Entry Effects on Cartel Stability and the Joint Executive Committee

Helder Vasconcelos*
European University Institute†

January 2000

Abstract

We extend the Green and Porter's (1984) model to consider entry, by studying two alternative types of incumbent firms' post-entry reactions: cartel breakdown and accommodation of the entrants. We show that cooperation is more unstable if entry costs are low and if incumbents accommodate the new firms. We then test the applicability of the theoretical model to the type of collusion that characterizes the nineteenth-century railroad cartel in the US. The results provide support for the model predictions. In particular, cartel stability has been found to be negatively correlated with the number of firms in the agreement.

*I would like to thank my supervisor Massimo Motta for all his help and advice, Pierpaolo Battigalli, António Brandão, Andrea Ichino, Soren Johansen, Val. E. Lambson, Stephen Martin and seminar participants at the 1999 C.I.E. Summer School, at the University of Copenhagen, for their valuable comments, and Natalia Fabra for many helpful discussions. Special thanks must go to Robert Porter for providing me with the data he used in his article. Of course, any errors remain my own. This article is based on chapter 1 of my dissertation. Financial support from Fundação para a Ciência e Tecnologia and Direcção Geral dos Assuntos Comunitários is gratefully acknowledged.

†Department of Economics. Via dei Roccettini 9. I-50016 San Domenico di Fiesole, Florence. Italy. Email: vasconce@iue.it.

1 Introduction

The objective of this paper is twofold. From a theoretical perspective, the paper contributes to the analysis of entry effects on cartel stability under demand uncertainty. From a more applied perspective, we empirically test some theoretical predictions about how entry can affect the pattern of collusive behavior of a group of firms organized in a cartel agreement to co-ordinate prices, making use of data on the US railroad cartel of the turn-of-the century.

We develop an extended version of the model proposed by Green and Porter (1984). In their seminal article, Green and Porter analyze infinitely repeated oligopoly games where market demand is subject to exogenous shocks and the firm's (past) actions are not observable, but they do not, however, consider the possibility of entry. We thus reexamine their model to understand how the stability of the collusive price structure can be influenced by an increase in the number of firms in the agreement or by the existence of a pool of potential competitors.

The framework we use in order to explicitly model the entry process is borrowed from Harrington (1989). We study two types of collusive equilibria in a repeated Bertrand game (with random demand and unobservable prices) between a set of active firms and a set of potential competitors that can enter the market by paying a one-time, fixed, sunk cost (entry cost). In a collusive equilibrium, the initially active firms have no incentive to cut prices in non-reversionary periods (because this would trigger a "price war") and the potential entrants have no incentive to enter, because the present value of the expected profits from entering the cartel is not sufficient to cover the entry cost. In the first type of equilibrium it is expected that entry would trigger a price war. In the second type of equilibrium it is expected that entry would be accommodated with a more inclusive agreement. It should be noted, however, that a major difference exists between the model developed in this paper and Harrington's (1989) framework. While Harrington's results are obtained in a context of almost perfect information,[1] our analysis restricts the information available to firms in the sense that, at each period of time, apart from past entry decisions a firm knows only its own past prices and output levels. We find that entry does reduce the scope of collusion under both types of equilibria. We then look for empirical evidence of the role

[1] In the model he presents there are simultaneous moves at each stage of the dynamic game.

played by entry using the data set from the experience of the Joint Executive Committee (henceforth JEC), a pre-Sherman Act (legal) cartel.

The Green and Porter (1984) model has been subject to previous empirical tests using the JEC data set. The model suggests that in industries working in a context of imperfect observability, price patterns include shifts between collusive regimes and competitive regimes along the collusive equilibrium path. Porter (1983b) and Ellison (1994), among others, demonstrated the existence of such regime shifts while examining this railroad cartel.[2] In another paper which is probably the closest to the empirical application developed in this study, Porter (1985), still using the JEC data set, analyzes empirically the determinants of both frequency and duration of competitive reversions of finite length. The main goal of the econometric work developed by Porter was to determine whether the JEC was less successful in maintaining cooperative prices because of entry of new firms. To this end, he ran regressions for both the full sample and two subsets of the overall sample in which there were structural changes due to entry occurrence, to test for the impact of entry on the likelihood of a price war beginning. As noted by Porter himself, using the incidence of competitive episodes reported by the press at the time as the dependent variable, the results obtained are quite discouraging. We regard the empirical application developed in this study as somewhat complementary to the work of Porter (1985). Using the same data set but considering a different specification of the econometric model and creating new variables to explore the causes of price wars occurrence, our findings confirm the predictions of the reexamined version of the Green and Porter (1984) model presented in this article. In particular, unlike Porter, we find that a larger number of firms in the industry increases the probability of entering a price war phase in the cartel.

The paper is organized as follows. Section 2 includes a brief description of the structural features of the basic theoretical model and some preliminary predictions about entry effects on cartel stability. The structure presented is based entirely upon the model developed in Green and Porter (1984). Departures from their assumptions are noted below. In Section 3 we develop the central analytical argument, extending the analysis of the preceding section to consider the possibility of entry of new firms. Section 4 briefly reviews

[2] However, while Porter (1983b) obtained the result that firms' price cost mark-ups were consistent with a Cournot behavior, Ellison (1994), allowing for serial correlation in the demand between periods, came to the conclusion that cartel members were setting prices collusively between price wars.

the operations of the JEC. A description of the data used in the empirical application and the estimation results are provided in sections 5 and 6, respectively. Section 7 contains some concluding comments.

2 The basic model

Following Tirole (1988), we will develop a model in the spirit of Green and Porter (1984) in which a cartel is sustained by oligopolistic firms acting non-cooperatively in a context of demand uncertainty.[3] In this section we briefly remind the reader of the main features of this well-known model for the case where entry is not allowed. In the following Section 3, we extend the model to analyze entry.

There exist n firms producing a homogeneous good and facing the same unit cost c. Firms choose prices in every period. Demand fluctuates randomly and its realizations are assumed to be independent and identically distributed (i.i.d.) over time. In each period there are two possible states of nature. With probability α the demand is zero ("low-demand state") and there is a positive demand with probability $(1-\alpha)$ (the "high-demand state"). In the latter case, demand is split into equal parts corresponding to those firms charging the lowest price.

Firms do not observe their rivals' prices. Thus, from the point of view of each single firm in a cartel a low demand for its product may be due to either secret price cutting by some competitors or a bad market demand shock.

A strategy, that is, a contingent plan of action, for a firm i in the repeated game is an infinite sequence $S_i = (S_i^0, S_i^1, ..., S_i^t, ...)$, where $S_i^0 \in R_+$ is a determinate initial price level, and $S_i^t : \left(R_+^2\right)^t \to R_+$ is a function that maps the prices charged and quantities faced by firm i in periods $1, 2, ..., t-1$ into a price p_i^t, for firm i in period t. In this game, we look for a Nash equilibrium with the strategy for the $i-$th player defined in the following way:

$$S_i^0 = p^*, \tag{1}$$

[3] We depart from Tirole's approach by considering that there are n firms in the agreement rather than two and also by allowing for a wider range of possible prices along the collusive path.

$$S_i^t\left(\left(q_i^0,p_i^0\right),...,\left(q_i^{t-1},p_i^{t-1}\right)\right)=\begin{cases} p^* & \text{if } q_i^{t-1}>0,\ p_i^{t-1}=p^*\ \text{, or} \\ & \quad \forall\tau\in[t-T,t-1],\quad p_i^\tau=p_c. \\ p_c & \text{otherwise.}\end{cases} \tag{2}$$

where $t=1,2,...,$ $\left(\left(q_i^0,p_i^0\right),...,\left(q_i^{t-1},p_i^{t-1}\right)\right)$ is the partial history with length t observed by firm i, $p^*\in(p_c,p_m]$ is the collusive price, while p_c and p_m represent the competitive and the monopoly price, respectively.

