Centre de Referència en Economia Analítica

Barcelona Economics Working Paper Series

Working Paper nº 141

Collusion and Fights in an Experiment with Price-Setting Firms and Production in Advance

Jordi Brandts and Pablo Guillén

July, 2004

Collusion and Fights in an Experiment with Price-Setting Firms and Production in Advance*

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Abstract

We present results from 50-round market experiments in which firms decide repeatedly both on price and quantity of a completely perishable good. Each firm has capacity to serve the whole market. The stage game does not have an equilibrium in pure strategies. We run experiments for markets with two and three identical firms. Firms tend to cooperate to avoid fights, but when they fight bankruptcies are rather frequent. On average, pricing behavior is closer to that for pure quantity than for pure price competition and price and efficiency levels are higher for two than for three firms. Consumer surplus increases with the number of firms, but unsold production leads to higher efficiency losses with more firms. Over time prices tend to the highest possible one for markets both with two and three firms.

JEL classification: D43, C91

Keywords: Experiments, Oligopoly, Collusion

*The authors thank Pedro Rey and Aurora García Gallego for helpful comments and the Spanish Ministry of Education and Science (SEC2002-01352) and the Barcelona Economics Program of CREA for financial support.

[†]Institut d'Anàlisi Econòmica (CSIC), Barcelona, jordi.brandts@uab.es

[‡]Harvard University

1 Introduction

In the most prominent theoretical models of oligopolistic competition, going back to Cournot (1838), Bertrand (1883) and Edgeworth (1925), firms only make decisions on one variable: price or quantity. These models have proven to be extremely useful for the study of a large variety of issues. However, for a more complete view of imperfect competition one needs to go beyond this, since firms' actual decision environments surely involve quite a number of dimensions. A natural step forward is to study situations in which firms decide on both price and quantity.

Competition in prices and quantities can be modeled in different ways. One of these ways is the "supply function" approach proposed by Grossman (1981) and Hart (1982). Here firms' strategies consist in complete functions of price-quantity pairs. The outcomes of market competition are the equilibria in supply functions; production is to order so that there is neither over nor underproduction.

Kreps & Scheinkman (1983) approached price-quantity competition using a two stage model in which firms decide on capacities first and then compete in prices. They solved the problem of inexistence of equilibrium in the so called Bertrand-Edgeworth model in which due to capacity restrictions there is no equilibrium in pure strategies. In their game firms actually first decide on capacities and then on prices. This two stage structure plus a surplus-maximizing rationing rule yields Cournot outcomes.

A simpler more direct way of representing price-quantity competition is to let firms decide on price and quantity combinations where the quantities have to be produced in advance and the demand buys from the cheapest producer(s). This is characteristic of many retail markets. The fact that total production can now be larger than total sales raises the question of what happens with the overproduced quantity. Underproduction also needs to be taken into consideration. The produced good may be completely perishable or not. If the good is of some durability, then unsold production may be carried over from one production period to another one, implying a dynamic situation. Theoretically, the first case has been studied by Maskin (1986) and Friedman (1988) and the second by Judd (1990).

Experimentally, price-quantity competition with advance production of a perishable good has been studied by Mestelman and Welland (1988). They investigate the effects of advance production in posted price and double auction markets with the kind of demand and supply functions with multiple steps that are standard in experimental economics. They compare the performance of the posted price institution with and without advance production and find that for the first case price and efficiency levels are both somewhat lower than in the second case. However, even with advance production, after 15 trading rounds both prices and the distribution of the surplus are very close to the ones corresponding to the Walrasian outcome. Mestelman and Welland (1991) study the case with advance production and inventory carryover and find similar results as for a perishable good.

In this paper we study the performance of experimental markets with posted prices and advance production of a perishable good with simple demand and cost schedules. The simulated demand has a "box-shape", i.e. it is willing to buy a constant maximum quantity for any price up to a maximum. Firms have identical constant marginal costs and a capacity limit. As shown below, this simplified structure facilitates the theoretical analysis and the comparison to previous results with other market rules.

We have several aims. First, we want to find out whether price-quantity competition behaves more like pure quantity or more like pure price competition. In our set-up these two types of interaction lead to very different predictions and existing experimental results also exhibit very different behavioral patterns. Bertrand and Cournot are often used as benchmarks in the context of the analysis of oligopoly. Our results provide an experimental benchmark for price-quantity competition.

Second, we want to study the impact of the number of firms on market outcomes, specifically on price and efficiency levels and on the distribution of the surplus between consumers and producers. For that purpose we compare experimental markets with two and three firms.

Third, we also study the evolution of behavior over time to shed light on how outcomes emerge as the result of the interaction process. In our experiments subjects interact in+ the same market throughout 50 rounds. This reflects the repeated interaction that takes place in actual oligopoly markets. It is also the way in which most, although not all, market experiments are conducted. We study how players adjust to others' behavior over time and bring about the observed data patterns.

Our experiment is meant to be a contribution to a more general view of how imperfect competition over time relates to the equilibria of certain static games. Theoretical studies of dynamic oligopoly like those of Maskin and Tirole (1987, 1988) and Jun and Vives (1999) typically characterize equilibrium behavior in relation to the static Cournot and Bertrand equilibria. Our results will shed - from a different perspective - some additional light on the comparison between dynamic behavior and static predictions.

With our work we also wish to contribute to a more complete view of the impact of the number of firms on market performance in experimental imperfect competition environments. This issue is one of the central themes of the economic analysis of oligopoly and can be seen as transversal with respect to different specific oligopoly models. It has recently been analyzed in a number of experimental studies with different types of imperfect competition. Dufwenberg and Gneezy (2000) address this question for the case of Bertrand price competition among identical firms with constant marginal costs and inelastic demand. Their results are that prices are above marginal cost for the case of two firms but equal to that cost for three and four firms.

Abbink and Brandts (2002a) examine the effects of the number of firms in a price competition environment in which firms operate under decreasing returns to scale and have to serve the whole market; there are multiple equilibria with positive price-cost margins. The most frequently observed market price is invariant to the number of firms. However, average prices do decrease with the number of firms, partially due to the declining prevalence of collusion. Abbink and Brandts (2002b) study price competition under constant but uncertain marginal costs. In accordance with the theoretical prediction for this case, market prices decrease significantly with the number of firms but stay above marginal costs.

Several studies report experimental results on related issues from quantity competition environments. Huck, Normann and Oechssler (1999, 2001) provide results and a recent survey of work on the effects of market concentration under repeated quantity competition. Their conclusion is that duopolists sometimes manage to collude, but that in markets with more than three firms collusion is difficult. In many instances, total average output exceeds the Nash prediction and furthermore, these deviations are increasing in the number of firms. The study by Brandts, Pezanis-Christou and Schram (2003) includes evidence that shows how repeated quantity competition with three and four firms with convex marginal costs is consistent with the one-shot prediction.[1] In a broad sense one can say that the price-cost margins found in experimental repeated quantity competition are qualitatively consistent with the Cournot prediction for the static game.[2]

Recall that our third aim was to study the evolution of behavior over time. The study of how adjustment over time takes place under imperfect competition is important, because it may give - as shown for instance in Selten, Mitzkewitz and Uhlich (1997) - insights into the rationale behind subjects' behavior. Our data exhibit a considerable adjustment

[1] They also find that under supply function competition, an increase in the number of firms also leads to lower prices.

[2] Offerman, Potters and Sonnemans (2002) also study experimental quantity competition, but focus on the effects of different information environments and not on the impact of changing the number of firms.

stage of about fifteen rounds, during which price and efficiency levels increase. During this stage we also observe fights for the market, some of them leading to bankruptcies. With enough experience we observe considerable tacit collusion at the demand's reservation price, somewhat more so for the case of two than for three firms. In this sense, behavior tends more to what one should expect under quantity competition than to what price competition would yield. Behavior settles down at a price-quantity configuration which is not an equilibrium.

All this is somewhat reminiscent of the view proposed by Chamberlin (1962) for the case of markets in which firms face each other repeatedly. He thought that for the case of few sellers behavior follows from the very structure of the industry. In Chamberlin (1962), p. 48, he states: "If each one [seller] seeks its maximum profit rationally and intelligently, he will realize that when there are two or a few sellers his own move has a considerable effect upon his competitors, and that this makes it idle to suppose that they will accept without retaliation the losses he forces upon them. Since the results of a cut by any one is inevitably to decrease its own profits, no one will cut, and, although the sellers are entirely independent, the equilibrium result is the same as though there were a monopolistic agreement between them".Indeed, in the process of fighting that we observe in our data, firms appear to realize how disadvantageous this behavior is and learn to avoid it.

In Section 2 we discuss our basic set-up choices and present some theoretical considerations for the game we study. In Section 3 we present design details and explain the experimental procedures. Section 4 presents our results. There are three appendixes. Appendix A contains the instructions, Appendix B includes Overall Tables and Appendix C contains graphs for all experimental markets in both treatments.

2 Basic Set-up and Theoretical Considerations

In our game, the demand is willing to buy any amount of the good up to a quantity of $q_{\max}$ at a constant maximum price of 100. This kind of 'box' demand schedule has previously been used for the study of double auctions by Holt, Langan and Villamil (1986) and more recently by Dufwenberg and Gneezy (2000) for the study of Bertrand competition. The buyer auction studied in Roth et al. (1991) has very similar features. This simple set-up has several advantages which will become clear below. We conducted experimental sessions with two and three firms, with $q_{\max}$ being 100 in the first case and, to allow for divisibility, 102 in the second case.[3]

Each of the n firms has the capacity of producing integer quantities up to $q_{\max}$ units at a constant marginal cost of 50 with no fixed costs. Each firm can serve the whole demand at marginal cost, just as typically assumed for standard price or quantity competition.

Firms simultaneously and independently decide on production quantities and on prices between 0 and $q_{\max}$. Once the production decisions are made, the quantities are produced instantaneously and the corresponding costs are incurred. Each firm offers all its produced units at the same price. It is as if they attached a label with the price on each unit of output. One can think of this situation as one in which two factories produce a perishable good like, say yogurt, and send it to the supermarket at a previously decided price.

Given the shape of the demand, if total production is less or equal than $q_{\max}$ all units are sold regardless of prices. If total production is higher than $q_{\max}$, then sales will depend on the prices set by the different producers. Taking the case of three firms, then if all three prices are different from each other the demand simply goes from lower to higher prices and keeps purchasing until it reaches 102; due to the type of demand schedule no rationing rule is needed. Some of the units of the highest price firm will remain unsold and are lost, since the good is completely perishable. There are several other possibilities

[3]Because 102 divided by 3 equals 34, an integer.

