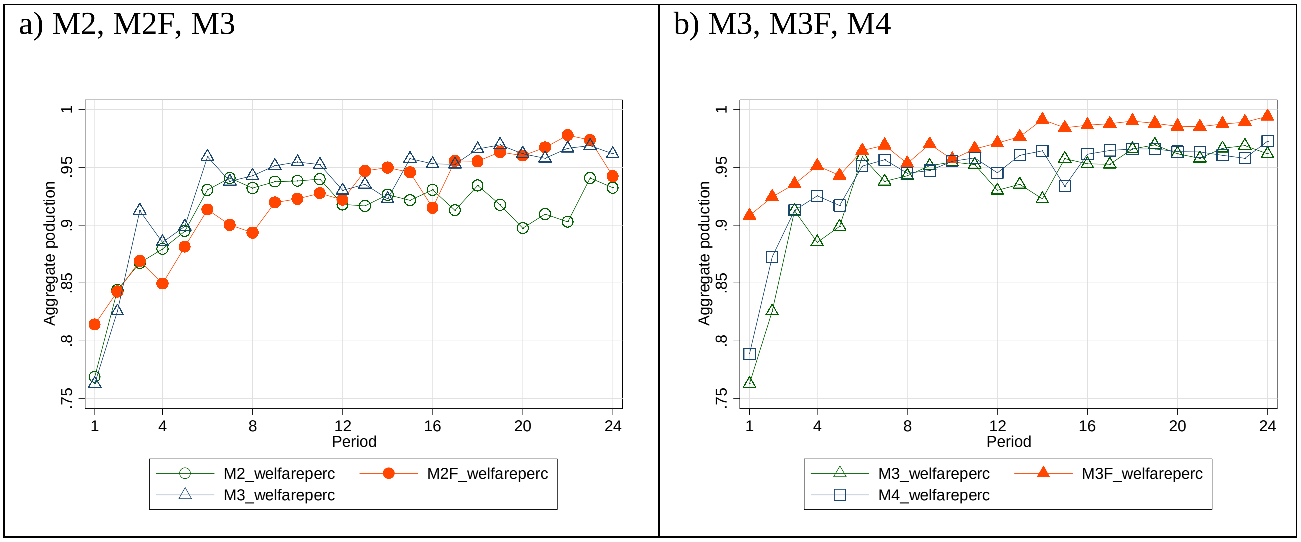


Table 7 shows the observed average efficiency level in the last 12 rounds, with the standard error in parenthesis. The row below gives the level of the observed average efficiency level relative to the Nash-equilibrium prediction in percentages. The efficiency levels are close to the Nash-equilibrium 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 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%[34] | 98.3% | 100.5% | 98.6% |
| | N=11 | N=11 | N=11 | N=11 | N=11 |
| % of NE prediction - earlier studies[35] | 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) |

**Error! Not a valid bookmark self-reference.** presents the results of the F-tests and Jonckheere test.[36] 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.

[34] 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.
[35] 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).
[36] The robustness tests, one-sided Wilcoxon rank-sum tests, confirmed our results at the same significance levels.

**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 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 |

**Results testing Hypothesis Ω.1: In markets with 3 competitors, introducing a forward market increases efficiency, and the effect is stronger than addion 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 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).

**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 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).

**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 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.[37] Figure 2 show 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