In words, the game lasts forever and initially each firm charges the collusive price. As soon as one of the n firms in the cartel observes a zero demand (and, therefore, earns zero profits), a punishment phase of T periods is triggered in which every firm adopts a Bertrand behavior.[4] At the end of the reversionary episode all firms return to collusive behavior and share the collusive profit (Π^*) until a zero demand is again observed by some (or all) firms.[5] Note that the length of the optimal punishment period can be neither zero nor infinite. First, under uncertainty, the optimal punishment cannot last forever since it may happen that everyone in the agreement faces zero punishment profit because of the realization of a "low demand state". Besides, if $T=0$, member firms would not expect losses in their future profits and would consequently have high incentives to defect.

Let V_n^+ represent the present discounted value of a firm's profit from date t on, assuming that date t belongs to a collusive phase. Analogously, let V_n^- denote the present discounted value of a firm's profit from date t on, assuming that date t is the beginning of a punishment period.[6] In this context we have:

$$V_n^+=(1-\alpha)\left(\frac{\Pi^*}{n}+\delta V_n^+\right)+\alpha\left(\delta V_n^-\right) \tag{3}$$

and,

$$V_n^-=\delta^T V_n^+. \tag{4}$$

[4]As was pointed out by Fudenberg and Tirole (1991), "no player can gain by deviating in the punishment phase, since play there is a fixed number of repetitions of a static equilibrium." (p. 186).

[5]As suggested by Abreu et *al.* (1986), it is possible that a global optimum might not be achieved with this penal code. It would be possible to implement punishments which are more severe than the Bertrand-Nash reversion by using a path with a *stick-and-carrot* structure. Nonetheless, we look at simple 'grim' strategies for the sake of simplicity.

[6]Because of stationarity, neither V_n^+ and V_n^- depend on time. In addition, the subscripts denote the number of firms in the agreement.

By solving this system one obtains:

$$V_n^+ = \frac{1}{1-(1-\alpha)\,\delta - \alpha\delta^{1+T}}\,(1-\alpha)\,\frac{\Pi^*}{n}, \tag{5}$$

$$V_n^- = \frac{\delta^T}{1-(1-\alpha)\,\delta - \alpha\delta^{1+T}}\,(1-\alpha)\,\frac{\Pi^*}{n}. \tag{6}$$

Equation (3) says that with probability $(1-\alpha)$ the demand state is high, each firm earns its share of the collusive profit and the game remains in the collusive phase, and thus each firm has the valuation V_n^+. However, with probability α, the "low-demand state" is achieved and in the next period a punishment phase starts. Equation (4) gives the present discounted value of the expected stream of profits at the beginning of this phase.

As we have seen, cartel members' strategies (1) and (2) prescribe a mechanism to punish deviations from the price structure agreed upon. Whether this punishment mechanism is self-enforcing will depend on the trade-off between potential short-run gains from deviation and the present value of expected future losses. This trade-off is captured by the analysis of the incentive compatibility constraint:

$$V_n^+ \geq (1-\alpha)\left(\Pi^* + \delta V_n^-\right) + \alpha\left(\delta V_n^-\right), \tag{7}$$

where $\delta \in (0,1)$ is the common discount factor. The right-hand side of the inequality shows that if the demand is high and the firm decides to undercut, it earns all the one-shot collusive profit, but by deviating it will trigger a punishment reversal in the following T periods. If the demand is zero, it will earn zero profits in the current period and a punishment phase starts in the next period.

Using equation (3) we can rewrite the incentive compatibility constraint in the following way:

$$\delta\left(V_n^+ - V_n^-\right) \geq \Pi^* - \frac{\Pi^*}{n}. \tag{8}$$

This relation says that a prospective deviant will decide to respect the agreement if the present discounted value of the long-run net gain from collusion is greater than the short-run gain from deviation.

The incentive compatibility constraint allows us to carry out a simple exercise of comparative statics with respect to the number of firms which

can provide us with some preliminary results on the effects of entry on cartel stability. First, looking at the right-hand side of relation (8) it can be seen that as the number of firms in the cartel increases, the higher the one-shot net gain from deviation is. Secondly, using equations (5) and (6) to develop the left-hand side of the incentive compatibility constraint, one finds that:

$$\delta\left(V_n^+ - V_n^-\right) = \delta\left(1-\alpha\right)\frac{\Pi^*}{n}\frac{1-\delta^T}{\left(1-\delta+\alpha\left(\delta-\delta^{1+T}\right)\right)} \geq 0. \tag{9}$$

Since $\delta \in (0,1)$, α belongs to the $[0,1]$ interval, T is positive, and $\Pi^* > 0$, we can conclude that the greater the number of firms, the smaller are the losses from any future competition triggered by firm deviations. Hence, as n increases, condition (8) is more difficult to satisfy, which means that collusion is more difficult to sustain when there is a large number of firms in the agreement.

A simple way to study the impact of entry on cartel stability is to take the extreme case in which $n \to \infty$. In this context, both $\delta\left(V_n^+ - V_n^-\right)$ and the share in the collusive profits $(\frac{\Pi^*}{n})$ converge to zero, which means that relation (8) is violated and, therefore, the cartel breaks down with probability one.

3 Considering entry

We will now describe a new version of the Green and Porter (1984) model in which the entry process is modeled explicitly. We will study a particular subset of the set of Perfect Bayesian Equilibria. In particular, we will assume that once entry occurs, incumbent firms can either engage in aggressive behavior for a while (Case 1) or accommodate the new entrants (Case 2).[7] Throughout the analysis of each of these cases, we will first give the necessary and sufficient conditions for a non-trivial degree of collusion to be sustainable and then characterize the minimum level of entry barriers which

[7] We are not considering here the situation where incumbent firms coordinate their behavior to force an entrant to exit from the industry. During the operation of the JEC, it was common knowledge that new competitors faced a “no-exit constraint”. As a consequence, “it would not be rational for a railroad cartel to engage in predatory pricing practices in response to entry.” (Porter 1985, p. 420). Thus, we have decided not to cover predatory pricing here, since it is clear that the use of this kind of threat against potential entrants will not have been credibly carried out by the railroad firms belonging to the nineteenth-century railroad cartel, whose pricing strategies we will discuss in the applied part of this paper.

should exist in order to avoid entry from taking place. Finally, we will explore the stability issue in further detail, by analyzing the relationship between the two necessary conditions for collusion to be sustainable.