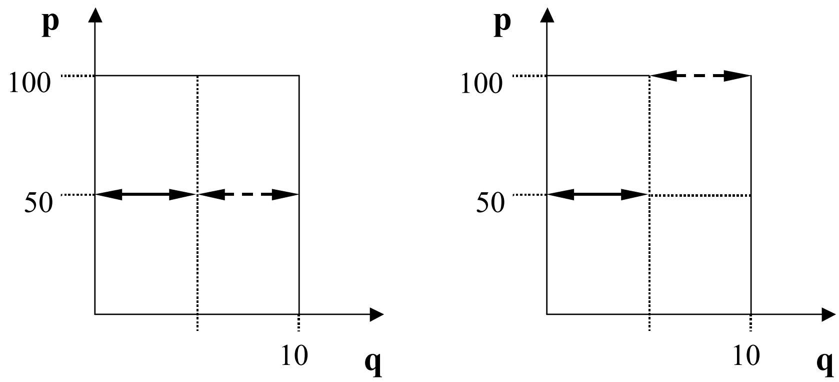
in which two of the firms set the same price, which is different from the one set by the third firm. If two firms set the same price which is lower than the one of the third firm and the sum of the produced quantities of the two firms is smaller than 102, then we are, in essence, in the same situation as when all three prices are different from each other. The two firms with the lowest price both sell their whole production and some of the units of the high price firm will not be sold.

If all three prices are the same, then consumers will buy from the different firms in proportion to the produced quantities: If the three firms have produced quantities q_1, q_2 and q_3 then firm i will have sales of $s_i = \frac{q_i}{q_1+q_2+q_3} * 102$ and the rest of the units of firm i's produced units will remain unsold, $i = 1, 2, 3$.More production leads to more presence in the market and, hence, to more sales.

If two firms set the same price which is lower than the third one and the joint production of the first two firms is higher than 102, then a proportionality rule applies, which is analogous to the one for the case where all three firms set the same price: If the quantities of the two low-price firms are q_1 and q_2, then the sales of firm i will be $s_i = \frac{q_i}{q_1+q_2} * 102$, $i = 1, 2$; the high-price firm sells nothing. If two firms set the same price which is higher than the one of the remaining firm, then the same proportionality rule applies as in the previous case to the quantity that still can be sold after the low-price firms has sold all its production, i.e. if q_1 and q_2 are now the quantities of the two high-price firms and q_3 corresponds to the one low-price firm, then the sales of the two first firms will be $\frac{q_i}{q_1+q_2}(102 - q_3), i = 1, 2$.

Note that in the box design price-quantity game pure price competition would be predicted to yield prices equal to marginal cost. The experimental study by Dufwenberg and Gneezy (2000) referred to above deals precisely with the case of a box-demand and presents evidence consistent with this prediction. In contrast pure quantity competition would lead, in the Cournot equilibrium, to the monopoly price equal to the demand's reservation value. We are not aware of any quantity competition experimental study with this kind of demand. However, it is reasonable to expect that in experimental studies of this type the stage-game Nash equilibrium will be a good predictor of behavior.

In contrast, for the price-quantity competition we consider there exists no equilibrium in pure strategies. We present the reasoning for two firms; it can be easily generalized for any number of firms greater than two.



FIGURES 1 AND 2. JUMPING-UP

Let $[(\bar{p}_1, \bar{q}_1), (\bar{p}_2, \bar{q}_2)]$ be a strategy profile and focus first on the quantity choices. Note first that if $\bar{q}_1 + \bar{q}_2 < q_{\max}$ then the strategy of any of the players is (weakly) dominated by a strategy in which the produced amount equals $q_{\max}$, i.e. at any price between 50 and 100 both firms would benefit from expanding their production until joint production reaches $q_{\max}$. If $\bar{q}_1 + \bar{q}_2 > q_{\max}$ then each of the players has an incentive to reduce production. This is so, because of the unit cost being 50, which is equal to the highest possible profit per unit. Due to the proportionality rules a reduction of production by one unit leads to a reduction in sales of less than one unit; foregone unit profits are hence less than 50 while saved costs are 50. If unit costs were zero firms would have an incentive to always throw their total capacity on the market. Our parameter choices can, hence, be expected to lead to the simple situation in which production ends up being equal to sales.

Now to prices. Observe first that if a firm's price is below 100 and is producing a positive amount then a unilateral increase in price will always be profitable. This 'jumping-up' is illustrated by the contrast between Figures 1 and 2, where in Figure 1 we have chosen to represent both firms producing the same quantity at marginal cost. A unilateral increase of firms 2's price leads to the positive profit represented by the shaded area. At $p_1 = p_2 = 100$ there is no possibility of unilateral price increases, but in this case unilateral under-cutting and expansion production to $q_{\max}$ will always be profitable for at least one of the firms, since the demand will only buy from the firm with the lower price. For instance, if $s_1 = 49$ and $s_2 = 51$, then the undercutting to a price of 99 with a simultaneous production expansion to 100 will be profitable for either firm. (This 'under-cutting' is illustrated in Figures 3 and 4).

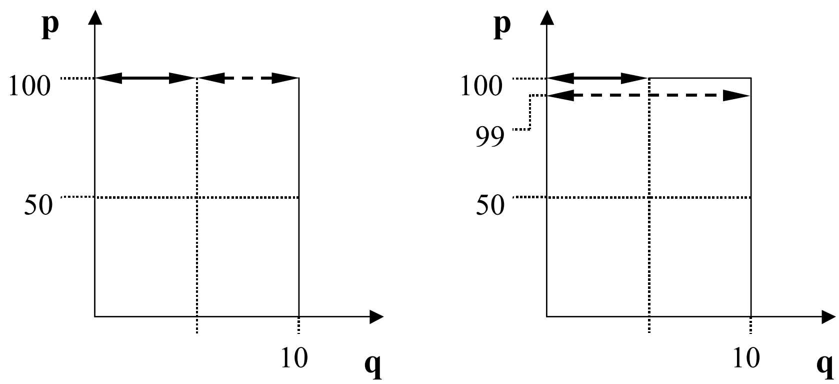
This only stops being true for firms with very high sales, the threshold being at 98 units. If a firm sells 99 or 100 units then undercutting will not be profitable, since in that case the firm is already a virtual monopolist. But, of course, in this case it is the other firm that will have a strong incentive to undercut. Hence, there is no equilibrium in pure actions.[4]

Since the game actually played in the experiments is finite, we know that there does exist an equilibrium in mixed strategies. The mixing will be over two variables and involve a payoff matrix of $(101 \times 101)^n$ cells. We will not consider the mixed strategy equilibrium. Indeed, as with applications to many other real contexts, taking it in account would not be very natural in our environment. In addition, even a large experiment may not generate enough data to reliably check the use of such a strategy. In the results section we will see that observed behavior does not suggest at all the use of any kind of mixed strategy.

Up to this point we have analyzed the one shot game. In our experiments we run 50 periods, our game is finitely repeated. Applying backwards induction we have the same

[4] If the market is shared 50-50 at a price of 51, there are no incentives to undercut, and at a price of 52 firms are indifferent between undercutting and expanding production or staying put.

lack of equilibrium in pure strategies. However some experimental results (see Selten, Mitzkewitz and Uhlich (1997)), claim that people actually behave like in an infinitely repeated game when the number of periods is large enough and the end of the game is far away.[5] If we think of our game as an infinitely repeated one, any result can be maintained in time if the discount factor, is high enough. In particular cooperation, to share the market at the monopolistic price could be maintained until a few periods before the last one. In the theoretical approach the threat that maintains collusion is typically considered to be Nash reversion, but in looser, broader terms one may think of the threat being any kind of fight for the market. We will get back to this issue when we discuss the results.



FIGURES 3 AND 4. UNDER-CUTTING

[5] Vives (1999) discusses the possible rationalizations of cooperation in finitely repeated games.

3 Experimental design

We obtained data from two experimental treatments. One with two firms (hereafter, 2F) and another one with three firms (hereafter, 3F).[6] In treatment 2F each firm chooses a quantity between 0 and 100 and one price (expressed in ECUs, Experimental Currency Units) also between 0 and 100. There is a constant cost of 50 ECUs per unit produced. Treatment 3F only differs in the number of firms and in that they can choose production levels from 0 to 102.

To accommodate losses we granted subjects an initial capital balance of 20,000 ECUs. If a firm lost more than this starting money it was considered bankrupt and forced to abandon the market. However, to preserve anonymity subjects that went bankrupt were asked to remain in their place until the end of the experimental session. Bankruptcies did actually occur in both our treatments so that monopolies appeared in 2F and doupolies and monopolies appeared in 3F. We will elaborate on this in the experimental results section.

As mentioned above fixed groups of subjects interacted in the same market during 50 rounds to represent the repeated nature of oligopolistic interaction. We conducted 14 markets of the 2F treatment and 9 markets of the 3F treatment. Below we consider each separate market to be one independent observation.

We ran all the experiments in the "LeeX" (Laboratori d'Economia Experimental) at Universitat Pompeu Fabra in Barcelona during the second half of the year 2002. The experiments were programmed using Urs Fischbacher's zTree toolbox. The total earnings of a subject from participating in this experiment were equal to his capital balance plus the sum of all the profits he made during the experiment minus the sum of his losses. We paid to each subject 2 EUR as a show-up fee and their profits at the rate of 2 cents of Euro per 100 ECU earned. Experiments lasted approximately one hour and a half.

[6] Appendix A contains instructions for the case of three firms.

Average earnings in the experiment were 16.5 EUR.

4 Experimental results

Figure 5 shows for both treatments the evolution of average weighted market prices, defined as the average of prices at which units were sold weighted by their respective market shares[7]. These averages include prices from all markets, among them those in which firms went bankrupt.[8] Below we will distinguish between behavior in markets with and without bankruptcies. Observe first that for both the cases of two and of three firms average weighted prices are evidently much closer to the quantity competition Cournot equilibrium than to the price competition Bertrand equilibrium. Prices actually appear to tend to the highest possible one. Stage-game equilibrium analysis does not suggest this, but - after the fact - it seems quite plausible that a reduced number of firms is able to establish high prices in a situation of (albeit, finitely) repeated interaction. Below we elaborate on how these prices come about.

Note first that the prices shown in Figure 5 exhibit upward trends; for n=2 prices stabilize after fifteen periods whereas for n=3 the trend appears to continue for a longer interval. Prices are about 50% higher in final rounds than in early ones. One can see that experiments with fewer rounds would have given an inappropriate impression of behavior for this kind of interaction.

[7] For technical reasons, we had to end one of the sessions of the 2F treatment in round 47. For this reason we only show the average weighted price up to that round.

[8] Appendix B presents price and quantity data disaggregated by rounds and markets.