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

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**

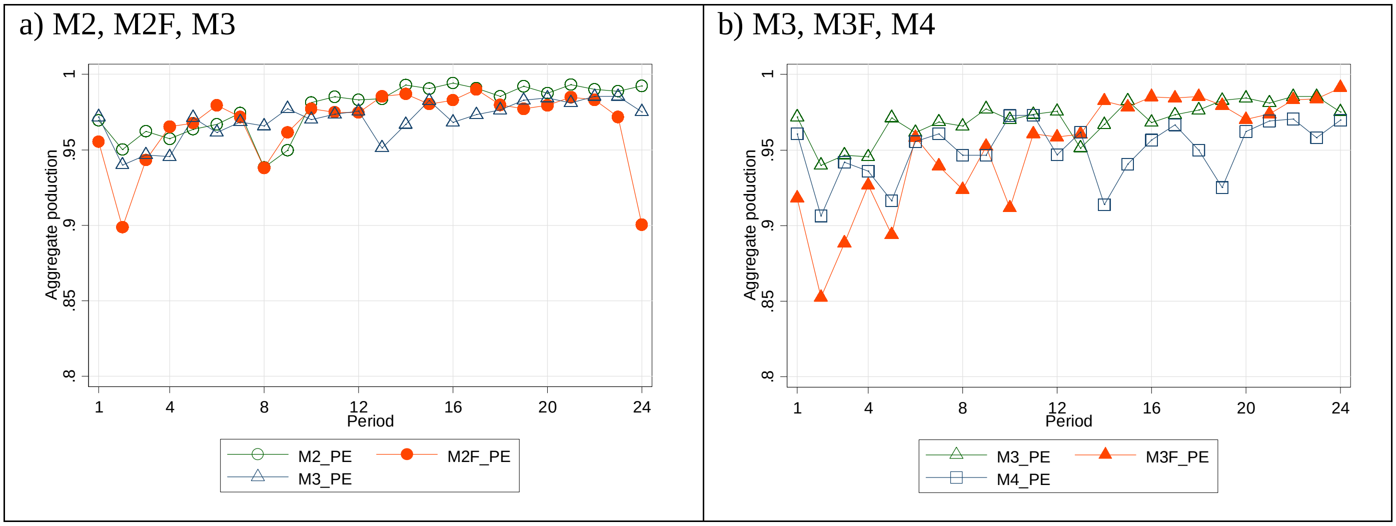


Table 9 shows the overall average of production efficiency in the last 12 rounds, with the standard error in parenthesis. The row below gives the size of the observed aggregated quantity relative to the Nash-equilibrium prediction in percentages.

**Table 9 Production efficiency averages in the last 12 rounds**

| | M2 | M2F | M3 | M3F | M4 |
|---|---|---|---|---|---|
| Average Production Efficiency | 99.0<br>(0.35) | 97.5<br>(0.81) | 97.6<br>(0.59) | 98.0<br>(0.69) | 95.4<br>(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)***<br>**(p=0.093)** | Φ(M3F) < Φ(M3)<br>(p= 0.666) |
| Number of observations | N= 1001 | N= 858 |

| | | |
|---|---|---|
| HΦ.2– Markets with 2 producers | **Φ(M3) < Φ(M2)****<br>**(p=0.019)** | **Φ(M2F) < Φ(M2)****<br>**(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. [38]

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

**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.
- 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).

**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:

- 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%.[39] Introducing a forward market to a market decreases production efficiency with 1.5%. Both decreases are significant.

### 3.4 Rationality in the forward market

Using the assumption of rational behavior, Allaz and Villa (1993) derived that the forward price will be equal to the spot price. 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: $P_{S-F} = \dfrac{P_S - P_F}{\frac{1}{2}(P_S + P_F)}$. 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 sell on the forward market thus accurately predicts the total number of units they sell on the spot market, which indicates rational behavior.

[39] 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.

### 3.5 Summary of results and comparison to earlier experiments

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 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)<br>• + 10% (high Nash-equilibrium) | + 20.9% ***<br>(LeCoq&Orzen, 2006) | + 17.8% *** |
| | **Largest increase by** | • **One more Competitor**: 7.5% higher than FM (low Nash-equilibrium)<br>• **Forward Market**: 2.3% higher than OMC (high Nash-equilibrium) | - | **Forward Market**: 4.7% higher than OMC<br>(not significant) |
| Market with 3 competitors | One more competitor | + 2.3% | + 19.6% ***<br>(Brandts et al., 2008 ) | + 4.4%<br>(not significant) |
| | FM | + 4.7% | + 9.5% **<br>(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**<br>(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 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 red 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.

## 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 the more realistic cost configurations of steeply increasing marginal costs, teasing apart competition and asset effect, and studying numbers of competitors that reflect better the market concentration in the European states.

Our experimental results suggest not only 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, but also that this effect is larger than that of the structural remedy 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 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 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), 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) reports 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 has is weaker and is now dominated by the effect of the behavioral remedy 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= | **Ω(M3F) > Ω(M4)*** (p< 0.001)** |

| | | | |
|---|---|---|---|
| | | 0.311<br>) | |
| 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.