3.1 The new model structure

Assume a countably infinite number of active and inactive firms represented by the set Z. $A^t \subset Z$, where the inclusion is *strict*, denotes the set of active firms in period t and $|A^t| = N^t$ (where $|A^t|$ is the number of elements of A^t).[8] Hence, $Z - A^t$ represents the set of potential entrants in each period t. Further, let both active and inactive firms have the same marginal costs of production.

We also assume that, for a potential entrant, entry and price decisions are not simultaneous. At each period t, the N^t active firms simultaneously announce the price to charge (p_i^t denotes the i-th firm's price in period t). At the same time, potential entrants decide about entry. A one-time entry (sunk) cost K (where $K \geq 0$) has to be incurred if entry takes place. It allows the firm to begin production one period later. Hence, prices are a post-entry decision for a potential competitor and past entry decisions are assumed to be perfectly observed by all active firms.[9]

If a firm i is initially active ($i \in A^0$), its overall strategy - S_i - can be represented as an infinite sequence of action functions (one for each period) $S_i = (S_i^0, S_i^1, ..., S_i^t, ...)$, where $S_i^0 \in R_+$ represents the initial price charged by firm i and $S_i^t : \left(R_+^2 \times 2^Z\right)^t \to R_+$. The domain of an action function S_i^t is the Cartesian product between the set of feasible prices p_i^τ, the set of possible outputs[10] q_i^τ and the set of active firms in period τ, where $\tau \in \{0, ..., t-1\}$. The range of S_i^t is represented by the set of possible prices that firm i can charge in period t. Hence, period t action function of an arbitrary active firm i tells it which price to set in the $t-$th period as a function of the feasible histories observed over the periods $\{0, ..., t-1\}$. More formally:

$$S_i^t\left(\left(q_i^0, p_i^0, A^0\right), ..., \left(q_i^{t-1}, p_i^{t-1}, A^{t-1}\right)\right) = p_i^t.$$

[8] Firm i is considered active at time t ($i \in A^t$) if it faces a positive demand in that period.

[9] Entry is generally a time-consuming process; therefore, following Harrington (1989), we assume that incumbent firms are able to change their price decisions in response to entry.

[10] q_i^t is the demand faced by firm i in period t.

where $\left((q_i^0, p_i^0, A^0), ..., \left(q_i^{t-1}, p_i^{t-1}, A^{t-1}\right)\right)$ is the partial history with length t observed by firm i, which is denoted by $h_i^t \in H_i^t$. Notice that h_i^t can be partitioned into the public partial history $(A^0, ..., A^{t-1})$ and the private partial history $\left((q_i^0, p_i^0), ..., \left(q_i^{t-1}, p_i^{t-1}\right)\right)$ observed by firm i.

If firm i is instead initially inactive ($i \in (Z - A^0)$), then its overall strategy is $E_i = (E_i^0, E_i^1, ..., E_i^t, ...)$. In the first period of the game ($t = 0$), $E_i^0 \in \{\text{Out, In}\} \times \{\infty\}$, where Out means "Do Not Enter the Market" and In means "Enter the Market". Moreover, with respect to the price decision, the set of feasible prices is a singleton.[11] For each period $t \in \{1, 2, ...\}$, there exists an action function E_i^t, which, given the history observed up to period $t-1$, tells the firm whether or not to enter at the beginning of period $(t+1)$. We consider entry as an irreversible decision. Thus, if entry occurs, firm i's strategy specifies the prices to be charged for the remainder of the horizon. The observed (partial) history is composed by the own price and entry decisions and by the demand faced by the firm up to the previous period. In formal terms, $E_i^t : \breve{H}_i^t \rightarrow \{\text{Out, In}\} \times \{R_+ \cup \{\infty\}\}$, where $\breve{H}_i^t \subseteq \left(\{\text{Out, In}\} \times R_+^2\right)$. Moreover,

$$\forall\, \breve{h}_i^t \in \breve{H}_i^t, \text{ if } \breve{h}_i^t = \left(..., (x_i^\tau, p_i^\tau, q_i^\tau), ...\right), \text{ where } x_i^\tau = \text{Out, then } q_i^{\tau+1} = 0.$$

It should be also noted that:

$$E_i^t\left((\text{Out}, \infty, 0), ..., (\text{Out}, \infty, 0)\right) \in \{\text{Out, In}\} \times \{\infty\},$$

while

$$E_i^t\left((\text{Out}, \infty, 0), ..., (\text{In}, \infty, 0)\right) \in \{\text{In}\} \times R_+.$$

In the discussion that follows, we will identify, for each of the considered cases of post-entry reaction, the conditions which should be satisfied in order for the incumbent firms to sustain a non-trivial degree of market power without giving rise to either internal or external defection. Following Harrington (1991), we consider that internal defection takes place when some active firm

[11] The only feasible price is $p_i^0 = \infty$, thus the firm will not face a positive demand in the first period of the game.

secretly undercuts the price while external defection occurs if some potential competitor decides to enter the market.[12]

3.2 Case 1. Cartel Breakdown

In this case we consider a situation in which incumbent firms respond to entry by reverting to competitive pricing for a finite length of time (T periods). Since we want to understand how incumbent firms effectively sustain collusion, avoiding not only internal deviations for profit, but also entry of new competitors, an active firm's strategy is designed in the following way:

$$S_i^0 = p^*, \tag{10}$$

$$S_i^t\left(h_i^t\right) = \begin{cases} p^* & \text{if } q_i^{t-1} > 0,\ p_i^{t-1} = p^* \text{ and } A^t = A^{t-1},\ \text{or} \\ & \quad \forall \tau \in [t-T, t-1]\,,\quad p_i^\tau = p_c. \\ p_c & \text{otherwise.} \end{cases} \tag{11}$$

where $t = 1, 2, \ldots$, $i \in A^0$, $N^0 = \left|A^0\right| = n$.

Hence, the incumbent firms charge the collusive price (p^*) at the beginning of the game and continue to set it as long as no firm faces a zero demand and no entry occurs. However, if some firm (active or inactive) has deviated from the proposed path or if a low-demand state has occurred, then the collusive price is reestablished after a (temporary) punishment phase.

Our aim is to find a trigger strategy equilibrium such that strategies (10), (11) are optimal and there is no incentive for the entry of new firms into the industry. To this end, consider the following strategy for a potential entrant:

$$E_i^0 = \text{Out} \tag{12}$$

$$E_i^t\left(\breve{h}_i^t\right) = \begin{cases} \text{Out} & \text{if } \quad i \in Z - A^t \\ S_i^t & \text{if } \quad i \in A^t \end{cases} \tag{13}$$

where $t = 1, 2, \ldots$, $i \in Z - A^0$.

[12] Note that the basic framework of Section 2 can be viewed as a special case of the extended model we present in this section, where the entry sunk cost is prohibitive ($K \to \infty$) and, therefore, external stability is not an issue.

This strategy calls for a potential entrant not to enter the industry. However, if the firm decides to enter, then the strategy also prescribes the price conduct which it should follow after its entry.[13] Remember that the incumbents will react to entry by setting a price p_c during a finite punishment period. Hence, once inside the market the best response of the entrant is to set p_c during the punishment period which is triggered by its entry, since the Bertrand solution constitutes a Nash equilibrium for the one-shot price game which is played in each single-period, given the number of active firms in the industry.