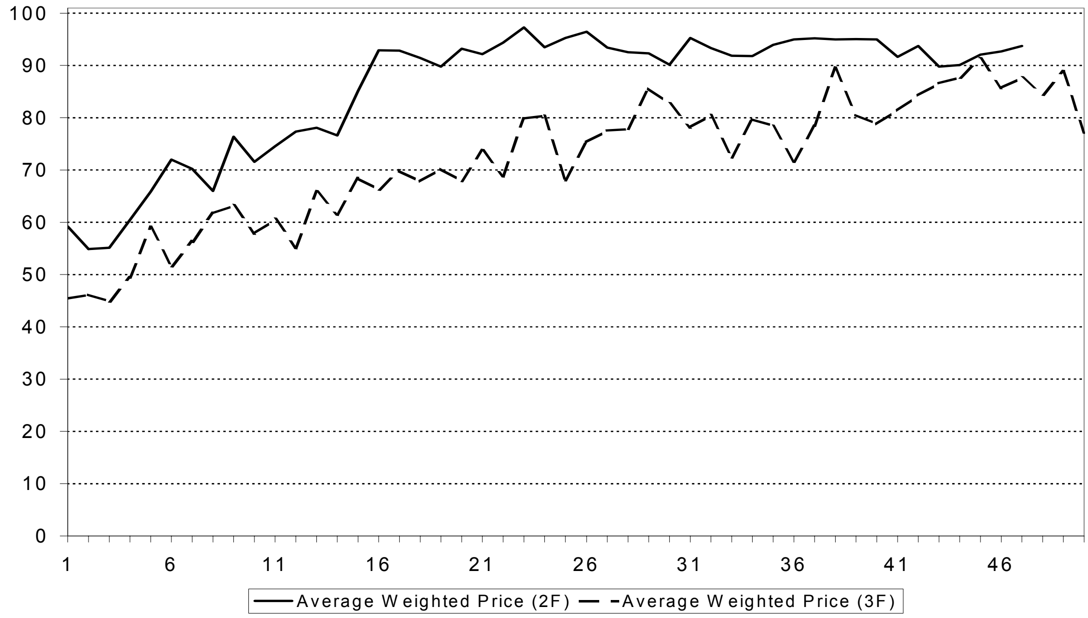


Figure 5. Average Weighted Price series, 2F and 3F

We now move to the comparison of behavior in 2F and 3F. We first describe the data at a descriptive level and then move to the presentation of statistical test results. Observe that prices for n=2 are always above those for n=3; for this last case we observe that prices go down a little in the last 3-4 rounds. This is the so-called end effect that has been observed before (see, for example, Selten and Stoecker (1986)) and is here intuitively plausible: Firms behave less cooperatively when the end of the experiment comes near.

Figure 6 shows the evolution of average total quantities over time for both treatments. Recall that any quantity beyond 100 in 2F and 102 in 3F can not be sold and is a pure loss. The Figure exhibits somewhat higher quantity levels for about 15 rounds; from then on total quantity fluctuates somewhat above 100 (102).[9] In this case visual inspection does not directly suggest a treatment difference.

[9] See the previous footnote for why the data for the 2F treatment extend only to round 47.

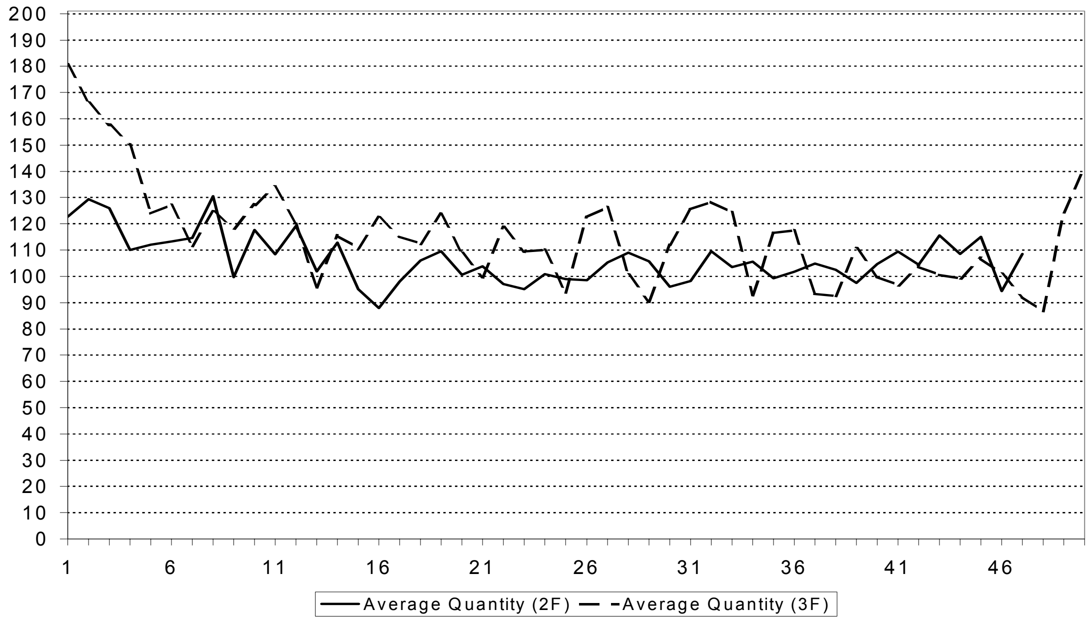


Figure 6. Average Quantity series, 2F and 3F

Figure 7 shows the evolution of average efficiency levels over time. The highest possible surplus is 5000 ECU's, which corresponds to the case where total production is equal to 100%. Efficiency is defined as the sum, in ECU's, of consumer and producer surplus as a fraction of 5000.[10] In our context inefficiency can only be the outcome of too little or too much production, with standard production inefficiency, i.e. less productive firms producing instead of more productive ones, not being possible. The data in Figure 7 suggest that efficiency for n=2 tends to be above that for n=3.

[10] Note that in the case of three firms efficiency can be negative, since high overproduction may make total costs larger than consumer surplus.

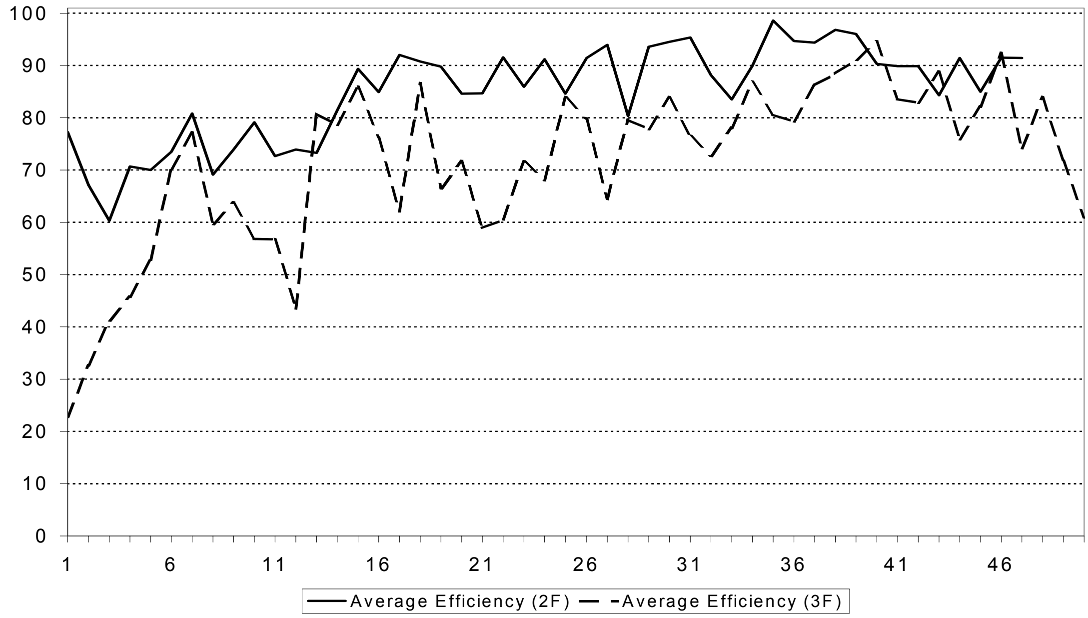


FIGURE 7. AVERAGE EFFICIENCY SERIES, 2F AND 3F

In Tables 1 and 2 we show average weighted price (AWP), average quantities and average efficiencies for each market in the two treatments taking in account rounds from 21 to 45. We compute the average using these 25 rounds in order to get rid of ending and starting effects.

We ran three separate permutation tests using the data in Tables 1 and 2 comparing the averages of the variables AWP, Quantity and Efficiency. Average weighted prices and efficiency levels do vary across the two treatments significantly (p=.02 and p=.06) For Quantity we do not find any significant treatment difference.

As mentioned above, some firms did go bankrupt in our experiments. We now look at market behavior distinguishing between markets in which bankruptcies did and did not occur. In Figure 8 we now show three series of average weighted prices for the 2F treatment; we show again the overall prices series, but now also the series for those markets that turned into duopolies and those that turned into monopolies. The Figure illustrates that the Average Weighted Duopoly Price follows the Average Weighted price rather closely. Figure 9 shows the analogous comparison for quantities in the 2F treatment.

Figures 10 and 11 show the price and quantity series pertaining to the 3F treatment. In this case we observe more differences between the different data series.

Market	AWP	Quantity	Efficiency
1	100	100	100
2	87.70	126	74
3	86.72	120.04	79.96
4	100	100	100
5	100	100	100
6	100	100	100
7	100	100	100
8	100	100	100
9	100	100	100
10	74.87	85.16	63.96
11	100	100.80	99.2
12	63.04	123.04	53.36
13	99.29	95.80	95.8
14	100	100	100

Table 1. 2F Data

At this point we know that price-quantity competition leads to high prices. However, it remains to be seen more in detail how these prices emerge. To understand the process behind the regularities we have reported one needs to look at the data from the individual markets. Appendix C presents two graphs for each market In the upper graph we see the evolution of prices for firms involved in the market along time. In the lower graph we see the evolution of quantities. The different kinds of lines correspond to different firms.

At first sight one can see that, for both treatments, there is considerable variation across markets. Recall that there are 14 markets in the 2F treatment. Four of these markets resulted in monopolies, and in all these the establishment of the monopoly is preceded by a phase of heavy fighting for the market and subsequent bankruptcy by one of the firms. In 2F markets 7, 8 and 9 the monopoly emerges relatively early on, but in market 12 the fighting continues until almost the end of the session.

In 8 of the 10 markets in which the duopolists persisted until the end, collusion near the monopoly/Cournot equilibrium price was established at some point. The Figures corresponding to 2F markets 1, 4, 5, 6, 9 ,13 and 14 reveal that in 7 of these 8 markets collusion was established rather quickly. Market 2 is, in a sense, an intermediate case. In markets 3 and 10 collusion was never established. In summary, in 2F markets we observe two remarkable patterns, which both lead to high prices. One is collusion after some adaptation or fighting time (markets 1,2,4,5,6,11,13 and 14). The other is the beginning of a monopoly after one firm goes bankrupt as the result of a fight (markets 7,8,9 and 12). With respect to the markets where fighting never stopped, it seems reasonable to speculate that, with more experience, firms would end up behaving according to one of the two patterns identified above.

In nine 3F markets price patterns emerge in a similar way. In some markets some firms leave the market after fighting has led to bankruptcies. Fights lead to duopolies (markets 1, 3 and 6) and then sometimes to monopolies (markets 2 and 4). In some markets firms manage to collude after some time (markets 7,8 and 9). Since there are three firms the time required to stabilize the market is longer and therefore we find more fights until the end of the experiment (markets 1, 5 and 6). That is, the number of rounds required to arrive to the monopoly price appears to be longer in the case of three firms. This could explain the result of lower price and efficiency and higher quantity.

