Price Leadership and Uncertainty about Future Costs*

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Abstract

Does uncertainty about future wholesale prices facilitate coordination? We address this question in the context of the Chilean retail-gasoline industry, where a policy intervention (Mepco) limited the week-to-week variation of wholesale prices. First, we show that Mepco caused a decrease in retail-gasoline margins in Chile. Second, using price leadership intensity as a proxy for the strength of coordination in a market, we show that margins decreased more in local markets with higher leadership intensity. We rationalize these findings in a repeated-game framework, showing that a reduction in uncertainty about future wholesale prices hinders price coordination incentives.

JEL codes: D22, D43, D83, L12, L41

Keywords: Price leadership, wholesale price uncertainty, tacit coordination, retail gasoline

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1 Introduction

Uncertainty about market conditions has been recognized by the antitrust literature as one of the factors that could prompt firms to break coordination (e.g., Green and Porter, 1984; Rotemberg and Saloner, 1986). In many industries, *future wholesale prices* represent a substantial source of market uncertainty. In the retail-gasoline industry, for example, retailers are exposed to the high volatility of future wholesale prices generated by various shocks affecting upstream crude-oil producers, oil refineries, or gasoline distributors. Other noteworthy features of the retail-gasoline industry are that differentiated gasoline retailers sell homogeneous products and adjust their prices frequently in response to changes in wholesale prices. Strategic interactions under these circumstances can be conducive to coordination schemes. This is reflected by recent antitrust enforcement against gasoline retailers (e.g., Clark and Houde, 2013, 2014).

In this paper, we present empirical evidence from the Chilean retail-gasoline industry to shed light on the relationship between uncertainty about future wholesale prices and the incentive to sustain tacit coordination. Unfolding this relationship is challenging because we do not observe the extent of firms' coordination. For this reason, we exploit the heterogeneity in *price leadership* across markets in the Chilean retail-gasoline industry as a proxy for the strength of coordination. Price leadership has been recognized as a plausible device to sustain tacit coordination, at least since the work of Stigler (1947), and recently by Miller, Sheu and Weinberg (2018); Byrne and de Roos (2019); McNamara (2019), among others.

We present a repeated-game framework to examine how uncertainty about future wholesale prices affects the incentives to sustain tacit coordination. Informed by specific features of the Chilean gasoline industry, we assume that firms observe a common marginal cost before choosing their prices, which are publicly observable.[1] In this context, suppose that firms play trigger strategies: they coordinate at supracompetitive prices and punish a deviation by setting price equal to marginal cost forever (i.e., static Nash prices). Our main result is easier to understand assuming the most-collusive agreement, although our results do not rely on this assumption

[1]Most of the gasoline sold by retailers in Chile originates from the state-owned company ENAP, which supplies about 90 percent of the Chilean demand for fuel products through a non-discriminatory pricing policy. Also, retail-gasoline prices are observable: since 2012, Chile mandates their public disclosure in real-time on a website.

(see Section 3). The intuition of our main result originates from the observation that, for any downward sloping demand, monopoly profits are convex in the marginal cost.[2] The convexity of the monopoly profit in the marginal cost implies that the gain from coordination—defined as the difference between the expected continuation payoff of coordination minus the expected continuation payoff of a deviation—is also convex, i.e., a "risk-loving" feature. This means that decreasing the variance of future wholesale prices *decreases* the gain from coordination.[3] Based on this insight, we propose two hypotheses on the effect of a reduction in the uncertainty of future wholesale prices on margins: (1) margins decrease after a reduction in the volatility of future wholesale prices; and (2) this reduction is larger in markets that experience a higher degree of coordination.

We empirically test these hypotheses by exploiting the implementation, in August of 2014, of a policy (called "Mepco") designed to reduce the volatility of wholesale prices in retail gasoline.[4] To identify the effect of Mepco, we need to control for the effects of other shocks that could be confounded with those of Mepco, such as the worldwide decrease in oil prices during the second semester of 2014. We do this by implementing a differences-in-differences research design using the universe of French gas stations as a control for Chilean gas stations, between 2013 and 2015. We use French retail-gasoline industry as a control because, as Montag and Winter (2020) argue, there were no country-specific policy changes that disrupted retail-gasoline markets in France during our sample period. Also, we are aware of only a handful of countries that tracked prices during the window of time of our analysis; of those countries, France possesses the best data for our analysis.[5] Finally, in Section 4, we show that before the implementation of Mepco, the trend of retail-gasoline margins in France and Chile are remarkably similar, suggesting that French stations are a valid control group for Chilean stations.