A free entry trigger strategy equilibrium is defined as a triple (p^*, T^*, n^*) such that the strategies in (10)-(13) form a Perfect Bayesian Equilibrium (PBE). The following two conditions are necessary and sufficient for (10)-(13) to form a PBE:[14]

$$\delta\left(V_{n^*}^{+} - V_{n^*}^{-}\right) \geq \Pi^* - \frac{\Pi^*}{n^*} \tag{14}$$

and,

$$\delta V_{n^*+1}^{-} - K \leq 0. \tag{15}$$

Notice that not only the collusive price ($p^* \in (p_c, p_m]$), but also the length of the punishment (T^*) are chosen (optimally) by the cartel to maximize the expected discounted joint profit subject to the constraints (14) and (15). As can be easily verified from equation (5), V_n^+ is a decreasing function of T.

As in Section 2, expression (14) represents the incentive compatibility constraint. If it holds, each of the n^* active firms finds it optimal to go along with the collusive path and to charge the collusive price p^* since the discounted loss from cheating is greater than the one-shot gain from deviation. On the other hand, condition (15) makes further entry into the industry unprofitable. Thus, when this latter condition holds, existing profits might be positive because profits with further entry[15] are expected to be negative,

[13] It should follow the strategy of an initially active firm (strategy (11)) for the remainder of the horizon.

[14] Notice that subgame perfection cannot be used as the equilibrium concept. This is a dynamic game with unobservable actions in which the only proper subgame is the whole game itself. Moreover, active firms are able to observe actions which are off the equilibrium path (remember that they know the set of active firms in the past periods).

[15] Defined net of the (sunk) costs of entry.

which means that "Out" is, in fact, a best response for an inactive firm.[16]

Using expression (6), it is straightforward to show that:

$$V^{-}_{n^*+1} = \frac{\delta^{T^*}}{1-(1-\alpha)\,\delta-\alpha\delta^{1+T^*}}\,(1-\alpha)\,\frac{\Pi^*}{n^*+1}\ . \tag{16}$$

Hence, it follows that (15) binds when:

$$\widetilde{K} = \frac{\delta^{T^*+1}}{1-(1-\alpha)\,\delta-\alpha\delta^{1+T^*}}\,(1-\alpha)\,\frac{\Pi^*}{n^*+1}\ . \tag{17}$$

Thus, even when incumbent firms decide to adopt a severe punishment as a response to either internal or external defection, a minimum level of entry costs should exist in order for the incumbent firms to be able to coordinate their pricing strategies without giving rise to the entry of new competitors. This minimum level of entry costs is given by equation (17). We now need to study how $\widetilde{K}$ is expected to react in response to the variation of the (*initial*) number of firms (n^*). Working through some algebra, one can show that:

$$\frac{\partial\,\widetilde{K}}{\partial n^*} = -\frac{\delta^{T^*+1}\,(1-\alpha)}{1-\delta\,(1-\alpha)-\alpha\delta^{T^*+1}}\,\frac{\Pi^*}{(n^*+1)^2} \leq 0. \tag{18}$$

At this point, it should be stressed that the *initial* number of firms is a parameter of the model affecting the viability of collusive agreements. In equilibrium the number of firms does not change, and so it makes sense to do comparative statics with respect to n^*. Turning to the interpretation of the result in (18), it can be concluded that, as expected, the greater the *initial* number of incumbent firms in the agreement, the lower will be the height of the entry barriers which must exist in order to avoid entry and allow active (incumbent) firms to sustain a non-trivial degree of cooperation. Notice, however, that there is a conflict between the immunity of collusion to internal deviation, on the one hand, and to external defection (entry), on the other. In fact, n^* must be low enough, since the maintenance of the tacit agreement becomes more difficult as the number of active firms increases. Nevertheless, from the analysis of relation (18), n^* also has to be high enough to discourage the entry of new competitors. Taking both forces into account, using conditions (14), (15) and (16), and knowing that

[16] The condition in (15) can be interpreted as a violation of the participation constraint corresponding to the pool of potential competitors.

$V^{-}_{n^*+1} = \delta^{T^*} V^{+}_{n^*+1}$, it can be concluded that n^* can only take values in the following interval:

$$\frac{\delta^{T^*+1}\Pi^* (1-\alpha) - K\left(1-\delta+\alpha\left(\delta-\delta^{T^*+1}\right)\right)}{K\left(1-\delta(1-\alpha)-\alpha\delta^{T^*+1}\right)} < n^* < \frac{1-\delta^{T^*+1}}{1-\delta(1-\alpha)-\alpha\delta^{T^*+1}}. \tag{19}$$

3.3 Case 2. Accommodation

Rather than following the policy of reacting to entry by starting a finite punishment period, cartel members might decide to accommodate the entrant by achieving a new collusive outcome.[17] If a potential entrant anticipates that, entering at period t, the N^t active firms will adopt post-entry accommodation behavior, then the necessary and sufficient conditions for a triple (p^*, T^*, n^*) to constitute a free entry trigger strategy equilibrium are now given by:

$$\delta\left(V^{+}_{n^*} - V^{-}_{n^*}\right) \geq \Pi^* - \frac{\Pi^*}{n^*} \tag{20}$$

and,

$$\delta V^{+}_{n^*+1} - K \leq 0. \tag{21}$$

Whenever condition (20) holds, an individual active firm predicts that it will make more profit by being loyal to the cartel agreement than by being disloyal; therefore, the agreement is unlikely to breakdown because of an internal deviation.[18]

Condition (21) specifies that, even though incumbents will allow new competitors to join the collusive process, potential entrants anticipate a negative post-entry profit, which means that “Out” is an optimal choice for them.[19]

[17]Wenders (1971) calls this policy a “price maintenance strategy”.

[18]It should be noted that although incumbent firms follow a policy of post-entry accommodation, we are still assuming that internal defection is followed by a finite period of cartel breakdown. Hence, conditions (14) and (20) coincide.

[19]Again, both p^* and T^* are chosen (by the cartel) to maximize the discounted profits, but now subject to constraints (20) and (21).

From eq. (5), we can easily conclude that:

$$V^{+}_{n^*+1} = \frac{1}{1-(1-\alpha)\,\delta-\alpha\delta^{1+T^*}}\,(1-\alpha)\,\frac{\Pi^*}{n^*+1}. \tag{22}$$

Hence, as in the previous case, we can compute the critical level of the entry sunk cost for which condition (21) is satisfied with equality:

$$\widetilde{K} = \delta\frac{1-\alpha}{\left(1-(1-\alpha)\,\delta-\alpha\delta^{T^*+1}\right)}\frac{\Pi^*}{n^*+1}\ . \tag{23}$$

If we start by comparing the critical levels of K which were found for Cases 1 and 2, it turns out that:

$$\left(\widetilde{K}\right)_{Case\ 2} - \left(\widetilde{K}\right)_{Case\ 1} = \left(\delta-\delta^{T^*+1}\right)V^{+}_{n^*+1} > 0. \tag{24}$$

Thus, as expected, for a given market structure (n^*) it is more difficult to sustain the collusive aggregate profit Π^* when potential entrants anticipate post-entry accommodation behavior by the active firms, since the minimum height of the entry barriers must be higher in the second case.