Market	AWP	Quantity	Efficiency
1	69.57	116.32	70.35
2	86.70	109.08	83.80
3	77.24	91.72	63.18
4	65.58	108.92	69.45
5	68.89	95.20	76.31
6	49.70	139.72	49.69
7	98.67	102	100
8	100	103.28	98.75
9	100	102	100

Table 2. 3F Data

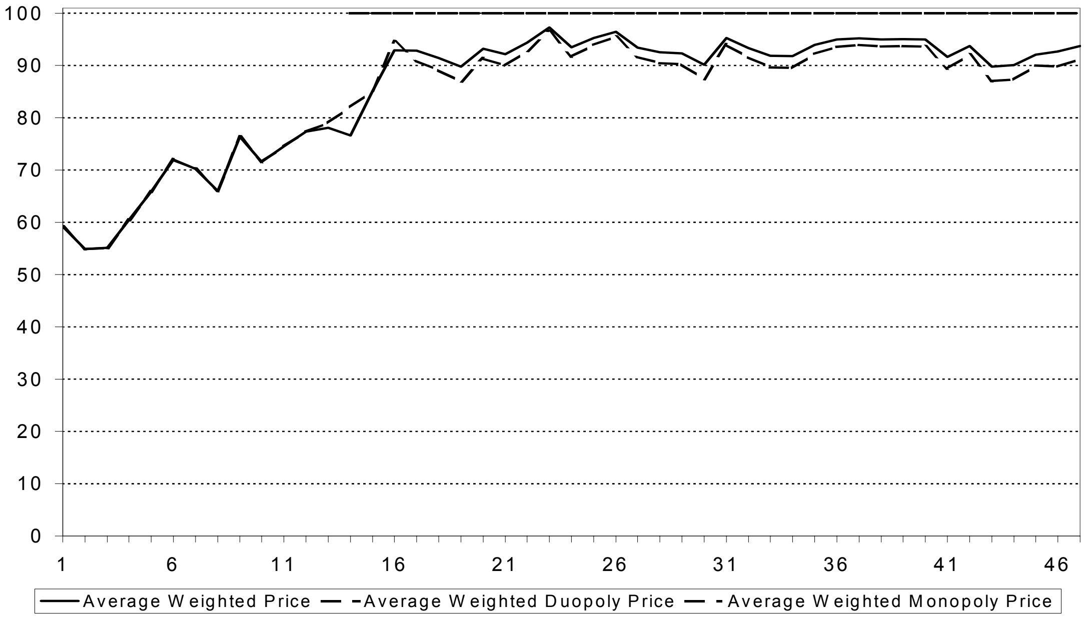


Figure 8. Price Series (2F)

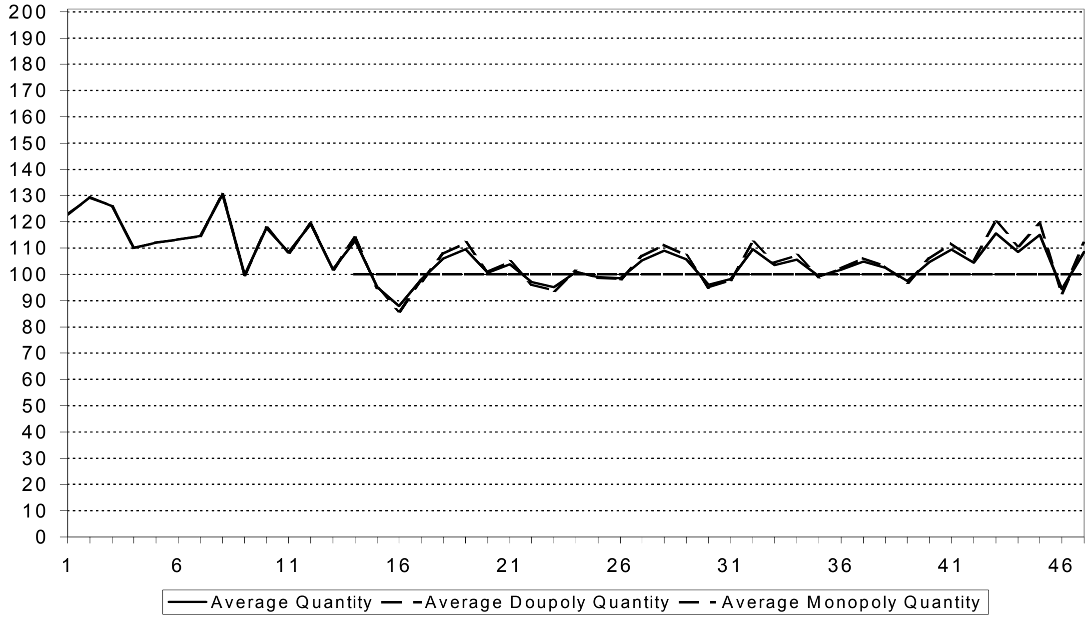


Figure 9. Quantity Series (2F)

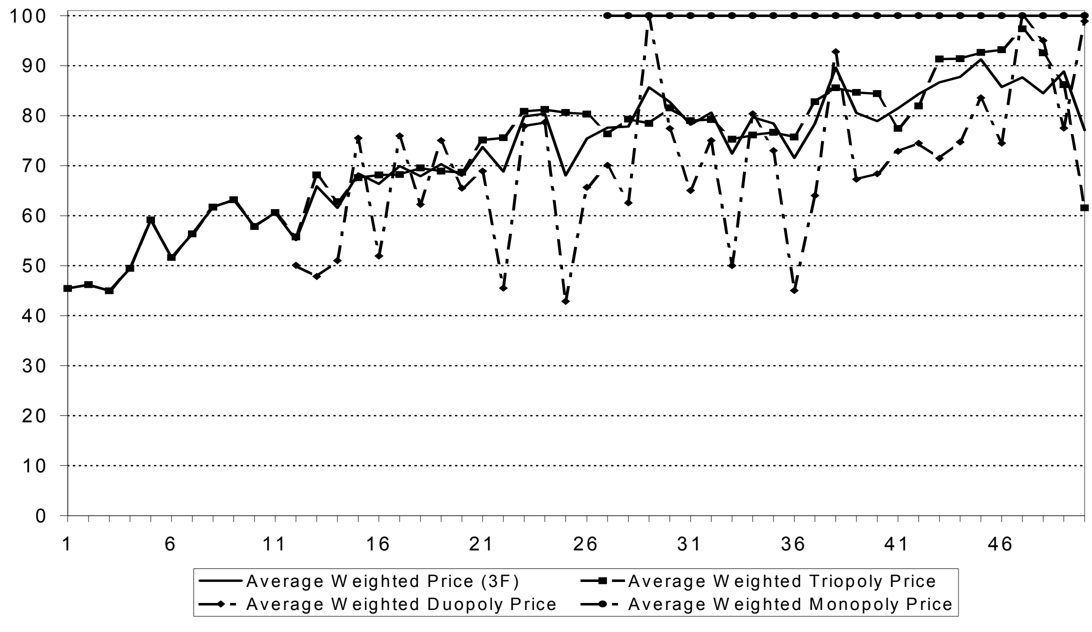


Figure 10. Price Series (3F)

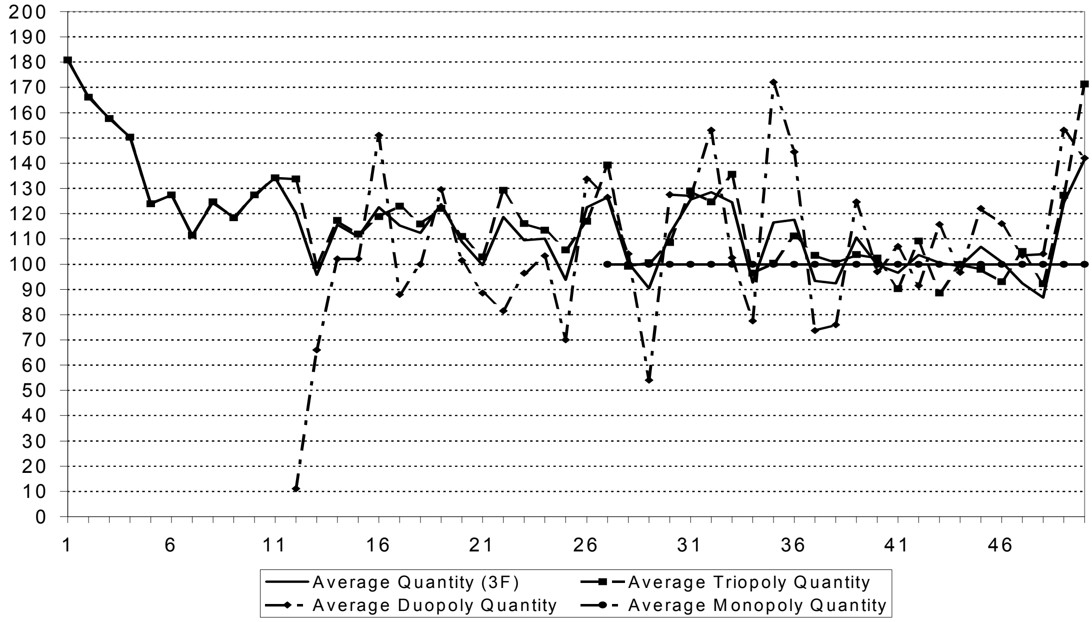


FIGURE 11. QUANTITY SERIES (3F)

5 Conclusions

In the standard Bertrand and Cournot models it is assumed that firms leave either price or output for an automatic mechanism to determine. In this paper we present results from experiments in which we relax this rather artificial feature head-on and allow firms to simultaneously choose prices and quantities. This is, in our view, a somewhat more natural approach and can also be seen as the first step towards the analysis of a dynamic situation involving the carry-over of inventories. However, we do not see this as the "right" environment, but as one more element that will help us understand competition among small numbers of firms. Markets are many and various. A complete view of competition among the few can only arise from the study of a variety of potentially relevant market environments.

We find that the kind of price-quantity competition we study leads mostly to behavior like that of standard quantity competition. In our data, in line with the Chamberlin (1962) proposal, no outcome except that of sharing the market at the highest price appears to be stable. In the absence of pure strategy equilibria for the stage game only the highest price has any "focal drawing power". This outcome is sometimes the result of collusion, while in other instances it arises after firms fighting for the market.

This results can neither be exclusively attributed to the fact that firms interact repeatedly with each other nor to the type of demand function we use, since we know that pure price competition would - under the very same conditions - lead to much lower prices. Increasing the number of firms does have the effect of favoring consumers. However, this may just be a transitory phenomenon, since pricing tends to the same pattern with both two and three firms. We speculate that the addition of firms would lead to results in the same line. More firms could lead to more fights and more bankruptcies. This will lead to a longer adaptation phase, but with convergence to the same final price level.

Would modifications of the basic market conditions lead to different behavior? Our impression is that increasing marginal costs would not substantially alter results. A downward sloping demand function could perhaps have the effect of making collusion more difficult, but with few firms we still expect firms to reach a stable situation at high prices.