[2]Monopolist profits $\pi(p,c) = (p-c)D(p)$ are maximized at the monopoly price $p^m(c)$. Let $g(c) \equiv \pi(p^m(c),c)$. We have $g''(c) = -D'(p^m(c))\frac{dp^m(c)}{dc} > 0$, so monopoly profits are convex in the marginal cost.

[3]Online Appendix A presents a number of more involved versions of this simple setting that support the same conclusion. These extensions are analytically intractable, but through simulations we show that reducing the volatility of future wholesale prices reduces firms' incentives to sustain tacit coordination.

[4]Mepco limits wholesale price changes in two consecutive weeks to 5 Chilean pesos per liter (3 cents per gallon). In Section 2, we explain Mepco in detail.

[5]We provide more details in Section 4.1.

We find that, while margins in Chile and France tracked each other well before the implementation of Mepco in Chile, margins became negatively correlated afterward: margins in France increased and margins in Chile decreased. The difference-in-difference estimates show that, after the implementation of Mepco, margins of Chilean gasoline stations decreased by about 45 percent relative to the margins of French gasoline stations.

To test our second hypothesis—that lower volatility of future wholesale prices reduces margins more in markets with a higher degree of coordination—we exploit three features of the Chilean gasoline industry. First, our data include *all* price changes made by all stations in the country since 2012. Second, every Wednesday, the state-owned company ENAP *publicly* announces the wholesale price of gasoline, which *remains fixed* for one week until the following Wednesday. Third, and in sharp contrast with other retail-gasoline markets, we find that 89 percent of Chilean gas stations change their prices only *once* per week, usually within one day from ENAP's announcement. These features, and the richness of our data, enable us to work with a well-defined time period (the week that takes place between two consecutive announcements by ENAP) and to identify the order in which gas stations change their retail prices in response to a change in wholesale prices. Capitalizing on these features, we define a *price leader* in each local market as the gas station that initiates price changes most frequently in that market throughout our sample period.

After we identify one leader in each market, we show that there is heterogeneity across markets in the *frequency* with which price leaders initiate price changes over the sample period. For instance, while in some markets the price leader initiates 90 percent of all price changes, in other markets, with the same market structure, the price leader initiates 50 percent of all price changes. For this reason, we propose a market-specific measure of *leadership intensity* that captures this heterogeneity. To define this measure, we first compute the percentage of weeks that each gas station initiates price changes in its market throughout our sample. We then rank gas stations by decreasing order according to this frequency. Using this ranking, we define the leadership intensity in a market as the percentage point difference between the frequencies of the gas stations ranked first and second. For example, consider a market with 3 gas stations where gas station A initiated 55 percent of the price changes, gas station B initiated 25 percent of the price changes, and gas station C initiated the remaining 20 percent of the price changes. In this market, gas station A is the leader (because it is the most frequent station to initiate price changes) and the market's leadership intensity is $55 - 25 = 30$ percentage points. According to this definition, a market with high leadership intensity is one where no firm in that market initiates price changes nearly as often as the price leader. From a descriptive perspective, and exploiting variation in leadership intensity across markets that have the same market structure, we find that leadership intensity is positively correlated with with higher margins, fewer stations undercutting the price leader, and faster price adjustments following changes in wholesale prices.

Using leadership intensity as a proxy for the strength of coordination in a local market, we implement a differences-in-differences research design to exploit within-market variation in outcomes across markets that are heterogeneous in leadership intensity. We find that after the introduction of Mepco, margins decreased more in markets with higher leadership intensity. For example, we find that margins decreased by 0.6 percent in markets located at the 5th percentile of the distribution of leadership intensity, whereas margins decreased by 5.5 percent in markets located at the 95th percentile. Furthermore, after the implementation of Mepco, we find that the duration of price adjustments increased and that more stations set prices below the market leader. These findings are stronger in markets with higher leadership intensity.