As in Case 1, the analysis will now focus upon the sensitivity of the critical level of entry costs $\widetilde{K}$ to changes in the *initial* number of firms in the agreement (n^*). The result can be summarized as follows:

$$\frac{\partial\,\widetilde{K}}{\partial n^*} = -\,(1-\alpha)\,\frac{\delta}{\left(1-\delta\,(1-\alpha)-\alpha\delta^{T^*+1}\right)}\frac{\Pi^*}{(n^*+1)^2} \leq 0. \tag{25}$$

Again, the sign of the impact induced by parameter n^* on the minimum height of the entry barriers is consistent with *a priori* conjectures. Thus, the reasoning developed in Case 1 with respect to the interpretation of this marginal effect can also be applied in this second case. In addition, in order for both internal and external stability to be assured, n^* should belong the following interval:

$$\frac{\delta\,(\Pi^*+K)\,(1-\alpha)-K\left(1-\alpha\delta^{1+T^*}\right)}{K\,(1-\delta)+\alpha K\left(\delta-\delta^{1+T^*}\right)} < n^* < \frac{1-\delta^{1+T^*}}{1-\delta\,(1-\alpha)-\alpha\delta^{1+T^*}}. \tag{26}$$

Extending this comparative statics exercise to study the impact induced by changes in the probability of a “low-demand state” occurrence (α) and

in the discount factor (δ) on the critical level of K, we find that whatever the type of incumbent firms' post-entry reaction is (cartel breakdown or accommodation of the entrants), $\frac{\partial \widetilde{K}}{\partial \alpha} < 0$ and $\frac{\partial \widetilde{K}}{\partial \delta} \geq 0$. Thus, when α takes higher values, once cartel stability is threatened by the higher temptation for an internal deviation to occur, a potential entrant predicts a lower present value of gross post-entry continuation payoff, and, as a consequence, a lower value of entry costs is compatible with an unprofitable entry. On the other hand, with an increase in the discount factor δ, meaning that a greater weight is attached to the positive stream of profits that the entrant will receive after the punishment period that follows entry, the value of the critical non recoverable entry cost ($\widetilde{K}$) should be higher in order for entry to be prevented. However, and similarly to what was said before with respect to n^*, attention should be paid to the range of values in which δ can vary without disturbing cartel stability. On the one hand, δ should not be too high to avoid entry. Notice that in a free entry setting "as the discount factor increases, the probability of entry rises since entry entails an initial profit loss, due to the cost of entry, and a future stream of positive profits" (Harrington 1991, p. 1089). On the other hand, there is another effect of varying δ on the incentive constraint of the active firms that we are not covering with this comparative statics analysis. In fact, looking at conditions (14), (20), it can be seen that as the discount factor takes lower values, the discounted value of long-run net gain from collusion decreases, while the single period gain from deviation remains unchanged. As a result, δ should not also be too low for active firms to find that they will not have incentives to deviate for profit.

3.4 Stability discussion

The results of the previous subsections suggest that when either δ or n^* vary, there is a conflict between having collusion immune to internal defection, on the one hand, and to the entry of new competitors, on the other. To understand further the model just described we will now turn to the analysis of the relationship between the two conditions that assure the existence of the internal and external stability of the cartel: the incentive compatibility constraint and the participation constraint, respectively, by providing a numerical example.

If active firms react to entry by discontinuing cooperation (Case 1), using expressions (14), (15), (16) and (22), one can derive conditions for which

the incentive compatibility constraint and the participation constraint bind, expressed in terms of the number of firms (n_{icc} and n_{pc}, respectively):

$$n_{icc} = \frac{1-\delta^{T^*+1}}{1-\delta(1-\alpha)-\alpha\delta^{1+T^*}}, \tag{27}$$

$$n_{pc} = \frac{\delta^{T^*+1}\Pi^*(1-\alpha) - K\left(1-\delta+\alpha\left(\delta-\delta^{T^*+1}\right)\right)}{K\left(1-\delta(1-\alpha)-\alpha\delta^{T^*+1}\right)}. \tag{28}$$

Since we want focus attention on the interaction between the discount factor and the number of firms, let us choose for baseline parameter values $\alpha = 0.1$, $\Pi^* = 950$ and $K = 400$. In addition, let us assume that the optimal punishment (T^*) lasts for 15 periods. Taking these values into account, Figure 1 summarizes the information contained in (27) and (28) in the form of a diagram, which presents n_{icc} and n_{pc} as functions of the common discount factor (δ).

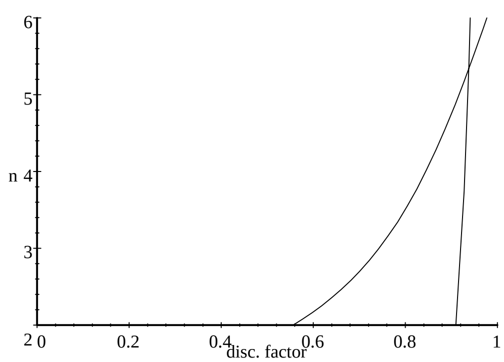

Figure 1. n_{icc} and n_{pc} as functions of δ (Case 1).

The figure shows a dashed line along which the incentive compatibility constraint of the active firms binds. It also shows the set of pairs (δ, n) for which a potential entrant post-entry expected profit is zero. Thus, whatever the point along the dashed line is, an incumbent firm expects the same payoff when it cheats and when it decides to be loyal to the agreement. On the other hand, if we take a point on the solid line, a potential competitor is indifferent between entering the market or not.

Notice that the desirable outcomes, the pairs (δ, n) for which relation (19) holds are represented by the set of points which are simultaneously

above the participation constraint locus and bellow the incentive compatibility constraint dashed line. As can be easily seen from the previous picture, this stability region allows for the possibility of having a free entry trigger strategy equilibrium in which there are 2, 3, 4 or 5 cartel members.

Let us now consider the situation in which incumbent firms decide to allow the new competitors to join the agreement immediately after entry takes place (Case 2). Using eqs. (16), (20), (21) and (22), it turns out that the incentive compatibility constraint and the participation constraint now bind when,

$$n_{icc} = \frac{1-\delta^{1+T^*}}{1-\delta\left(1-\alpha\right)-\alpha\delta^{1+T^*}}, \tag{29}$$

$$n_{pc} = \frac{\delta\left(\Pi^*+K\right)\left(1-\alpha\right)-K\left(1-\alpha\delta^{1+T^*}\right)}{K\left(1-\delta\right)+\alpha K\left(\delta-\delta^{1+T^*}\right)}. \tag{30}$$

Continuing to assume the same baseline values as indicated above for α, Π^*, K and T^*, the relations between n and δ which are implicit in conditions (29) and (30) are graphed in Figure 2.

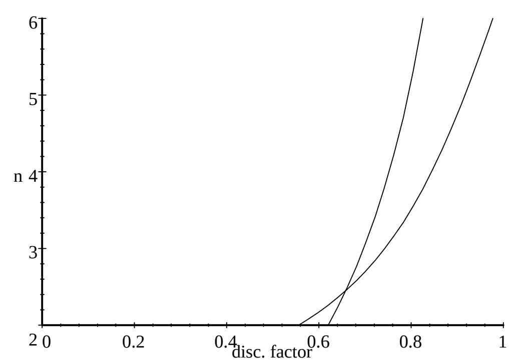

Figure 2. n_{icc} and n_{pc} as functions of δ (Case 2).