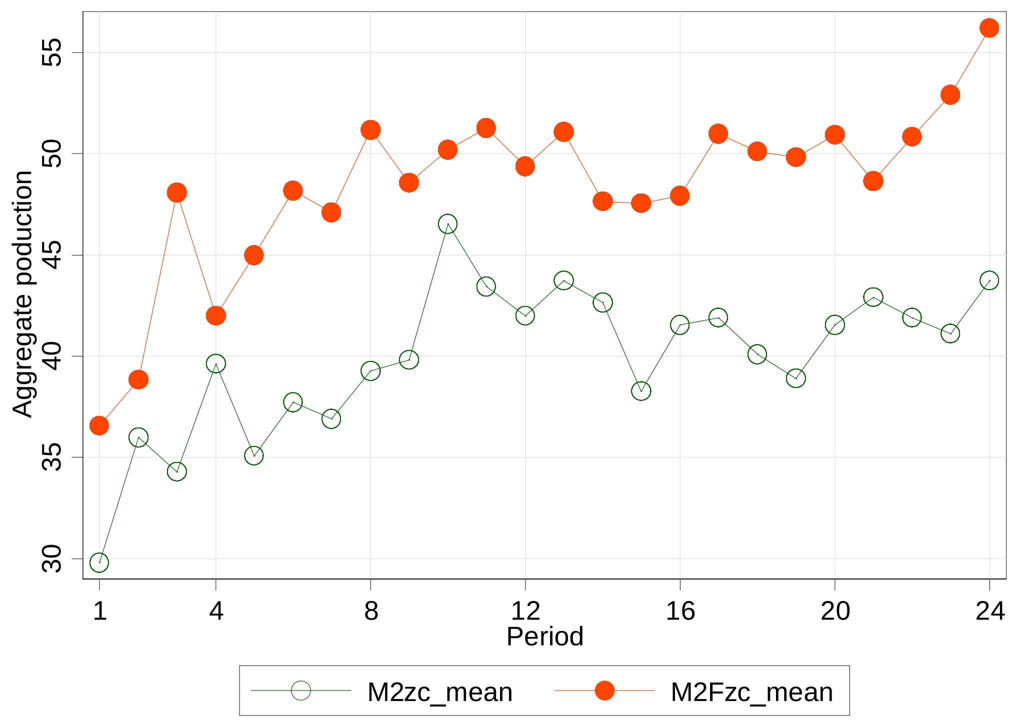
**Table 16 Theoretical predictions no-cost markets**

| | 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[40] |
| $q_t$ | 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,41 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**




[40] One generator produces 18 units, the other 19 units.
[41] 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<br>(1.91) | 50.3 9<br>(2.51) |
| % of NE prediction | 79.9% | 83.8% |
| Number of observations | N=11 | N=11 |
| *% of NE prediction LeCoq and Orzen (2006)*[42] | *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 18Tests**

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

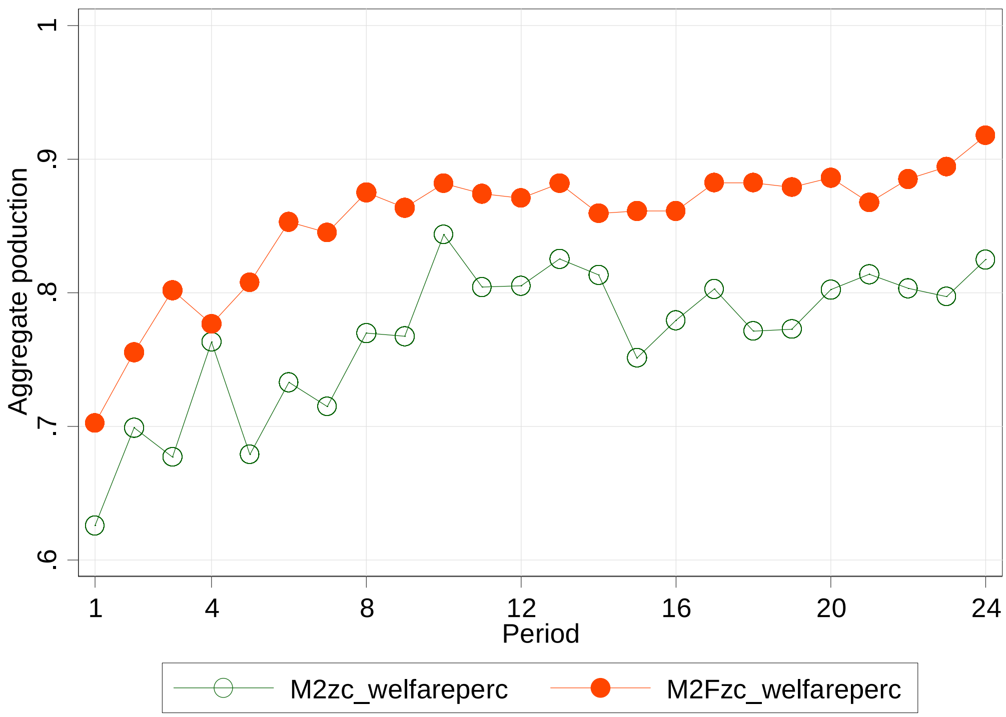
| Robustness tests | | |
|---|---|---|
| OLS regression with correction for clustering on group level, followed by one-sided F test on equality of the coefficients | | **M2Fzc> M2zc*** (p<0.010)** |
| | | N= 572 |

Figure 4 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

[42] 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).

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).

**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 | 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 | 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 | 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 |