After showing how the reduction in uncertainty in wholesale prices caused by Mepco impacted local market outcomes, we turn to examining how these changes took place in the weeks around the implementation of Mepco. We take this approach to examine whether Mepco had an immediate effect, taking into account that when Mepco was implemented, the level of wholesale prices was stable. Therefore, in the short-run, Mepco could only affect outcomes through its impact on future wholesale-price uncertainty.

We find several pieces of evidence suggesting that Mepco disrupted the effectiveness of price leaders as a tacit coordination device in the short run, specially in those markets with high leadership intensity. Specifically, we find that after the implementation of Mepco, market outcomes changed, relative to the five previous weeks, in a way that is consistent with Mepco disrupting tacit coordination. First, the probability of price matching in a market decreased, and the number of the stations undercutting the price set by the leader increased. Second, the length of time between the first and the last price change (length of the pricing cycle) increased. Third, the range of retail prices increased. Further, these effects were stronger in markets with higher leadership intensity. This evidence is consistent with Mepco disrupting tacit coordination. Following this first week after the implementation of Mepco, firms returned to the same pre-Mepco levels of price matching, price range, and price undercutting. However, margins decreased relative to the period before the implementation of Mepco. All these finding taken together suggest that price leadership may have become a less effective coordination device after the implementation of Mepco.

Related Literature.

Our paper contributes to the literature that examines how uncertainty affects the incentives to sustain tacit coordination. Green and Porter (1984) study a model where demand fluctuations are not directly observed by firms when setting their prices. These unobservable shocks can trigger a punishment when the realized level of demand is low, even if no firm has defected. Based on this framework, O'Connor and Wilson (2019) study whether better predictive algorithms impact coordination incentives. In our context there is no uncertainty about current market conditions, but instead about future market conditions—i.e., in our setting, firms observe the wholesale price in the current period before making pricing decisions. Rotemberg and Saloner (1986) explore the effect of the business cycle on the incentives to sustain coordination when demand is subject to i.i.d. shocks. They find that firms have less incentives to sustain coordination when the market demand is high (i.e., during booms). Haltiwanger and Harrington Jr (1991) relax the assumption of i.i.d. shocks and show that the incentive to sustain coordination is the lowest when demand is falling (rather than when the level of demand is high). Similar to these papers, we focus on how a form of market uncertainty affects coordination incentives. As in Haltiwanger and Harrington Jr (1991) and in contrast to Rotemberg and Saloner (1986), we discuss the implications of serial correlation and the incentives to sustain coordination conditional on the current and future levels of costs. We find that the incentive to sustain coordination may not be the highest when markets conditions are favorable, but instead it depends on how uncertainty is generated by the underlying stochastic process. More importantly, our focus is on how the incentives to sustain coordination are affected by a *reduction* of future uncertainty, which is not the focus of any of these papers.

Our work is also related to Borenstein and Shepard (1996), who find that collusive margins will be *larger* when wholesale prices are expected to decrease. We find the opposite: margins in Chile fell even though marginal costs were (likely) expected to decrease. In contrast to Borenstein and Shepard, we explain this empirical finding as caused by the reduction in the variance of future wholesale prices caused by the implementation of Mepco, thus impacting the firms' coordination incentives.

The empirical literature on price leadership and market coordination is extensive and has been reinvigorated in the last few years. Busse (2000) examines how multi-market contact in the U.S. telecommunications industry facilitates the implementation price leadership. Kauffman and Wood (2007) examine the relationship between price leadership and tacit collusion in the music-CD and books industry. In their data, they find price rigidity and leader-follower behavior, which they interpret as evidence suggesting tacit collusion. Miller, Sheu and Weinberg (2018) examine how prices announced by a market leader serve as focal points that facilitate coordination. Lewis (2012) and Byrne and de Roos (2019) explain in detail how price leaders may facilitate coordination in retail-gasoline markets. Alé-Chilet (2018) examines the implementation of a cartel in the Chilean retail-pharmacy industry. In this case, the cartel agreed on a coordination mechanism in which the smallest member of the cartel initiated price changes, in order to reduce the incentives of other cartel members to deviate from the collusive agreement. Alé-Chilet finds that the implementation of this collusive scheme resulted in price increases of up to 132 percent. Finally, McNamara (2019) examines how a small electricity generator in Texas became a price leader through engaging in costly signaling, much in the spirit of Byrne and de Roos (2019). McNamara finds that through tacit coordination, the leader and the follower were able to increase prices by 5 percent on average, though the largest price increases reached 1,500 percent. Other papers have describe other tacit coordination mechanisms that do not involve price leaders. For instance, Harrington Jr and Ye (2018) develop a theory of collusion in which firms coordinate on costs announcements, instead of coordinating on prices. These announcements influence the prices thatmarket buyers propose to sellers, which in equilibrium are higher than competitive prices. We contribute to this literature by providing evidence on the incentives to sustain tacit coordination through price leaders.

