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Tacit Collusion under Imperfect Monitoring in the Canadian Manufacturing Industry: An Empirical Study

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Abstract

The paper undertakes a cross-sectoral analysis of a salient empirical implication of the model of tacit collusion advanced by Abreu et al (1986). Specifically, the prevalence of a first order Markovian process for alternating between price wars and collusive periods is assessed by means of non-parametric tests. The analysis focuses on 30 different industries in Canada. The evidence provides weak support for optimal collusion in one industry, which is consistent with the idea that such collusive arrangements are unusual.

JEL-Code: L130, L220, L610.

Keywords: tacit collusion, game theory, Canada, price war.

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1. Introduction

Tacit collusion is an elusive phenomenon and game-theoretical models provide foundations for the presence of multiple pricing regimes [see e.g. Jacquemin and Slade (1992) and Rees (1993) for overviews]. In a related vein, influential models by Green and Porter (1984) and Rotenberg and Saloner (1986) justify price wars as an equilibrium phenomenon for sustaining collusion, which contrasts with Friedman (1971), who postulates an infinite Nash-reversal in the punishment phase of an infinitely-repeated trigger strategy oligopoly game. The nature of price wars is dictated by the choice of punishment, the nature of shocks and the information structure that prevails [see Slade (1990), Lu and Wright (2010) and Knittel and Lepore (2010)].

The main goal of this paper is to provide further empirical evidence on game-theoretical models with embedded price wars. There is precious little empirical evidence of price-wars, and we extend the empirical literature by focusing on a cross-sectoral analysis instead of the typical single market examples found in the literature. We base our analysis on a non-parametric test first developed by Berry and Briggs-BB (1988) to analyse the possibility of an optimal collusive agreement following Abreu, Pearce and Stachetti-APS (1986) and Knittel and Lepore (2010).

Specifically, the present paper considers the test of the Markovian implication of the APS model in the case of homogeneous and more narrowly defined industries within Canada's manufacturing industry. The application, based on monthly data, is appealing as we conceive criteria for defining price wars that rely not only on the price variation of the product but also on price changes related to (weighted) input components, following the rationale that cost asymmetries impact collusion [as in Ivaldi et al, (2003)]. Therefore, in contrast with previous studies, we investigate the consistency with game-theoretical models outside the realm of an explicit cartel, even though we expect an optimal collusive equilibrium to be relatively rare, even if one is generous in defining periods of price war. In particular, we undertake a large scale sectoral investigation and benefit from the availability of relevant disaggregated data in the case of the Canadian manufacturing industry, which allow us to consider more homogeneous and narrowly defined industries. The paper is organized as follows. The second section discusses conceptual aspects related to the APS model and empirical criteria for delineating price wars. The third section presents the basic aspect of the BB test. The fourth section discusses data sources and presents the empirical results of the tests. The fifth section brings some final comments.

2. Tacit collusion and price wars

2.1- Basic conceptual aspects

The model by Abreu et al (1986) extends the influential paper by Green and Porter (1984). A well-known signal extraction problem emerges given independent and identically distributed demand shocks that make deviations from collusion difficult to detect. Beyond the standard concavity assumption on the objective function of the firms, an important assumption of the model is the monotone likelihood ratio property that indicates that the price distribution conditioned on the aggregate output Q_t is such that a smaller price is more likely to be associated with a larger quantity Q_t than a small one [see e.g. Tirole (1988) and Hajivassiliou (1989)]. The hypothesis is important to allow less restrictive behaviors than those prevalent in the Green and Porter model.

The APS model legitimates price wars as an equilibrium phenomenon. In collusive periods firms will produce q^+ and will obtain a payoff of V^+ that refer to the best element on the set of perfect symmetric equilibria. However, if one firm observes a price below the trigger p^+, a punishment phase begins where firms operating with q^{--}, that corresponds to larger output that leads to a smaller payoff given by V^{-}. It refers to the worst element in the set of perfect symmetric equilibria.