Comparing these results with those obtained when analyzing Case 1, it should be first noticed that since we are assuming (as in Case 1) that active firms revert to competitive pricing behavior whenever an internal deviation occurs, the dashed line is unaffected. However, now we are considering accommodation as the post-entry incumbents' response, thus the participation constraint locus shifts up. Because of this upward shift of the solid line, the

area corresponding to a positive expected post-entry profit[20] increases and, as a consequence, the region in which incumbents manage to support a stable collusive outcome substantially reduced.[21] Note, in this direction, that now a stable cartel can be composed by at most two active firms.

This analysis shows that even when strictly positive entry barriers exist, a non-trivial degree of cooperation is easier to support as an equilibrium outcome when the cartel members' norm is reversion to a Bertrand conduct for a while as a response to entry.[22] This finding is particularly relevant to us since, even though it is *ex-ante* optimal for cartel members to threaten entrants with a breaking up of the cartel if entry occurs,[23] accommodating the new railroad firms by allocating them market shares was considered by some authors as the incumbents' best reply to entry during the operation of the JEC.[24] In addition, it should be emphasized that entry, in the equilibria of this model, is inherently a disequilibrium phenomenon. Entry is never expected in equilibrium. When it occurs, the enlarged set of active firms coordinate on a new equilibrium taking for granted that entry will not occur any more and an anticompetitive conduct by the cartel members becomes more difficult to attain.[25] This is important for the interpretation of the empirical results: Since entry is actually observed during the period under study, this means that the data cannot be fully explained by the equilibrium model. It has to be explained with unexpected changes in exogenous variables such as a decrease of the entry sunk costs to enter the railway business.[26]

[20] That is, the area below the participation constraint locus.

[21] This area corresponds to the pairs (δ, n) for which relation (26) holds.

[22] As we have seen, the existence of a pool of potential competitors is a more important constraint on the maintenance of a stable agreement when cartel members decide to accommodate the entrants. The intuition behind this result is just that the anticipation of a tougher price competition in Case 1 makes entry less attractive.

[23] Notice, however, that we are not considering the possibility of "renegotiation" of equilibria. This is certainly an important further development of this study, since, as was stressed by Fudenberg and Tirole (1991), if "players have the opportunity to negotiate anew at the beginning of each period, then equilibria that enforce *good* outcomes by the threat that deviations will trigger a *punishment equilibrium* may be suspect, as a player might deviate and then propose abandoning the punishment equilibrium for another equilibrium in which all players are better off." (p. 175).

[24] As we will explain in further detail in the next section.

[25] That is, as entry occurrs the cartel becomes (internally) less stable. For a formal discussion on this, see Section 2.

[26] If such costs become lower than the critical level indicated in expression (23), the cartel looses its immunity with respect to external defection.

4 The Joint Executive Committee

In this section we will briefly review the history of the Joint Executive Committee railroad cartel in the period between 1880 and 1886.[27]

The JEC was a public and legal agreement[28] formed in April 1879 and involved the railroads in the market. The aim of this cartel was to control the transport of grain, flour and provisions from Chicago to the East Coast. The colluding firms agreed upon a transport price structure and each member of the cartel was allocated a market share. Our attention can be focused on the movements of grain without loss of generality, since the prices for transporting flour and provisions were very closely related to the grain rate.[29]

Two sources of arguments have led us to consider that it is reasonable to accept that the Green and Porter (1984) model fits this specific case. First, prices set by cartel members were not perfectly observable by its rivals.[30] Moreover, variability of aggregate demand was not only related to prices charged by cartel participants but also to some "unpredictable stochastic forces".[31]

Entry occurred twice during the sample period we cover in this article. However, Porter (1983b) states that "bankrupt railroads were relieved by the courts of most of their fixed costs and instructed to cut prices to increase business"(p. 303). This fact led some authors to defend the position that because of the existence of this "no-exit constraint", the incumbent firms' best response to entry was to accommodate entrants, allocating them market shares. Our claim here is that even though entry can lead the incumbent firms to an accommodation strategic behavior, the greater the number of firms in the agreement, the higher will be the probability of future price wars. In other words, we are interested in testing how entry may affect cartel (internal) stability.

[27] A more detailed analysis of the history of the JEC cartel can be found in MacAvoy (1965).

[28] Note that this cartel took place before the Sherman Act (1890).

[29] With respect to this, MacAvoy (1965) pointed out that "it was not possible to isolate grain rates from the rest so that grain agreements could have been broken while agreements on provision and merchandise rates were not." (p. 71).

[30] In this direction , Hajivassiliou (1997, p. 6) remarks that "special shipping rates were sometimes secretly arranged with selected costumers".

[31] Porter (1985, p. 420).

Variable	Description
GR	Grain rate; in dollars per 100 lbs.
TQG	Total quantity of grain shipped (in tons).
Lakes	Dummy variable; =1 if Great Lakes were open to navigation.
PW	Cheating dummy variable; =1 when cheating was reported to have occurred.
N	Number of firms in the cartel.
Firm 1	Grain shipped by the New York Central (in tons).
Firm 2	Grain shipped by the Penn (in tons).
Firm 3	Grain shipped by the Baltimore and Ohio (in tons).
Firm 4	Grain shipped by the Grand Trunk Railway (in tons).
Firm 5	Grain shipped by the Chicago and Atlantic (in tons).
TopDev1	Highest positive deviation from previous average quantity
TopDev2	Highest negative deviation from previous average quantity

Table 1: List of Variables

5 The data

In this section we describe the data used in the econometric models. We deal here with weekly time-series data which was gathered and disseminated to member firms by the JEC.

The data available corresponds to the period which starts at the first week of 1880 and finishes on week 16 in 1886. Within the 328 sample points, five different periods related to changes in the cartel composition can be distinguished. During the first 27 weeks there were 3 firms in the cartel: the New York Central, the Penn and the Baltimore and Ohio. The Grand Trunk Railway entered the cartel in week 28 of 1880. In week 11 of 1883 the New York Central added another line to its network. A fifth firm - the Chicago and Atlantic - entered the cartel in week 26 of 1883. Finally, in week 12 of 1886 this last entrant decided to leave the cartel due to a dispute with a non-JEC railroad (the Erie). A list of variables which will be used in the econometric models is presented in Table 1.[32]

The price variable, GR, is the weekly reported price of grain (in dollars per lbs). This is an index provided by the JEC after pooling all the member firms. The quantity variable, TQG, is the aggregate tonnage of grain

[32]Variables $Topdev1$ and $Topdev2$ are reported in absolute value and measured in tons (times 10^{-3}).

which was shipped by the JEC members in each of the weeks included in the sample period. The Lakes variable is a dummy variable which takes the value one whenever the Great Lakes were open to navigation and steamers could, therefore, compete with the railroads.[33] PW is the "cheating" dummy, and equals one when cheating was reported to have occurred in the Railway Review and is used as a proxy of cartel breakdowns. Variable N reports the number of firms in the agreement and it captures structural changes in the cartel composition due to entry of new firms or departures from the JEC.