Finally, our work also relates to the broader literature examining different features of gasoline markets including the work of Lewis (2008) (price dispersion and local competition), Deltas (2008) (asymmetric response to changes in wholesale price), Lewis and Noel (2011) (Edgeworth cycles), Lewis (2011*b*) (search), and Clark and Houde (2013, 2014) (collusion). Montag and Winter (2020) and Luco (2019) examine how price-transparency policies impacted competition in the German and Chilean retail-gasoline industry, respectively. For a survey of the empirical literature on retail-gasoline, see Eckert (2013).

2 Market and Policy Reform

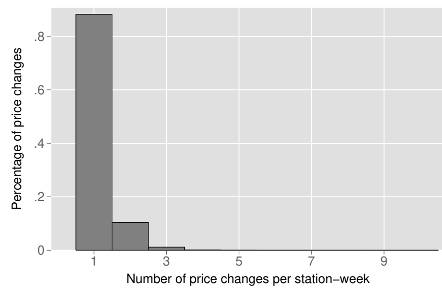
2.1 Industry Background and Policy Intervention

Chile is a net importer of oil. Over the last decade, around 90 percent of the Chilean demand for fuel products has been supplied by the state-owned refinery ENAP. Every Wednesday, at 7pm, ENAP *publicly* announces changes in wholesale prices for gasoline. These changes become effective on Wednesday at midnight and the new wholesale prices *remain fixed* until the following Wednesday. The majority of gas stations follow the single change in wholesale prices every week: In our data, 89 percent of the gas stations change their prices *once per week*, and 9.7 percent change prices twice (see Figure 1a). Further, 82 percent of the price changes take place on Thursday (see Figure 1b), the day when ENAP's announcement materializes. These features allows us to work with a well-defined time period—the week that takes place between two announcements—and to cleanly identify the timing of price changes in any given week. These features are an advantage relative to other settings where it is not possible to identify the station that initiate price changes, or where there are heterogeneous wholesale gasoline suppliers, or where prices are adjusted frequently (even within a day) and Edgeworth cycles emerge.[6]

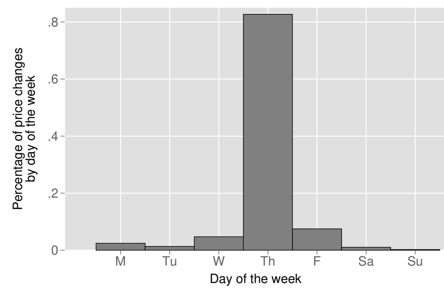
The Chilean retail-gasoline market is dominated by three brands: Copec, Shell, and Petrobras

[6] An "Edgeworth cycle" is a pricing cycle that begins with a price increase followed by a series of small price cuts until one firm restarts the cycle with a large price increase, or either wholesale price changes are not observed or. Maskin and Tirole (1988) introduce a theory of dynamic competition in homogeneous goods markets consistent with Edgeworth cycles. This theory has found empirical support in Noel (2007*a*,*b*) and Lewis (2012), among others.