Whether an industry remains in the punishment phase or resume the cooperative phase depends on a second trigger p^{-} and if $p > p^{-}$ the industry remains on the punishment phase whereas collusion will be resumed if $p < p^{-}$.

An important implication of the dynamic model of APS is that upon obtaining an indicator variable for prevalence of price wars one can justify a first order Markov process and thus the probability that a state of high profits that prevails in period t depends only on the state at period t_{-1}. Empirical tests on the Markovian hypothesis based on a non-parametric test is found in Berry and Briggs (1988) and encounters further applications in Briggs (1996) and Zeidan and Resende (2010). In the case of tacit collusion it's then crucial to discuss criteria for empirically defining price wars.

2.2- Empirical delineation of price wars

The first wave of the empirical literature that deals with models that result in periods of price wars include Porter (1983), Lee and Porter (1984) and Ellison (1994), who sought to detect consistencies with game-theoretical collusive models, and concentrated on the well-known Joint Executive Committee cartel. Later developments concentrate on other cases, with different methodologies to derive periods of price war, which are usually analysed by observing the market clearing prices throughout a period of time. The main problem in precisely defining the beginning and end of a price war in the present context is in to which extent a price decrease results from an undercutting of prices by firms with the sole intention of punishing deviation from a collusive period or in the other multiple causes that may result in a price decrease, such as fluctuations in demand, changes in productive capacity, costs shocks and firms' strategic behaviour other than punishment for a collusive agreement. In the present case, since the theoretical model of Abreu et al (1986) in which we base our empirical analysis uses informational noise, any one of these reasons can raise the probability of phase transitions initiating a price war, but there is still difficult in translating the necessary indicator of a price war in the model to real data.

The precise definition of a price war, in terms of duration and characteristics, depends on the idiosyncrasies of particular industries and the quality of available data. Morrison and Winston (1996) define price war in the aviation market as the situation in which the prices fall more than 20% in a quarter. The war ends when the prices go up, no matter by how many percentage points. Zhang and Round

(2011) use the same criterion, but they define the end of a price war in the situation in which prices go up by 5%. Ross (1997) uses a method of rank combination, with a statistical test to differentiate price averages between one quarter and the same in the preceding year. Busse (2002) uses a qualitative criterion, appealing to periodical articles and other reports that indicate the existence of a price war. Borenstein and Shepard (1996) analyse accounting data, arguing that a pointer of prices war is disclosed by the price of the companies' shares.

Our sectoral approach uses data on industry costs and market prices, which means we cannot use approaches such as Borenstein and Shepard (1996) because they rely on firm-level data. We do have some qualitative indicators, especially newspaper articles that show periods of price war in some industries in Canada during the period analysed. However, we rely on quantitative data rather than the qualitative approach of Busse (2002). This way, we will use a modified version of the Morrison and Winston (1996) approach, with the recognition that a methodology based solely on the analysis of prices and costs variations can present the problem of specification and diagnosis errors. In particular, we consider observations on net price changes with respect to standard deviation benchmarks to indicate a regime shift - more details are provided in section 4.1.