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Appendix A: Instructions

This is an experiment about economic decision-making. The experiment is divided into periods. Each of you will have the role of a firm. In each period firms have to decide which quantity to produce and at which price to sell. To make your decision you should take into account that:

1) You can produce any integer quantity between 0 and 102.

2) You can set any integer price between 0 and 100 ECU (experimental account units).

3) The production of each unit costs you 50 ECU's, whether you sell it or not.

4) You are not the only firm offering products, specifically there will be three firms offering products in each market.

5) At the beginning of the experiment it will be randomly determined which firms will be in which market.

6) In each market the three firms will be the same period after period.

7) Consumers (simulated by computer) will always by 102 units.

8) If the firms set three different prices, consumers will always start buying the cheaper units,

a. if the firm with the lowest price has produced less than 102 units then consumers will buy the rest of the units up to 102 from the firm that has set the second lowest price

b. if the quantity produced by the two firms that have set lower prices is less than 102 then consumers will buy the rest of the units, up to 102, from the third firm.

c. if, in contrast, the firm with the lowest price has produced 102 units then consumers will buy the 102 units from him and the firms with the higher prices will sell 0 units.

9) if the three firms set the same price and the sum of the quantities produced by the three firms is smaller than or equal to 102 then the three firms will sell all produced units.

10) if, in contrast, the three firms set the same price and the sum of the quantities produced is larger than 102 then consumers will buy in proportion to the quantities produced; i.e., if one firms has produced X units, a second firm has produced Y units and the third firm has produced

Z units, then the first firm will sell $\frac{X}{X+Y+Z} * 102$ units, the second firm will sell $\frac{Y}{X+Y+Z} * 102$ units and the third firm will sell $\frac{Z}{X+Y+Z} * 102$ and the rest of the units will not be sold.

11) if two firms set the same price, this price is the lowest and the quantity produced by these two firms is larger than 102, then consumers will buy in proportion to the quantity produced, i.e. if one firm has produced X units and the other firm has produced Y units then the first firm will sell $\frac{X}{X+Y} * 102$ units, the second firm will sell $\frac{Y}{X+Y} * 102$ units and the rest of the units will not be sold.

12) if two firms set the same price and it is not the lowest the same proportional rule than under 11) will be applied subject to the remaining quantity up to 102; i.e. if the third firm produces Z at the lowest price the quantities sold will be $\frac{X}{X+Y} * (102 - Z)$ and $\frac{Y}{X+Y} * (102 - Z)$.

13) if your firms makes losses it will be bankrupt, this means that the program will automatically set a price and a quantity equal to zero for all remaining rounds, the other firms will continue to be able freely set prices and quantities.

14) even if you are the owner of a bankrupted firm you will have to remain in your seat until the end of the experiment to preserve anonymity.

On your computer you will see 5 screens:

1) The input screen where you will have to type your price and quantity in the corresponding spaces.

2) The results screen will inform you about the prices and quantities of the other firms, as well as about your earnings in the period and your accumulated earnings. You can press the button "OK" after you have read it and this screen will disappear in 20 seconds.

3) The history screen will inform you about prices, quantities and earnings of all previous periods.

4) The waiting screen will appear whenever you have to wait till everybody is finished.

5) The total earnings screen will appear at the end of the experiment and will inform you of your total earnings in Euros.

You will not be allowed to communicate with each other during the experiment. If you have any doubt about the instructions you may now ask publicly. If you have a question or doubt during the experiment, raise your hand and we will talk to you personally.

The experiment has 50 periods You start with 20000 ECU's which will always appear added to your total earnings. You will be paid 2 cents of a Euro for each 100 EAU's plus the 3 Euros that you will already have received for your participation.

Appendix B: Overall Tables[11]

Prices	M1		M2		M3		M4		M5	
	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.
1 to 5	70.00	27.39	53.00	9.75	33.20	17.43	81.14	18.06	60.80	21.91
6 to 10	69.90	26.57	56.67	20.95	81.50	8.63	100.00	0.00	100.00	0.00
11 to 15	78.68	25.52	77.00	11.51	73.10	11.45	100.00	0.00	100.00	0.00
16 to 20	100.00	0.00	90.50	9.75	75.16	4.69	100.00	0.00	100.00	0.00
21 to 25	100.00	0.00	82.00	10.95	83.70	4.13	100.00	0.00	100.00	0.00
26 to 30	100.00	0.00	76.00	8.94	84.40	12.60	100.00	0.00	100.00	0.00
31 to 35	100.00	0.00	81.00	12.45	90.00	4.85	100.00	0.00	100.00	0.00
36 to 40	100.00	0.00	100.00	0.00	96.60	2.16	100.00	0.00	100.00	0.00
41 to 45	100.00	0.00	100.00	0.00	63.40	14.42	100.00	0.00	100.00	0.00
46 to 50	100.00	0.00	100.00	0.00	57.50	10.61	100.00	0.00	100.00	0.00

Quantities										
	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.
1 to 5	124.00	41.14	112.00	55.41	160.00	22.36	92.60	17.11	80.40	33.28
6 to 10	160.00	22.36	108.00	38.34	112.00	21.68	100.00	0.00	100.00	0.00
11 to 15	94.20	37.53	100.00	0.00	137.40	25.67	100.00	0.00	100.00	0.00
16 to 20	100.00	0.00	121.00	28.81	122.00	0.71	100.00	0.00	100.00	0.00
21 to 25	100.00	0.00	158.00	42.66	110.20	8.23	100.00	0.00	100.00	0.00
26 to 30	100.00	0.00	122.00	25.88	120.00	27.39	100.00	0.00	100.00	0.00
31 to 35	100.00	0.00	150.00	50.00	100.00	0.00	100.00	0.00	100.00	0.00
36 to 40	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00
41 to 45	100.00	0.00	100.00	0.00	170.00	27.39	100.00	0.00	100.00	0.00
46 to 50	100.00	0.00	100.00	0.00	110.00	14.14	100.00	0.00	100.00	0.00

Prices	M6		M7		M8		M9		M10	
	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.
1 to 5	85.96	15.28	55.20	11.08	49.82	9.35	53.02	6.50	53.36	5.60
6 to 10	100.00	0.00	50.08	0.17	58.47	24.30	43.40	6.54	51.00	11.40
11 to 15	100.00	0.00	62.00	21.68	60.00	30.16	59.79	4.35	41.26	12.35
16 to 20	100.00	0.00	100.00	0.00	100.00	0.00	92.00	17.89	67.14	25.33
21 to 25	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	81.00	19.95
26 to 30	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	70.47	24.44
31 to 35	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	75.44	11.44
36 to 40	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	81.95	3.48
41 to 45	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	65.47	19.63
46 to 50	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	47.50	0.71
			m		m		m			

Quantities										
	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.
1 to 5	102.00	2.83	160.00	41.83	154.00	45.06	166.00	13.87	108.00	16.05
6 to 10	100.00	0.00	136.60	60.22	126.00	76.03	166.00	46.69	119.00	5.48
11 to 15	100.00	0.00	100.40	99.50	112.00	57.62	125.80	49.43	143.20	52.17
16 to 20	100.00	0.00	90.00	22.36	100.00	0.00	100.00	0.00	78.40	83.70
21 to 25	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	45.00	45.96
26 to 30	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	82.00	41.02
31 to 35	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	90.80	30.22
36 to 40	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	90.00	28.28
41 to 45	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	118.00	37.01
46 to 50	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	160.00	56.57
			m		m		m			

2F Overall Tables (1)

[11] Tables show price and quantity averages and standard deviations for every particular market. These statistics are computed for batches of five periods. "m", "d" and "t" denote that the market ends with monopoly, duopoly or triopoly respectively.

Prices	M11		M12		M13		M14	
	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.
1 to 5	57.36	4.93	49.76	3.26	62.71	7.08	62.20	15.18
6 to 10	63.60	12.72	34.24	27.95	88.73	2.89	100.00	0.00
11 to 15	97.60	5.37	62.08	11.41	95.32	2.12	90.00	22.36
16 to 20	100.00	0.00	66.28	15.77	97.79	0.24	100.00	0.00
21 to 25	100.00	0.00	78.20	19.81	98.63	0.29	100.00	0.00
26 to 30	100.00	0.00	71.85	25.29	99.16	0.29	100.00	0.00
31 to 35	100.00	0.00	59.76	7.99	99.47	0.00	100.00	0.00
36 to 40	100.00	0.00	53.00	2.39	99.47	0.00	100.00	0.00
41 to 45	100.00	0.00	52.41	4.27	99.69	0.28	100.00	0.00
46 to 50	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00

m

Quantities								
	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.	Avg.	Est.Dev.
1 to 5	114.00	11.40	115.20	34.32	92.20	11.26	100.00	0.00
6 to 10	100.00	0.00	87.00	37.78	97.40	1.34	100.00	0.00
11 to 15	102.00	4.47	84.00	23.82	95.80	1.10	110.00	22.36
16 to 20	100.00	0.00	99.60	39.09	95.00	0.00	100.00	0.00
21 to 25	100.00	0.00	80.00	39.62	95.00	0.00	100.00	0.00
26 to 30	100.00	0.00	121.80	62.14	95.00	0.00	100.00	0.00
31 to 35	100.00	0.00	109.60	66.05	95.00	0.00	100.00	0.00
36 to 40	100.00	0.00	146.20	35.35	95.00	0.00	100.00	0.00
41 to 45	104.00	8.94	157.60	42.09	99.00	2.24	100.00	0.00
46 to 50	100.00	0.00	50.50	70.00	100.00	0.00	100.00	0.00

m

2F Overall Tables (2)

Prices	M1		M2		M3		M4		M5	
	Avg.	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**
1 to 5	39.29	37.52	47.92	19.50	53.49	3.45	31.17	22.95	51.58	2.00
6 to 10	55.86	38.44	54.98	8.97	39.85	17.72	51.80	0.73	49.91	0.22
11 to 15	62.92	14.41	64.46	12.10	47.88	21.56	60.56	7.30	52.31	3.42
16 to 20	80.69	20.86	55.21	7.19	51.18	0.82	54.56	3.63	50.60	1.23
21 to 25	51.00	36.47	53.08	12.04	80.75	17.65	54.32	5.50	79.58	4.36
26 to 30	67.97	28.38	80.40	43.83	95.02	4.95	58.16	6.92	68.04	8.44
31 to 35	79.02	26.57	100.00	0.00	58.35	12.92	54.58	3.76	60.66	11.00
36 to 40	71.52	21.91	100.00	0.00	67.79	14.37	60.85	17.08	69.68	8.77
41 to 45	78.35	24.86	100.00	0.00	84.29	21.69	100.00	0.00	66.50	5.29
46 to 50	78.51	24.58	100.00	0.00	99.80	0.45	100.00	0.00	78.78	14.67
	d		m		d		m		t	