FIGURE 1: Price changes by station–week and day of the week



(a) Price changes by station–weeks



(b) Price changes by day of the week

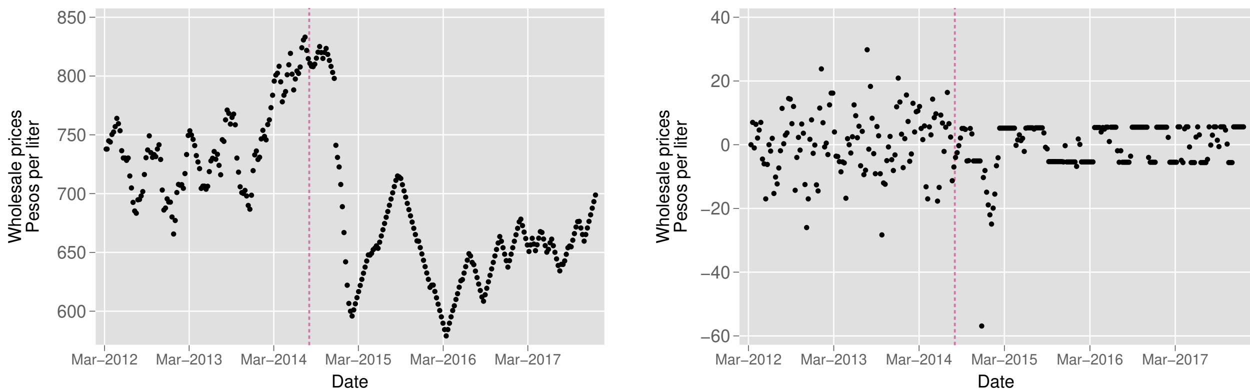
Note: Distribution of price changes by station–week and day of the week over the sample period. Most gas stations change only once per week on Thursdays.

with 41, 27, and 18 percent of the gas stations in the country. Independent retailers and local chains account for the remaining 14 percent of the stations. Some stations are owned by a brand, and it is the brand itself that decides retail prices. Other stations are independently operated (i.e., they have freedom to set the retail markets), and buy their fuel product exclusively from one of the brands. The remaining stations are unbranded or belong to local chains, and they buy fuel product from any supplier.

On August 1st, 2014, the Chilean government implemented a mechanism to stabilize gasoline prices (called "Mepco"). Mepco operates by manipulating gasoline-specific taxes on a week-to-week basis, to limit the variation of wholesale-price changes in two consecutive weeks. In practice, this reform bounds the variation of wholesale prices by accumulating wholesale-price changes that are larger than the policy limit. These accumulated changes are passed to wholesale prices in subsequent weeks, when the concurrent change is smaller than the policy limit. Finally, Mepco went through a series of adjustments between its introduction and January 2015. Since then, Mepco has operated without additional adjustments.

Figure 2 plots both the level of wholesale prices for each week and the weekly change in wholesale prices, identifying with a vertical line the date of Mepco's implementation. The figure shows that the introduction of Mepco reduced the variance in wholesale price changes: Mepco bounded the week-to-week variation by (approximately) 3 cents of a dollar per gallon, with some exceptions during the adjustment period. In addition to this, during the second semester of 2014, world oil prices decreased significantly. Finally, the Chilean government made a one-time adjustment to the parameters of Mepco that resulted in a 60 pesos decreases in wholesale prices in November of 2014.

Figure 2: Wholesale prices over time



(a) Wholesale prices

(b) Weekly change in wholesale prices

Note: Panel (a) presents the evolution of wholesale prices over time. Panel (b) presents the evolution of the weekly changes in wholesale prices. Both figure identify the introduction of Mepco with a vertical dashed line.

2.2 Data

Our dataset on real-time price changes was provided by the Chilean National Energy Commission (CNE) and contains all the retail price changes reported on the government website, as well as station characteristics including brand, address, latitude, and longitude. These data were generated as the result of a policy intervention that took place in 2012 and mandated all gas stations in the country to post their retail prices on a government website. Under this policy, gas stations have 15 minutes to update their prices online after they have changed them at the pump.[7] We augment these data by manually collecting all the announcements of wholesale

[7] The government enforces the policy by visiting and sanctioning gas stations misreporting prices.

prices made by ENAP since 2012.

An observation in our data is a price/time/station combination. Our dataset contains 432,113 observations, corresponding to 1,481 gas stations that sell gasoline of 93 octanes over 300 weeks-market.[8] We report summary statistics of our data in Online Appendix B. The table shows that, during our sample period, the average margin of a station was 76.41 Chilean pesos per liter (henceforth "pesos"), the average range of margins in a market was 7.5 pesos, that price matching was not uncommon, and that, on average, it took 30 hours for all stations in a market to update their prices after the first retail-price change took place.

We also obtained ownership information for 69 percent of the gas stations in our sample.[9] Among the stations for which we have ownership data, 79 percent are operated by single-station owners and 14.4 percent are operated by two-station owners. Of the remainder 6.6 percent, 5.4 percent correspond to owners who operate three or four stations. Finally, only 1.2 percent of the stations for which we have access to ownership information, are registered as being operated by individuals or companies who own five or more stations. Hence, though multi-station ownership takes place in our data, relatively few stations fall in this category.