3. The Berry and Briggs Test

Berry and Briggs (1988) and Briggs (1996) focus on an empirical implication of the APS model that refers to the prevalence of a Markov process for an indicator variable that classify the period as collusive or subject to a price war. The starting point on the nonparametric test proposed by Berry and Briggs (1988) considers a binary series $\{I_t\}_{t=0}^{T}$ that represents a collusive state in period *t* if $I_t = 1$ and a price war if $I_t = 0$. The null hypothesis of the test refers to a Markov process of order *K* that is tested against an alternative hypothesis of a Markov process of order $M > K$. A useful summary of the test procedure is provided by Briggs (1996) and Zeidan and Resende (2010) and the current presentation closely finds the latter and more detailed approach. First, one should divide the series in terms of two sets S_i^M , with i = 0,1, so as to construct a binary indicator variable I_t . In the present application we consider the case of a null hypothesis of a first-order Markov process ($K = 1$) against an alternative hypothesis of a second order process ($M = 2$). In that case, one needs to partition the series in $2^M = 4$ possible histories at (t_{-1}, t_{-2}) as given by *(0,0)*, *(0,1)*, *(1,0)* and *(1,1)*. A first-order Markov process means that state of the indicator variable in period t depends only on the prevailing state at t_{-1} but not t_{-2}. Therefore, conditioning on information available at t_{-2} should not be relevant and conditioned to histories H^M that include the same history for *K* periods, one should have $P(I_t = 1/ H_i^M) = P(I_t = 1/ H_j^M)$ under the null hypothesis.

The indicator variable $I_t \in S_0^M$ can be conceived in terms of independent essays conditioned to a given history. Thus a binomial distribution can be justified upon a Bernoulli distribution in each period and a consistent estimator can be based on the method of moments. Let $\mu_i = \sum_{I_t C S_i^M} I_t / N_i$ denote the proportion of situations where $I_t = 1$ given $I_t \in S_i^M$ and N_i the number of observations in S_i^M . It follows that 4 sub-samples are considered for the test in the case of a first-order Markov setup. The sample mean provides a consistent estimator of the population mean μ^0. Similarly, $v_i = \mu_i(1-\mu_i)$ is a consistent estimator for the population variance v^0, where $\sqrt{N_i}[(\mu_i - \mu_i^0)/\sqrt{v_i}$ converges to a standard normal distribution. In the case of a first-order Markov process, one should impose restrictions that the means are equal for the *M*-histories containing the same *k*-history, with $\boldsymbol{R}$ being a matrix with dimension $2^K(2^{M-K} - 1)$ by 2^M. Specifically, one should consider $\boldsymbol{R}\mu^0 = 0$, where μ^0 denotes the vector of means. Under the null hypothesis $\boldsymbol{R}\mu$ is normally distributed with mean 0 and variance $\boldsymbol{RVR}^T$, in which $\boldsymbol{V} = diag\{v_1/N_1, \ldots v_4/N_4\}$ stands for the variance matrix for μ and $(\boldsymbol{R}\mu)^T(\boldsymbol{RVR}')^{-1}(\boldsymbol{R}\mu)$ follows a chi-square distribution with parameter given by the number of restrictions. On our present application we have $K=1$ and $M=2$ and therefore the restriction matrix has two rows that are respectively given by $[1\ -1\ 0\ 0]$ and $[0\ 0\ 1\ -1]$. In fact, they impose the restriction that for a common history at t_{-1}, one should have equal means independently of the history at t_{-2} such that $\mu_1 = \mu_2$ and $\mu_3 = \mu_4$. The test statistic therefore follows a χ^2 under the null hypothesis of a first-order Markov process against a second-order alternative.

4. Empirical Analysis

4.1- Data Construction

The paper relies on monthly data for the manufacturing industry in Canada available from Canada's national statistical agency (http://www.statcan.gc.ca). The sectoral data is available at the 5 and 6 digits level in terms of North American Classification System-NAICS of 2002. We considered changes in prices to devise criteria for defining price wars. Specifically, a proxy for net price changes was considered as follows:

$$\Delta NP_i = \Delta P_i - \sum_{j=1}^{J} w_{ij} \ \Delta IP_j \qquad (1)$$

where $\Delta P_{iy} = (ln\ P_{it} - ln\ P_{i,t-1})*100$ and $\Delta IP_{it} = (ln\ IP_{it} - ln\ IP_{i,t-1})*100$. We are considering, therefore, changes in prices the price of product net of weighted changes in the main input prices. Data were sourced from CANSIM Statistics Canada, using 60 of the 3206 tables contained in the database[1]. The adopted criterion for inputs considers the J items that comprise at least 80% of the costs. The weight refers to the average cost share, since the cost shares show very little variation during the period analyzed. The sample used in the study referred to monthly data along the 1992-1/2009-3 period.