The original data set developed by Porter (1983b) is here expanded to include also measures of firms' individual weekly quantities.

The theoretical model presented in sections 2 and 3 assumes imperfect observability of prices charged by opponents; thus the inclusion of this new set of variables is crucial since each firm infers rivals price-cutting from the development of its own demand. In this sense, if someone deviates from the allotted quantities one should expect the deviant firms to sell a suspiciously high quantity, while the nondeviant firms should observe an unusually small demand. Both factors contribute to the occurrence of a price war, due to the beginning of a punishment period. To capture these factors, we have constructed two more variables. The variables are the following:

$$\begin{aligned} Topdev1_t &= \max_{i \in A^t} \left\{ Firm_i^t - \frac{1}{N^{t-1}} \sum_{j \in A^{t-1}} Firm_j^{t-1} \right\} * 10^{-3}, \\ if\ Firm_i^t &> \frac{1}{N^{t-1}} \sum_{j \in A^{t-1}} Firm_j^{t-1} \end{aligned}$$

and,[34]

$$Topdev2_t = \max_{i \in A^t} \left\{ \left| Firm_i^t - \frac{1}{N^{t-1}} \sum_{j \in A^{t-1}} Firm_j^{t-1} \right| \right\} * 10^{-3},$$

[33] Briggs (1996) considers lake steamers as another type of entrant which competed with the cartel for traffic. We do not follow his position. Instead, we consider lake traffic as alternative transportation services through the Great Lakes to ports along the Lake Erie, while the JEC cartel was operating.

[34] Notice that A^t, A^{t-1} and N^{t-1} are part of the notation introduced in Section 3.

Variable	Mean	Standard Deviation	Minimum Value	Maximum Value
GR	.2465	.0665	.125	.4
TQG	25384.4	11632.77	4810	76407
Lakes	.5732	.4954	0	1
PW	.3811	.4864	0	1
N	4.3506	.6273	3	5
Firm 1	13110.6	6302.5	2403	35973
Firm 2	5845.8	3412.5	1292	24258
Firm 3	2200.5	1610.9	189	11277
Firm 4	2843.3	2144.1	0	9592
Firm 5	1384.1	2147.3	0	13732
TopDev1	7.3801	4.6896	.0195	25.1905
TopDev2	4.1460	2.1029	.106	12.961

Table 2: Summary Statistics

$$if\ Firm_i^t \ < \ \frac{1}{N^{t-1}} \sum_{j \in A^{t-1}} Firm_j^{t-1}$$

where $t = 2, ..., 328$, $i, j = 1, ..., 5$ and $Firm_i^t$ is the quantity shipped by the i-th firm in period t.

Since we do not have information about the quantities allotted to cartel members, and thus individual deviations from allocations cannot be computed, we have constructed the variables $Topdev1$ and $Topdev2$ as measures (in absolute value) of the maximum positive and negative firm deviations from the average quantity in the previous period, respectively.

Table 2 presents some summary statistics of the variables.

Remember that one of the main arguments of the theoretical model presented in sections 2 and 3 is that a (tacit) agreement may be more difficult to reach and sustain when the number of firms in the cartel is larger. Using the information provided by variable PW, we constructed some descriptive statistics about the proportion of weeks during which the member firms colluded, controlling for the number of firms in the agreement. Table 3 presents these results and can be seen as a first empirical approach to the main problem we want to address in this paper.[35]

[35] Using the same data set, Briggs (1996) presents a similar table. However, he does not

Number of Firms	Number of Weeks	Collusive Periods (%)
3	27	100 %
4	159	72,33 %
5	142	42,96 %

Table 3: Proportion of Collusive Periods and Cartel Compositon

Note that when only the initial three firms composed the cartel, collusion was sustained during all the first twenty-seven weeks of the sample. However, when four and five firms were in the cartel, collusion was successfully sustained for only 72% and 43% of the correspondent periods, respectively. Therefore, these results, although based on very simple descriptive statistics, reveal that it is reasonable to admit that the entry of additional firms to the cartel affected its profitability and stability.

6 The econometric models

In this section we will present binary choice econometric models and discuss some of their results.

Binary choice models have been widely used in empirical applications to cross-section data. Nevertheless, there are also some time-series applications in which these tools can play a very important role. In this paper we cover one of the latter cases since we are examining the economic decisions that cartel members had to make, in every single period of time, with regard to whether to cooperate or to begin a price war.

The use of binary choice models relies on a strong assumption of independence across observations. In this particular model, we think that it is reasonable to assume that this is the case. Remember that the Green and Porter (1984) model is developed in a context of uncertainty about the level of demand and unobservability of rival's actions. It defends that a price war is triggered whenever a firm observes an unusual drop in its demand. However, the probability of a breakdown of the cartel agreement depends on a "signal-extraction problem"[36] which is faced by each of the cartel participants. In addition, the model assumes that the realizations of demand are

take into account the fact that from week 12 of 1886 on there were only four firms in the cartel, because of the departure of the Chicago and Atlantic.

[36]Tirole (1988, p. 263).

independently and identically distributed (i.i.d.) over time. In those circumstances, each member firm cannot verify if the absence of demand was caused by a realization of a low demand state or by a deviation of someone else in the agreement.

It is, therefore, clear that an equilibrium outcome in which the collusive price is charged forever is not sustainable. Price wars must occur in order for the collusive behavior to be sustained and, indeed, during the history of the JEC, attempts to achieve a price coordination met with phases of aggressive price competition.

The aim of the econometric models presented in this section is to identify the causes of the price wars which occurred in the American railroad cartel during the nineteenth century. Namely, we test if the data is consistent with the use of the trigger strategies of the type described in the Green and Porter (1984) model. Besides, we test the importance of entry effects on the collusive price scheme designed by the JEC.

Let us start by assuming that the indicator of cartel breakdown (PW_t) can be explained according to the following logit model:

$$PW_t = \frac{1}{1+e^{-Z_t}}, \tag{31}$$

where

$$Z_t = \beta_1 + \beta_2 Topdev1_t + \beta_3 Topdev2_t + \beta_4 N_t + \beta_5 Lakes_{t-1} + \beta_6 TQG_{t-1} * (1 - PW_{t-1}) + \varepsilon_t$$

where $t = 2, ..., 328$ and ε is an unobserved disturbance.

Equation (31) represents the (cumulative) logistic distribution function. It shows that PW_t is not only non-linear in the independent variables, but in the $\beta' s$ as well. Therefore, we cannot use the OLS procedure to estimate the parameters. However, using (31) we have that,

$$\frac{PW_t}{1 - PW_t} = e^{Z_t}. \tag{32}$$

Now, $\frac{PW_t}{1-PW_t}$ is simply the *odds ratio* in favor of a cartel breakdown. If we take the natural log of (32), we obtain the model we want to estimate:

$$L_t = \ln\left(\frac{PW_t}{1 - PW_t}\right) = Z_t \tag{33}$$

or equivalently,

$$L_t = \beta_1 + \beta_2 Topdev1_t + \beta_3 Topdev2_t + \beta_4 N_t + \beta_5 Lakes_{t-1} + \beta_6 TQG_{t-1} * (1 - PW_{t-1}) + \varepsilon_t.$$

Notice that L_t, the log of the odds ratio, is not only linear in the independent variables, but linear in the parameters also. The Maximum-likelihood estimation results of this model are reported in the left half of Table 4[37] and the interpretation of the values presented in column (1) is as follows: β_i measures how the log-odds in favor of a cartel breakdown changes as the independent variable associated with β_i changes by one unit, controlling for all other predictors in the model.