Quantities										
	Avg.	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**
1 to 5	169.60	110.29	133.60	38.37	159.60	81.92	184.80	47.40	175.00	12.75
6 to 10	100.60	57.06	136.60	62.07	165.40	64.16	117.00	40.47	137.80	23.49
11 to 15	132.60	27.02	135.20	58.46	89.60	57.08	81.40	31.80	104.60	13.79
16 to 20	104.00	68.47	158.00	51.45	132.20	57.56	112.60	32.00	90.20	20.75
21 to 25	110.20	73.69	139.80	65.93	60.40	24.10	115.40	46.40	63.00	30.32
26 to 30	110.60	61.82	103.60	39.66	102.00	1.00	85.20	48.44	111.40	44.28
31 to 35	122.00	44.72	102.00	0.00	130.80	56.48	119.20	56.93	116.20	37.51
36 to 40	105.80	3.83	102.00	0.00	85.20	69.92	122.80	38.11	92.20	10.62
41 to 45	133.00	41.14	102.00	0.00	80.20	44.46	102.00	0.00	93.20	34.04
46 to 50	134.40	40.17	102.00	0.00	113.00	24.67	102.00	0.00	94.60	57.03
	d		m		d		m		t	

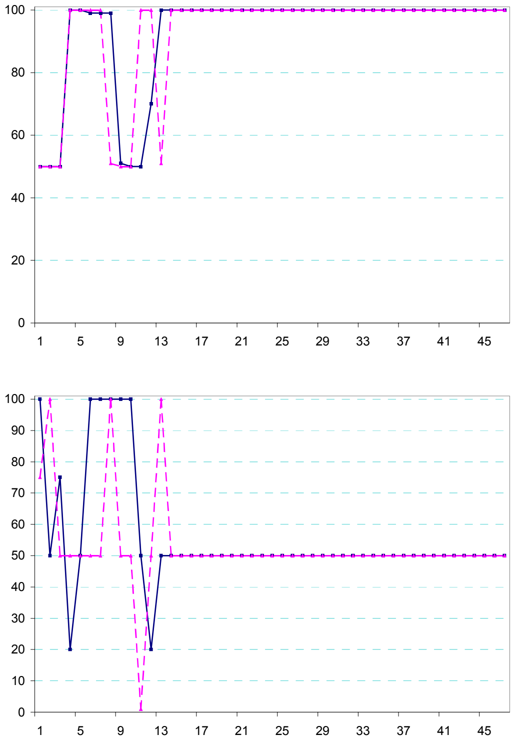
Prices	M6		M7		M8		M9	
	Avg.	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	
1 to 5	61.70	2.03	51.50	12.32	55.62	8.28	49.02	11.09
6 to 10	72.19	6.44	57.55	6.00	57.87	13.42	83.33	17.95
11 to 15	58.71	4.10	54.59	5.31	69.63	14.67	89.80	22.81
16 to 20	67.04	4.43	56.98	5.75	100.00	0.00	100.00	0.00
21 to 25	55.62	3.56	93.33	9.43	100.00	0.00	100.00	0.00
26 to 30	48.88	1.66	100.00	0.00	100.00	0.00	100.00	0.00
31 to 35	48.18	2.14	100.00	0.00	100.00	0.00	100.00	0.00
36 to 40	48.44	1.77	100.00	0.00	100.00	0.00	100.00	0.00
41 to 45	47.39	19.96	100.00	0.00	100.00	0.00	100.00	0.00
46 to 50	40.00	41.83	91.84	17.69	77.98	23.98	96.00	8.94
	d		t		t		t	

Quantities								
	Avg.	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**	**Avg.**	**Est.Dev.**
1 to 5	153.20	28.73	105.20	8.76	182.20	43.76	138.40	31.67
6 to 10	139.80	44.80	121.20	27.22	76.00	21.62	102.00	0.00
11 to 15	135.00	37.46	135.80	24.80	96.40	40.46	126.80	34.22
16 to 20	123.00	3.81	127.40	32.21	99.20	5.54	102.00	0.00
21 to 25	161.40	35.00	102.00	0.00	102.80	0.84	102.00	0.00
26 to 30	173.80	17.04	102.00	0.00	102.80	0.84	102.00	0.00
31 to 35	160.00	42.87	102.00	0.00	103.60	0.89	102.00	0.00
36 to 40	109.40	2.61	102.00	0.00	103.20	0.45	102.00	0.00
41 to 45	94.00	78.96	102.00	0.00	104.00	1.00	102.00	0.00
46 to 50	60.00	54.77	122.00	30.20	125.20	43.65	129.20	60.82
	d		t		t		t	

3F Overall Tables

Appendix C: Graphs[12]

[12] For every market the upper picture represents individual price series and the lower individual quantity series (Pictures start on the next page). The first fourteen markets shown come from 2F. The next nine come from 3F. For every market the upper picture shows prices and the lower one quantities.



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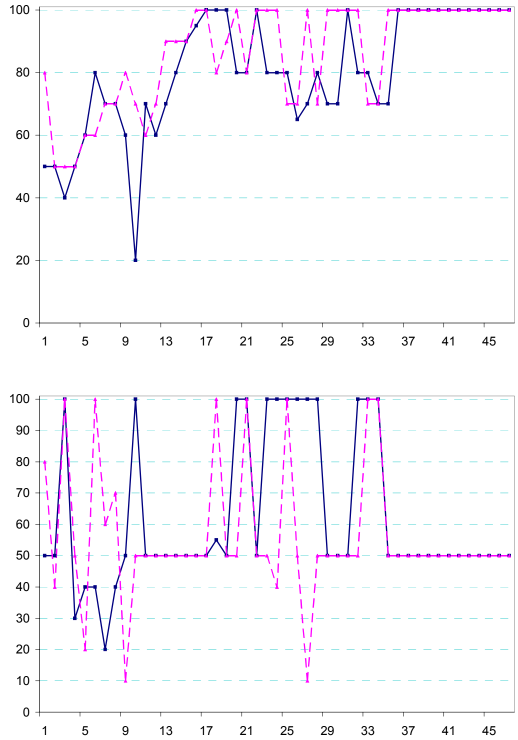
M1



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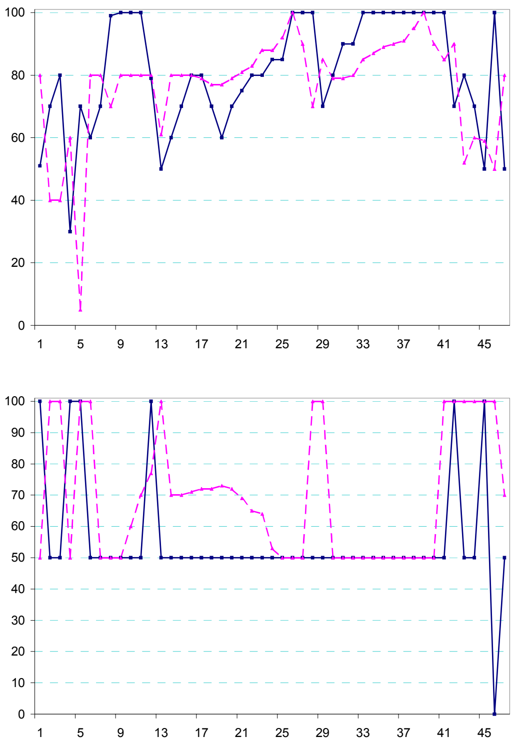
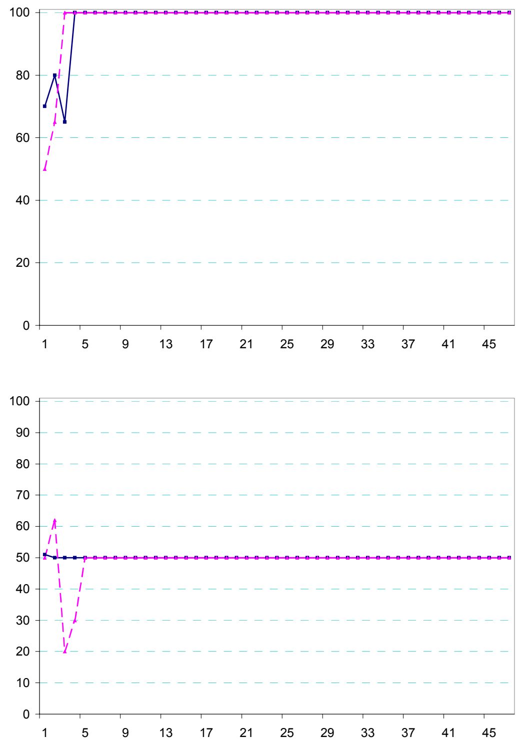
M2



0 20 40 60 80 100
0 10 20 30 40 50 60 70 80 90 100
1 5 9 13 17 21 25 29 33 37 41 45