The APS model refers to homogeneous products and thus it was important to select more homogenous and narrowly defined industries, what led to an initial selection of 30 sectors. In the present application we first consider a parsimonious criterion for identifying price wars. Specifically, we consider that a price war has started if a reduction of at least two standard deviations has taken place in period relatively to period t_{-1} whereas we assume that the collusive phase has been

[1] Examples include Table 281-0035 - Average hourly earnings for salaried employees (paid a fixed salary) (SEPH), including overtime, unadjusted for seasonal variation, for selected industries classified using the North American Industry Classification System (NAICS), monthly; Table 329-0044 - Industry price indexes for primary metal products and metal fabricating products, monthly (index, 1997=100), and Table 329-0046 - Industry price indexes for electrical and communication products, non-metallic mineral products, petroleum and coal products, monthly (index, 1997=100)

resumed if one observes an increase of one standard deviation. The criterion would be even more appealing in the case of normality, though the assumption of normality for net price changes was untenable in 26 out of the 30 sectors as indicated by the Shapiro-Wilk test.

The summary statistics and related Shapiro-Wilk tests are reported in table 1.

INSERT TABLE 1 AROUND HERE

It is important to emphasize that optimal collusion equilibria are likely to be a rare phenomenon and we are yet proposing a simple criterion for defining a price war that will generate the indicator variable used for testing for the Markovian implication of the APS model. In fact, ideally we would prefer weekly data as the available monthly data can mask part of the price variation. Even so our conservative approach provides more confidence for favourable results that might emerge from the tests.

4,2- Empirical Results

The results of the tests for the selected industries are presented in table 2

INSERT TABLE 2 AROUND HERE

The evidence taking as reference a 5% significance level does not favour the non-rejection of the hypothesis of a first-order Markov for the totality of considered sectors. However, marginal evidence consistent with a first-order Markov process emerges in the case of plastic bottles (p=value of 0.086).

Finally, it is worth mentioning that we considered a robustness check by focusing on gross instead of net price changes. The evidence thus obtained was not consistent with a first-order Markov process in the totality of sectors and further corroborates the notion that collusive equilibria along the lines of the APS are likely to be uncommon.

5. Final Comments

The paper aimed at providing a large scale sectoral investigation of the Markovian implication for a price war indicator under the Abreu et al (1986) tacit collusion model. Detailed monthly data on the Canadian manufacturing industry allowed us to undertake the analysis at disaggregated and narrowly defined industries. Moreover, the availability of input cost information was instrumental for defining and implementing a price war criterion that is the basis of the test.

The evidence indicated a marginal support for the Markovian hypothesis only in the case of the plastic bottle sector. There is some anecdotal on occasional prevalence of price wars in that particular sector [see, for instance, Bauerlein, 2009, writing for the Wall Street Journal]. Evidence, even marginal, of optimal collusion, should be an important tool for market regulators. In the absence of explicit collusion or of the so-called “smoking gun” indirect inferences are worth being considered.

Nevertheless, it becomes clear that more detailed data is still required and would include details on the informational structure prevailing in different industries and more specific firm-level information.