Finally, in Section 4.1 we use data from the French retail-gasoline industry as a control group for the Chilean retail-gasoline industry. These data are part of the data used by Montag and Winter (2020), who generously shared it with us.

2.3 Market definition

A common strategy used in the literature to define local markets, when quantity or volume data are not available, consists in grouping stations within a fixed radius around each of them. This radius could be measured by linear distance, driving distance, or driving time (e.g., Hastings 2004; Lewis 2008; Chandra and Tappata 2011; Lewis 2011*a*; Luco 2019). This approach is easy

[8] In Chile, retailers sell gasoline of 93, 95, and 97 octanes. More than half of all the gasoline sales are 93 octanes. See https://www.cne.cl/wp-content/uploads/2015/05/Venta_mensual_combustibles-20-12-2018.xls.

[9] We cannot access the records for the remainder 31 percent of stations because these records are kept in physical copies located at regional offices spread across the country, and not in a centralized repository.

to implement and recognizes that competition is mostly local, but it may count the same gas station multiple times, specially in areas with high density of stations. Another approach to define local markets is to partition the set of gas stations, allocating each station into a single market. We follow this approach and create a partition based on a clustering algorithm, as in Carranza, Clark and Houde (2015).[10] We implement our clustering algorithm using the driving time between pairs of stations. This definition of local markets takes into account traffic patterns that are likely to impact a consumer's decision of which station to visit. Online Appendix C presents an in-depth explanation of the algorithm.

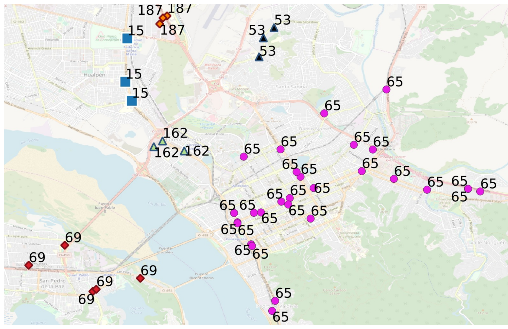
Figure 3 presents examples of local markets in two highly populated cities in Chile. Figure 3a shows that the algorithm identified six markets in Concepción and the surrounding areas. Notice that most of the stations in these local markets are connected to each other through some of the main avenues in the city, ensuring that the driving time between them remains relatively low. Figure 3b shows the markets identified by the algorithm in Puerto Montt. In this case, there are three local markets in the city (labeled 24, 46, and 168), plus one additional local market along the highways that connect this city with others that are located further north (labeled 77). It is worth highlighting that the algorithm is capable of distinguishing between stations that are located at sea level (e.g., market 24) and stations that are at higher ground (e.g., market 168). Though the distance between these local markets may not appear to be large, in practice the driving time between them is enough for the algorithm to recognize them as different local markets. Also, as in the case of Concepción, in these local markets most of the stations are connected by a few main roads.

We describe the local markets identified by the clustering algorithm in two ways. First, Figure 4a reports the distribution of the number of stations in our sample that were assigned to markets with different market structure. For example, of the 1,481 stations in our sample, the algorithm identified 57 (3.85 percent of all stations) as not having competitors within 30 minutes, and 68 as being in duopoly markets.[11] As the figure shows, most stations were identified as located in

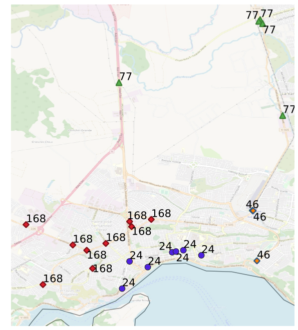
[10] Alternatively, a partition can be established by administrative boundaries (e.g., town, city, or region) or natural boundaries (e.g., rivers).

[11] The 30-minute cutoff is not chosen by the algorithm but by us. We experimented with other cutoffs in the neighborhood of the one we finally chose and the results where similar. The 57 single-station markets are in low-income and small villages located in remote and rural areas, so we exclude them from the analysis.