M3



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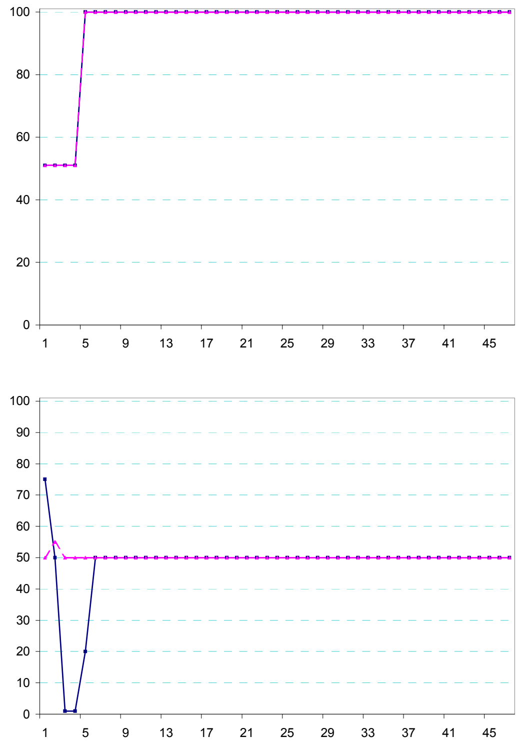
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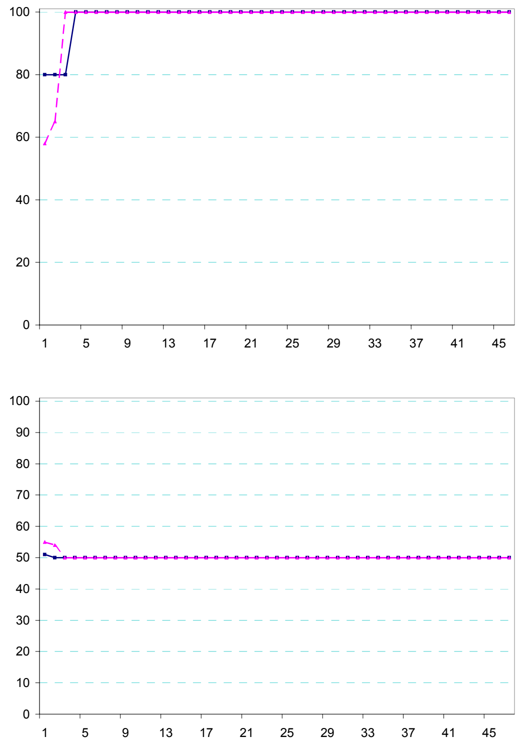
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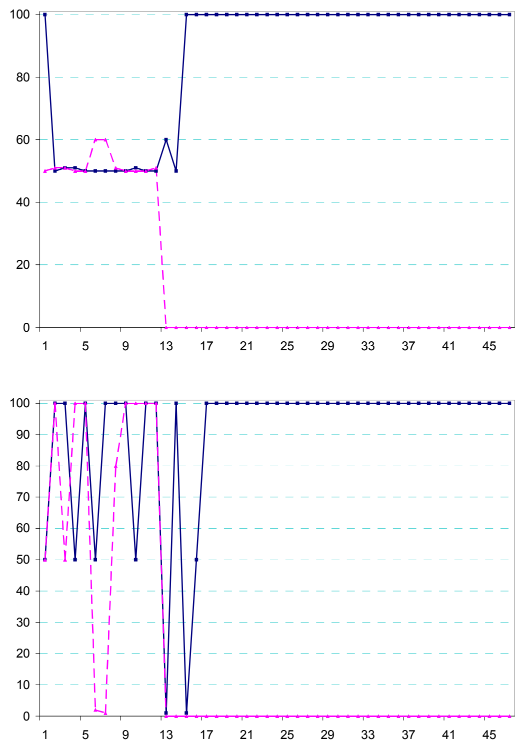
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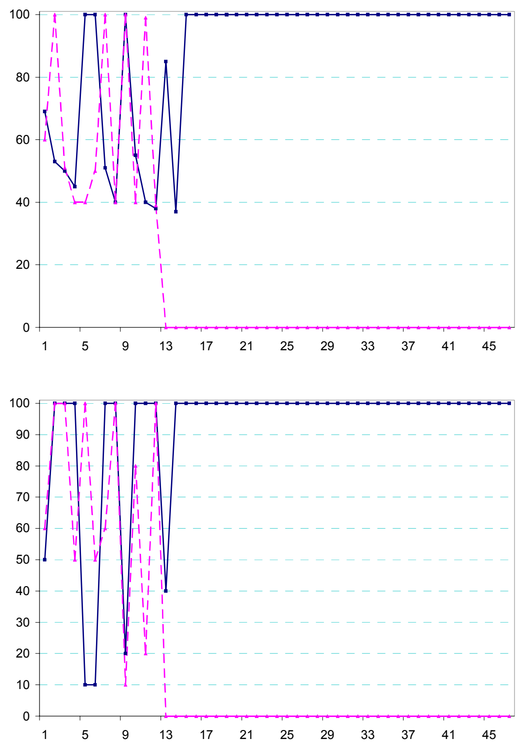
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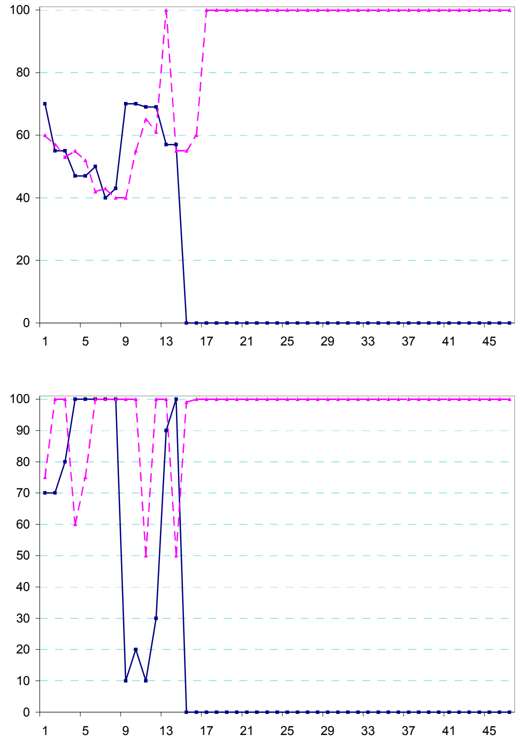

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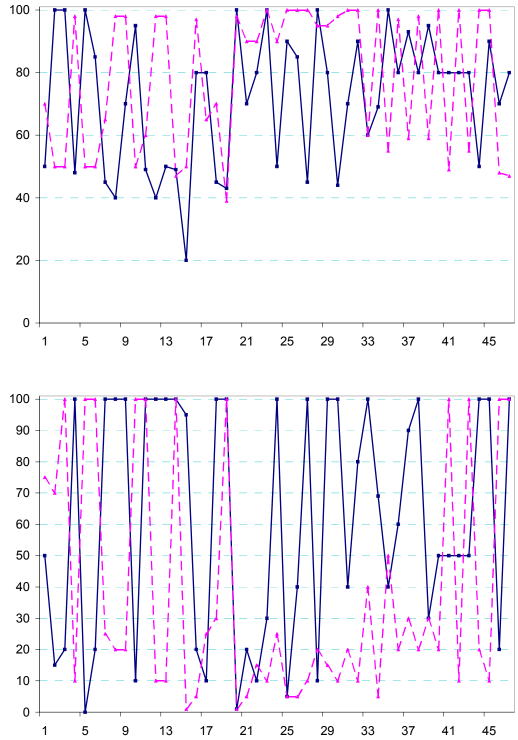

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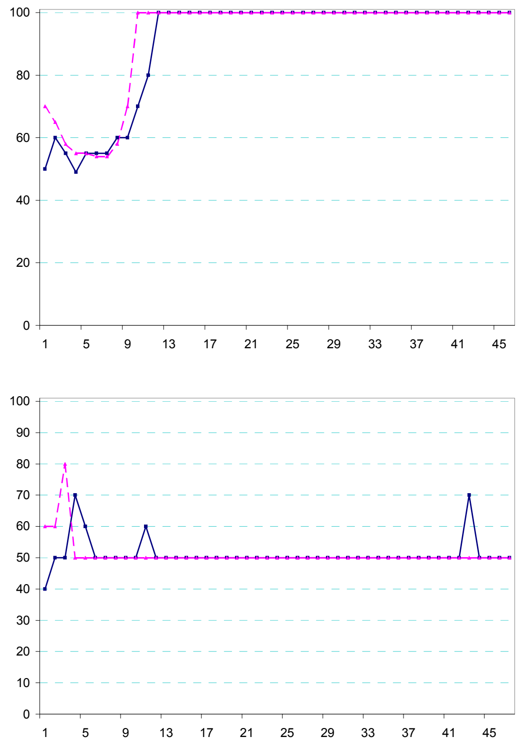

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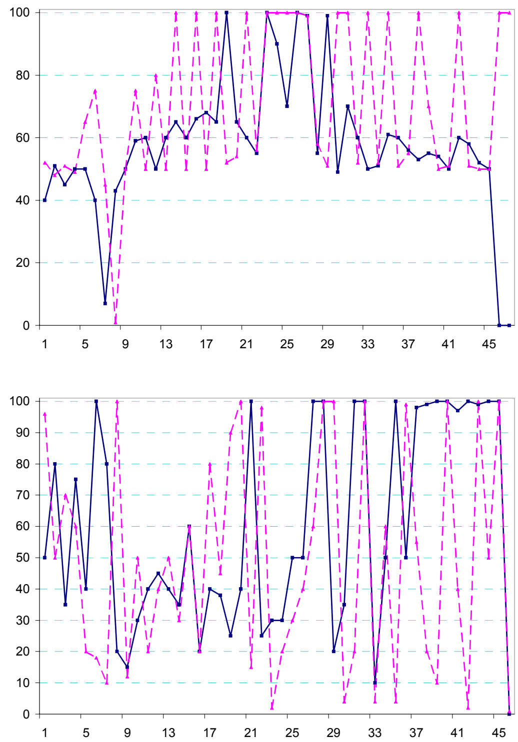