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Table 1

Summary statistics

Sector	Mean	Std. Dev.	Min	Max	W	p-value
Flour milling (31121)	-0.0001	0.0163	-0.0539	0.0570	0.9726	0.0005
Vegetable fat and oil (31122)	0.0006	0.0235	-0.0758	0.0763	0.9934	0.4899
Sugar manufacturing (31131)	0.0026	0.0172	-0.0462	0.0698	0.9713	0.0003
Pulp mills (32211)	0.0008	0.0324	-0.1440	0.0857	0.9545	0.0000
Paper mills (322121)	0.0006	0.0180	-0.0412	0.0944	0.9540	0.0000
Newsprint mills (322122)	0.0007	0.0219	-0.0579	0.1087	0.9637	0.0000
Paperboard mills (32213)	0.0009	0.0181	-0.0612	0.0798	0.9095	0.0000
Paperboard container (32221)	0.0007	0.0120	-0.0405	0.0374	0.9724	0.0004
Paper bag and coated (32222)	0.0001	0.0108	-0.0433	0.0423	0.9694	0.0002
Synthetic dye (32513)	-0.0014	0.0231	-0.0604	0.0981	0.9785	0.0030
Resin, synthetic rubber (32521)	-0.0009	0.0136	-0.0415	0.0522	0.9832	0.0145
Fertilizer manufact (32531)	0.0041	0.0300	-0.1424	0.1104	0.9242	0.0000
Pesticide and other agr (32532)	-0.0014	0.0159	-0.0566	0.0504	0.9660	0.0001
Plastic pipe,pipe fitting (32612)	0.0003	0.0139	-0.0444	0.0631	0.9805	0.0057
Laminated plastic plate (32613)	0.0003	0.0103	-0.0358	0.0321	0.9846	0.0236
Polystyrene, urethane (32614)	0.0003	0.0113	-0.0573	0.0339	0.9571	0.0000
Plastic bottle (32616)	0.0000	0.0099	-0.0285	0.0307	0.9936	0.5153
Veneer Plywood (321211)	0.0001	0.0328	-0.1376	0.1389	0.9511	0.0000
Wood window (321911)	-0.0007	0.0142	-0.0378	0.0456	0.9914	0.2625
Wood container (32192)	0.0007	0.0150	-0.0494	0.0397	0.9909	0.2216
Glass product manuf (32721)	-0.0007	0.0183	-0.0844	0.0697	0.9086	0.0000
Cement manufacturing (32731)	0.0003	0.0153	-0.0694	0.0592	0.8934	0.0000
Ready-mix concrete (32732)	-0.0001	0.0154	-0.0702	0.0473	0.9139	0.0000
Concrete product (32733)	-0.0004	0.0162	-0.0693	0.0493	0.9359	0.0000
Lime Manufacturing (32741)	0.0014	0.0176	-0.0794	0.0605	0.9100	0.0000
Aluminum production (33131)	-0.0019	0.0460	-0.1364	0.1651	0.9808	0.0063
Metal tank (33242)	0.0007	0.0149	-0.0491	0.0615	0.9475	0.0000
Power, distribution manuf. (335311)	0.0014	0.0194	-0.0561	0.0814	0.9464	0.0000
Battery manufacturing (33591)	0.0000	0.0123	-0.0654	0.0716	0.8935	0.0000
Communic and energy wire (33592)	0.0000	0.0148	-0.0626	0.0606	0.9383	0.0000