Figure 3: Examples of markets



(a) Concepción



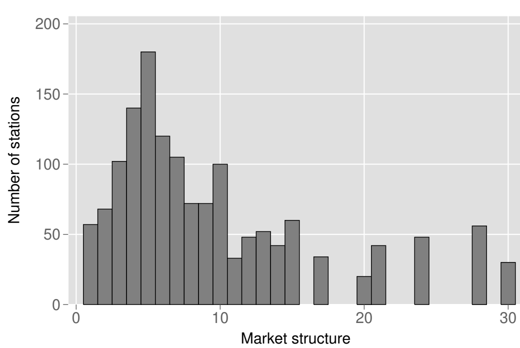
(b) Puerto Montt

Note: The figures presents markets as defined by the Hierarchical Clustering algorithm for two cities in Chile.

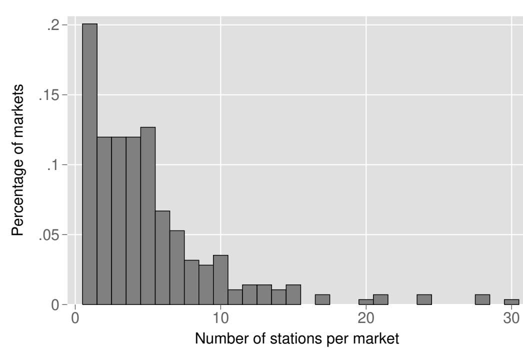
markets with between three and ten stations.

Second, one could consider the distribution of the number of stations per market. We present this in Figure 4b. The clustering algorithm identified 286 markets. Of these, 57 correspond to single-station markets as we described above, while 70 percent of markets have between 2 and 10 stations. Only 10 percent of markets have more than 10 stations, and these markets are located in the largest cities in the country.

Figure 4: Market distribution



(a) Number of stations by market structure



(b) Number of stations per market

2.4 Price Leadership

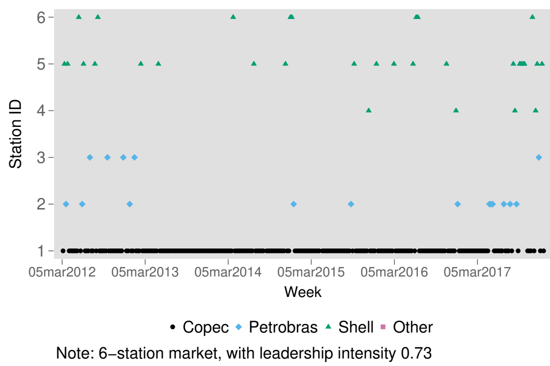
To define price leadership, we exploit two features of the Chilean retail-gasoline industry: First, that wholesale prices in Chile change once a week, and second, that most stations change prices once per week. Because most stations change prices once per week, a measure of price leadership would take into account the order in which stations change prices every week. We define a price leader in each market as the gas station that initiates prices changes most frequently throughout our sample. We find that Copec stations—that account for 41 percent of the stations in the country—are leaders in 82 percent of the markets, and initiate 60 percent of the price changes in our sample.[12] Figure 5 shows that there is heterogeneity across markets regarding the frequency with which a leader moves first. In the plots, the horizontal axis corresponds to weeks, and the vertical axis corresponds to a within-market station id. A point in the plot indicates the station that changed first in a given week. Figure 5a and Figure 5b show two markets where price changes are initiated predominantly by one gas station. In contrast, Figure 5c and Figure 5d show markets where it is less evident that one station initiates price changes predominantly.

Informed by this heterogeneity across local markets we define a measure of *leadership intensity* for each market. To compute this measure, we rank gas stations in decreasing order according to the percentage of weeks that each gas station initiates price changes throughout our sample period. We define leadership intensity as the difference between the frequencies of the gas stations ranked first and second. This measure of leadership intensity is bounded between zero and one and it is higher in markets that have a clear leader.