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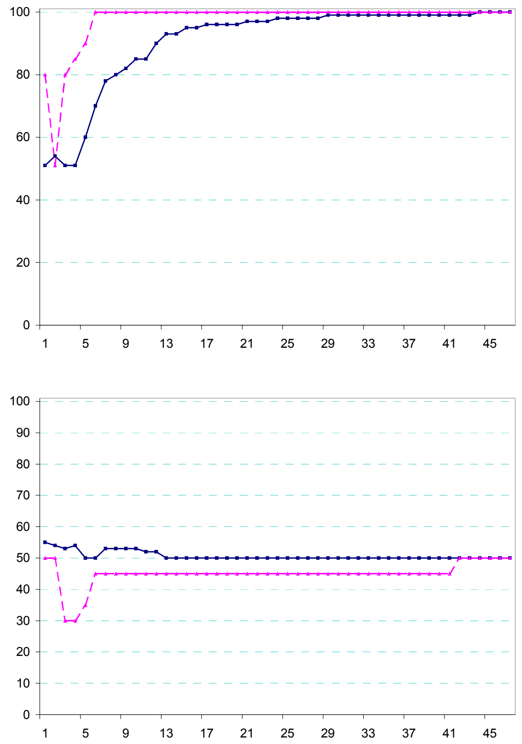
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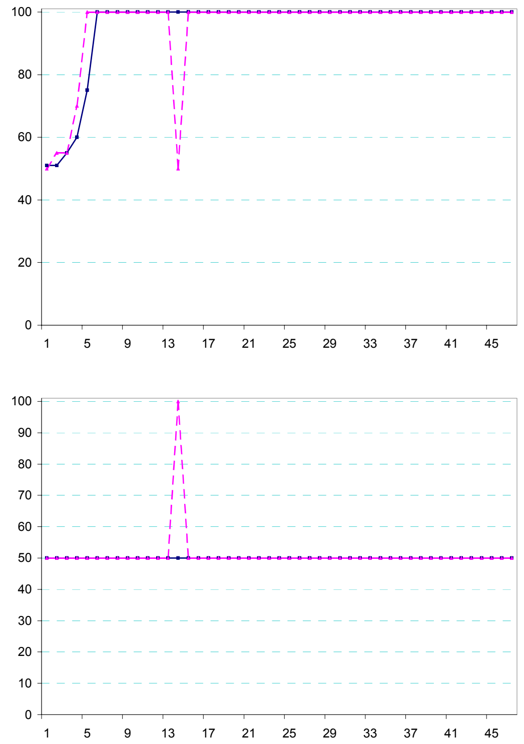
M13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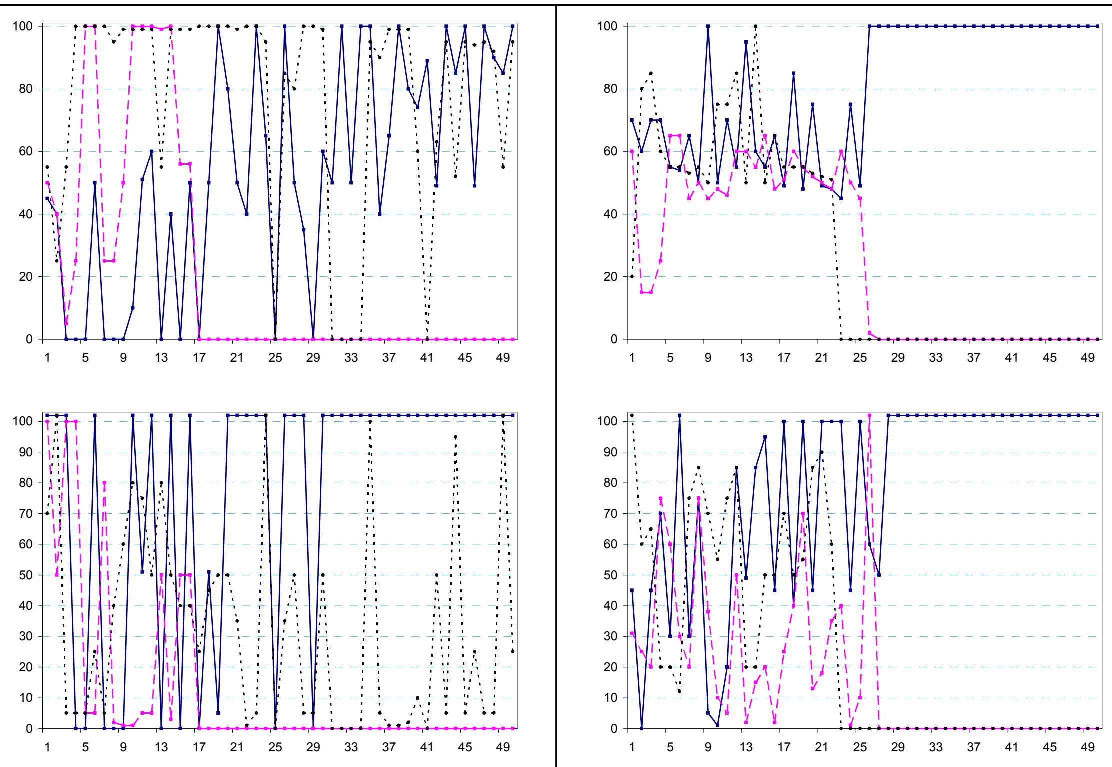
M14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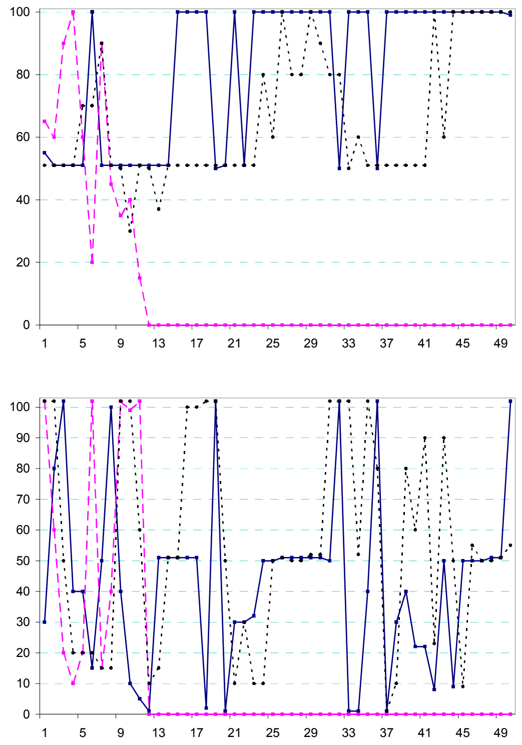
M1 M2



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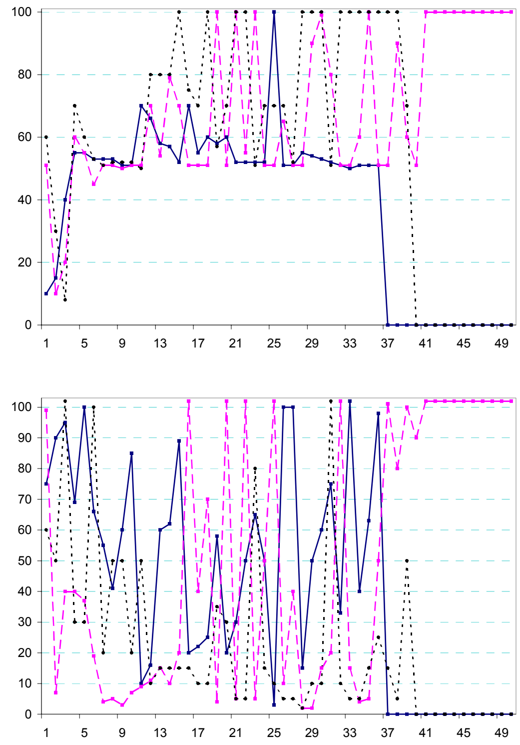

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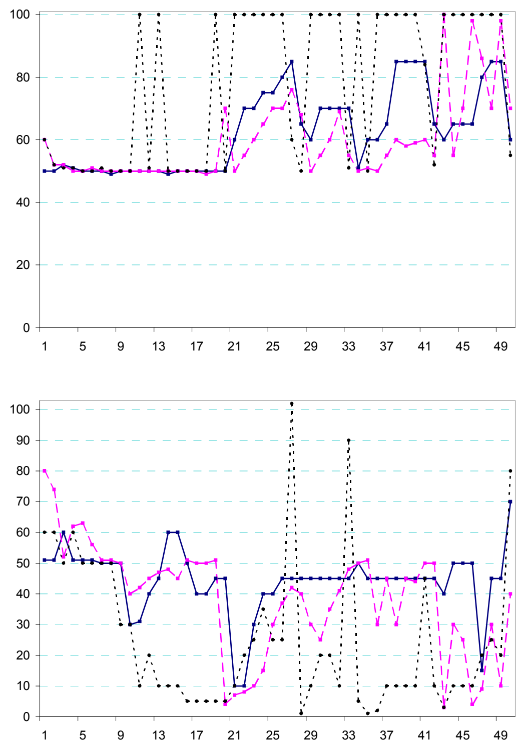
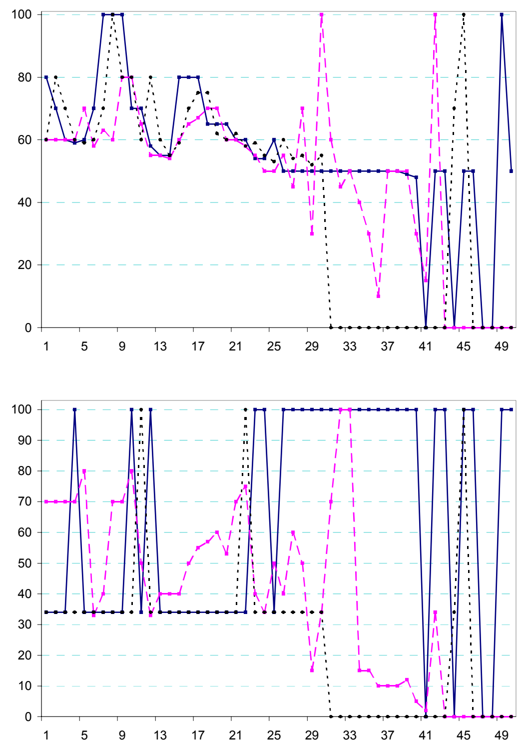


M5



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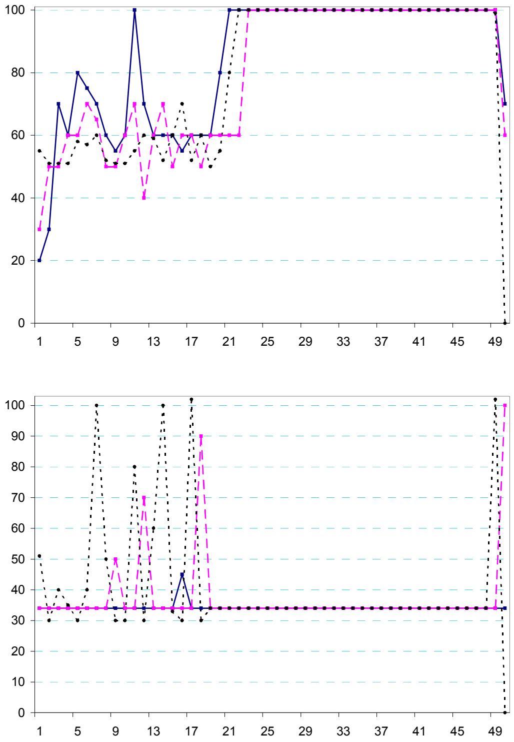
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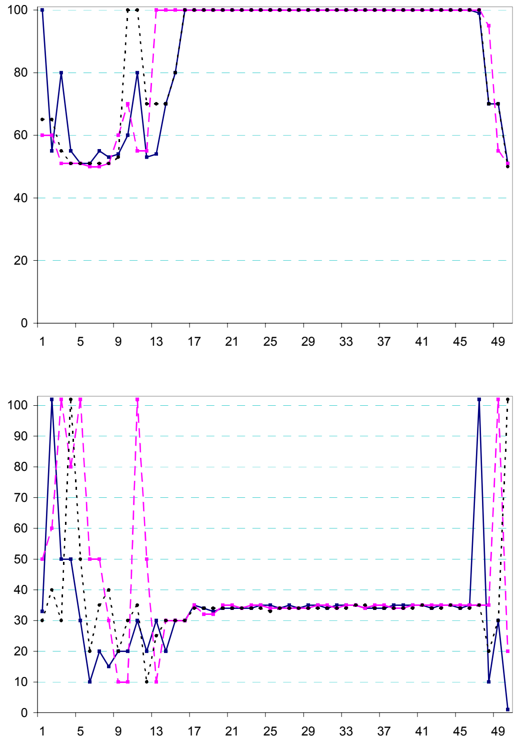
M7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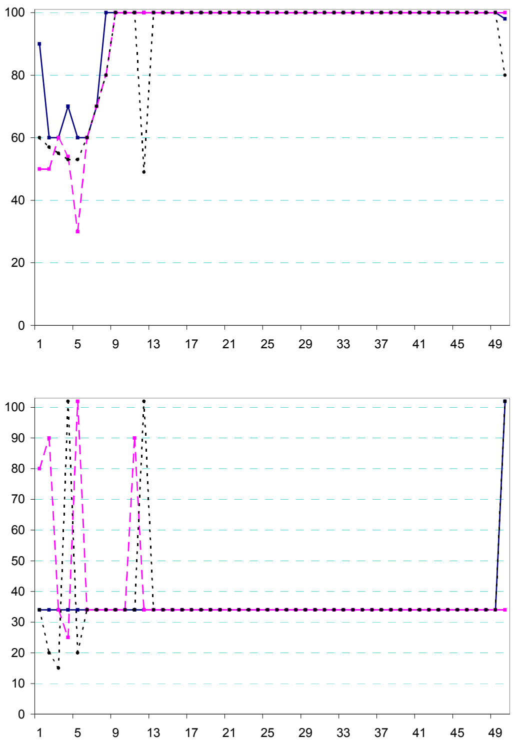
M8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M9