Note: the sectors are listed with the NAICS classification codes in parentheses

Table 2

Non-parametric tests for first-order Markov process for the indicator variable

Sector	History (t-1,t-2)												Test statistic	p-value
	(1,1)			(1,0)			(0,1)			(0,0)				
	µ	Var	N	µ	Var	N	µ	Var	N	µ	Var	N		
Flour milling (31121)	0.964	0.035	165	0.166	0.138	6	1	0	6	0.179	0.147	28	155.990	0.000
Sugar manufacturing (31131)	0.976	0.023	167	0	0	4	1	0	4	0.133	0.116	30	7.00E+03	0.000
Pulp mills (32211)	0.981	0.019	159	0	0	3	1	0	3	0.075	0.069	40	8.76E+03	0.000
Paper mills (322121)	0.976	0.024	166	0	0	4	1	0	4	0.129	0.112	31	6.93E+03	0.000
Newsprint mills (322122)	0.976	0.024	166	0	0	4	1	0	4	0.129	0.112	31	6.93E+03	0.000
Paperboard mills (32213)	0.989	0.011	174	0	0	2	1	0	2	0.074	0.069	27	1.53E+04	0.000
Paperboard container (32221)	0.99	0.01	193	0	0	2	1	0	1	0.111	0.099	9	1.85E+04	0.000
Paper bag and coated (32222)	0.964	0.035	167	0.5	0.5	6	1	0	6	0.115	0.102	26	201.9113	0.000
Synthetic dye (32513)	0.976	0.023	169	0.2	0.4	5	0.8	0.16	5	0.154	0.13	26	18.803	0.000
Resin, synthetic rubber (32521)	0.965	0.034	142	0	0	5	1	0	5	0.094	0.085	53	4.40E+03	0.000
Fertilizer manufact (32531)	0.969	0.03	161	0.4	0.489	5	1	0	5	0.088	0.08	34	354.631	0.000
Pesticide and other agr (32532)	0.972	0.027	179	0	0	5	1	0	5	0.313	0.215	16	6.26E+03	0.000
Plastic pipe,pipe fitting (32612)	0.977	0.023	172	0.25	0.433	4	1	0	4	0.12	0.106	25	188.206	0.000
Laminated plastic plate (32613)	0.973	0.027	183	0.5	0.5	4	1	0	4	0.143	0.122	14	85.785	0.000
Polystyrene, urethane (32614)	0.968	0.031	190	0.6	0.489	5	1	0	5	0.4	0.24	5	8.883	0.003
Plastic bottle (32616)	0.985	0.015	199	0.5	0.5	2	1	0	2	0.5	0.25	2	2.940	0.086
Veneer Plywood (321211)	0.985	0.015	196	0	0	3	1	0	3	1	0	3	Sing matrix	-
Glass product manuf (32721)	0.953	0.045	149	0.333	0.471	9	0.777	0.172	9	0.158	0.133	38	24.215	0.000

Cement manufacturing (32731)	**0.955**	**0.043**	**178**	**0.5**	**0.5**	**8**	**1**	**0**	**8**	**0.364**	**0.231**	**11**	**22.550**	**0.000**
Ready-mix concrete (32732)	**0.967**	**0.032**	**183**	**0.571**	**0.494**	**7**	**0.857**	**0.122**	**7**	**0.375**	**0.234**	**8**	**7.179**	**0.007**
Concrete product (32733)	**0.96**	**0.038**	**176**	**0.571**	**0.494**	**7**	**1**	**0**	**7**	**0.2**	**0.16**	**15**	**62.132**	**0.000**
Lime Manufacturing (32741)	**0.972**	**0.028**	**176**	**0.428**	**0.494**	**7**	**0.714**	**0.204**	**7**	**0.267**	**0.196**	**15**	**8.9106**	**0.003**
Aluminum production (33131)	**0.978**	**0.021**	**182**	**0**	**0**	**4**	**1**	**0**	**3**	**0.25**	**0.188**	**16**	**8.15E+03**	**0.000**
Metal tank (33242)	**0.963**	**0.035**	**164**	**0.428**	**0.494**	**7**	**0.857**	**0.122**	**7**	**0.148**	**0.126**	**27**	**26.7109**	**0.000**
Power, distribution manuf. (335311)	**0.978**	**0.021**	**186**	**0**	**0**	**3**	**1**	**0**	**3**	**0.231**	**0.178**	**13**	**8.51E+03**	**0.000**
Battery manufacturing (33591)	**0.985**	**0.015**	**194**	**0**	**0**	**2**	**1**	**0**	**2**	**0.286**	**0.204**	**7**	**1.24E+04**	**0.000**
Communic and energy wire (33592)	**0.973**	**0.027**	**182**	**0.25**	**0.433**	**4**	**1**	**0**	**4**	**0.2**	**0.16**	**15**	**64.816**	**0.000**

Note: the sectors are listed with the NAICS classification codes in parentheses