We will start with a brief comment about the goodness of fit of the model. First of all, it should be stressed that models with discrete dependent variable are never constructed with the aim of maximizing goodness of fit, but we would like to say a few words about it. Moreover, note that analyzing the Likelihood Ratio Index[38] may be misleading, since on the one hand values between 0 and 1 have no natural interpretation and, on the other, an $LRI = 1$ may be indicative of a flaw in the model. For all these reasons, we should focus our attention on the χ^2 test on the significance of the parameters. Following this line of reasoning, Table 4 shows that the (null) hypothesis that all the independent variables' coefficients are zero is strongly rejected, hence the model in hand can be considered to be statistically significant.

Turning to the interpretation of the findings, it should be noticed first that the variable $Lakes_{t-1}$ is not statistically significant; however this result agrees with the theory since, as stressed by Porter (1985), the opening or closing of the Great Lakes gave rise to demand fluctuations which were anticipated by the incumbent firms and should therefore not affect cartel stability.

In the case of variables $TopDev1_t$ and $TopDev2_t$, the coefficients' signs confirm the predictions of the theoretical model developed in sections 2 and 3. However, it should be noted that variable $TopDev2_t$ has a higher explanatory power[39] and the magnitude of the associated coefficients is completely different: while for an increase of 1 ton (times 10^{-3}) in the maximum positive individual quantity deviation from the average quantity in the previous

[37] Standard errors are reported in parentheses with $p < 0.1 =^{\sim}$, $p < 0.05 =^{**}$, and $p < 0.01 =^{*}$.

[38] $LRI = 1 - \frac{\ln L}{\ln L_0}$, where $\ln L_0$ is the log-likelihood computed with only one constant.

[39] Its *p-value* is less than 0.05, while the *p-value* of variable $TopDev1_t$ belongs to the range $p < 0.1$.

Independent Variable	**Odds Ratio (1)**	**Odds Ratio (2)**
$TopDev1_t$	$1.091^{\sim}$	1.625^{*}
	(0.052)	(0.294)
$(TopDev1_t)^2$		$0.987^{\sim}$
		(0.007)
$TopDev2_t$	1.315^{**}	3.142^{**}
	(0.169)	(1.449)
$(TopDev2_t)^2$		0.939
		(0.039)
$TopDev1_t * TopDev2_t$		$0.955^{\sim}$
		(0.023)
N_t	5.106^{*}	5.631^{*}
	(2.017)	(2.326)
$Lakes_{t-1}$	0.697	0.787
	(0.313)	(0.355)
$TQG_{t-1} * (1 - PW_{t-1})$	0.824^{*}	0.813^{*}
	(0.017)	(0.018)
N. Obs.	327	327
Prob > Chi^2	0.000	0.000
Log Likelihood	−85.431	−80.868
Pseudo R^2	0.607	0.628

Table 4: Estimation Results

period the log-odds in favor of a price war occurrence goes up by about 0.09, the same increase in absolute value of the maximum negative individual quantity deviation from the average quantity in the previous period gives rise to an increase of 0.315 of the log-odds ratio. In other words, what seems to really affect the probability of a cartel breakdown is an unusual drop in the demand faced by some firm(s) in the agreement. Hence, the hypothesis that firms will revert to a price war whenever their own demand falls below a certain threshold (the "inference problem"[40]) is consistent with the data over the whole sample.[41]

In the case of variable N_t, as predicted by Stigler (1964), our results confirm that the greater the number of firms in the cartel, the more difficult it is to support a collusive outcome, that is, the likelihood of a price war occurrence increases as the number of cartel members increases. It thus appears that even though firms that entered the JEC were accommodated by cartel members, entry affected the continuation of the collusive agreement in a negative way.

Finally, we included the variable $TQG_{t-1} * (1 - PW_{t-1})$ to capture the effect of a change in the previous period aggregate quantity, provided that period $t - 1$ was a collusive period. It turns out that, as predicted by the theoretical model under consideration, price wars were more likely to occur the smaller the aggregate quantity sold in the last (collusive) period. Again, this result goes in the direction of the predictions of the theoretical model we are considering here. Remember that a price war can be triggered not only by a deviation of some member(s) of the agreement, but also by a realization of a "low-demand state" in the previous (collusive) period, which is exactly the causal effect we intend to measure with this last variable.

We have also estimated an alternative model which explores the eventual existence of an interaction effect between the variables $TopDev1_t$ and $TopDev2_t$. This model contains, in addition to all the variables considered in the previous model, the cross product between these two variables as well

[40] Porter (1985, p. 417).

[41] Ellison (1994) constructed four different 'market share' variables to control for the same kind of effects that we intend to capture here with the inclusion of the $TopDev1_t$ and $TopDev2_t$ variables. Notice, however, that, in contrast with our approach, none of his econometric models tests *simultaneously* the effect induced by a deviation on the market shares of both the deviant and the nondeviant firms. Moreover, some of his ('market share') variables are not significant, and the signs of some of the estimated coefficients in his regressions are not the expected ones.

as their quadratic main effects.

Column (2) of Table 4 presents the estimation result of this model. Firstly, the quadratic terms, as opposed to the level variables, have an estimated coefficient whose value is lower than one, but only the $(TopDev1_t)^2$ variable is significant at better than 10% level; secondly, there is a substantial and significant first order interaction effect between the two variables. This latter result has a possible economic interpretation. It suggests that the likelihood of a price war is higher when the business stealing effect triggered by a deviation is evenly spread amongst all the nondeviant firms, as opposed to the case in which the deviation harms only the business of a very restricted group (in the limit case, one) of nondeviant firms.

To summarize, the results of both the basic model and its extension which considers interaction effects support the conjectures of the extended version of the Green and Porter (1984) model presented above. In particular, it reveals that the greater the number of firms belonging to the cartel agreement, the less likely it was that firms would succeed in co-ordinating their pricing behavior; thus entry played an important role as a determinant of the likelihood of a cartel breakdown.

7 Conclusion

In this paper we have defined which conditions should be met in order for cartel members to maintain a non-trivial degree of market power in a context of imperfect observability of rivals' behavior and when there existed the threat of entry of new firms. To this end, we have developed an extended version of the Green and Porter (1984) model in which entry is modeled explicitly. In particular, where incumbent firms can respond to entry either by adopting a perfectly competitive behavior for a while or by accommodating the new firms. The model suggests that entry barriers are necessary for an oligopoly with some degree of collusion to prevail. It also shows that even when strictly positive entry barriers exist, the existence of a pool of competitors is a more important constraint on the maintenance of a stable agreement when a potential entrant expects that incumbents will allow him to join the (tacit) agreement.

A natural extension of the model we develop in this paper would examine cases in which the firms have the opportunity to negotiate anew at the beginning of each period of the infinite horizon game. For the purposes of

this paper, however, models of this sort are classified as the subject of future research.

In the empirical part of this study, we focus on time-series data on the

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