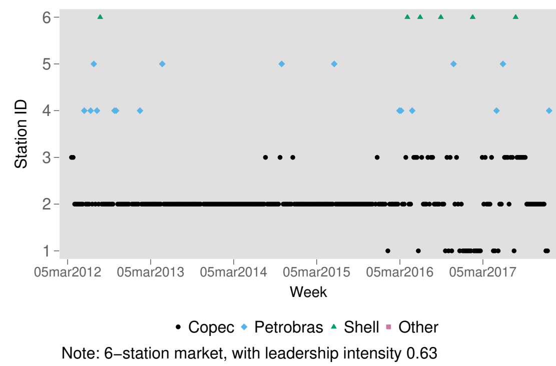
Figure 5a shows a market with 6 gas stations where the price leader (gas station 1) initiates 80 percent of all price changes. In this market, the second most-frequent gas station to initiate price changes initiates 7 percent of all price changes. Thus, the leadership intensity in this market is 0.73. Figure 5c shows another market with 6 gas stations. In this case, more than one gas station initiate price changes frequently. In fact, ranking gas stations according to the percentage of

[12] This finding is consistent with explanations proposed in the literature to justify the existence of price leaders including firm size (Byrne and de Roos, 2019), consumer loyalty (Deneckere, Kovenock and Lee, 1992), capacity constraints (Deneckere and Kovenock, 1992), asymmetric information (Rotemberg and Saloner, 1990), and cost heterogeneity (Amir and Stepanova, 2006; Van Damme and Hurkens, 2004).

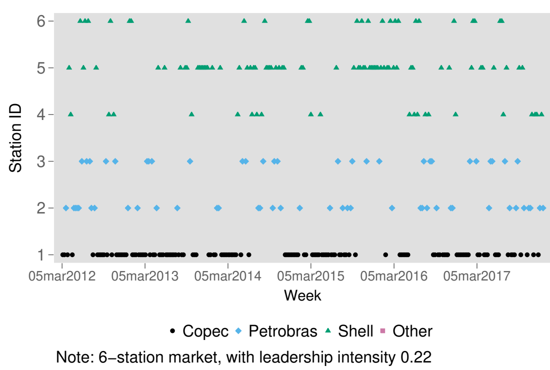
FIGURE 5: Heterogeneity in the intensity of leadership across markets



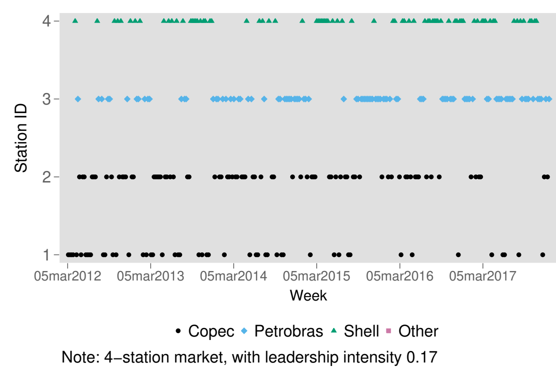
(a) High leadership intensity



(b) High leadership intensity



(c) Low leadership intensity



(d) Low leadership intensity

Note: The two figures at the top present examples of two markets in which there is a clear leader. The two figures at the bottom present examples of two markets that do not have a clear leader.

weeks for which they initiate price changes, we have that the station that ranks first initiates 42 percent of all the price changes (the market leader), and the station that ranks second initiates 20 percent of the changes. Thus, the leadership intensity in this market is 0.22. In Table 1, we further examine the relationship between leadership intensity and market characteristics such as the number of stations and brands that operate in the market, population density, among others. The table shows that leadership intensity is lower in markets with more stations, in markets with more brands, and in more dense markets.

Finally, we examine how leadership intensity correlates with local market outcomes including

Table 1: Leadership and market characteristics

	Dependent variable: Leadership intensity				
	(1)	(2)	(3)	(4)	(5)
Number of stations	-0.015***	-0.015***	-0.014***	-0.013***	-0.013***
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)
Number of brands	-0.040**	-0.050**	-0.032*	-0.041**	-0.040
	(0.017)	(0.023)	(0.017)	(0.020)	(0.030)
1[Copec is present]		0.052			0.046
		(0.059)			(0.071)
1[At least on independent is present]		0.020			-0.015
		(0.035)			(0.050)
Population density (standardized)			-0.024*	-0.029**	-0.027*
			(0.013)	(0.015)	(0.015)
Percentage of people under the poverty rate (standardized)			0.034**	0.045*	0.049
			(0.017)	(0.026)	(0.030)
Mean household income (standardized)				0.025	0.024
				(0.019)	(0.019)
Mean dependent variable	0.36	0.36	0.36	0.35	0.35
Observations	229	229	217	166	166
R^2	0.171	0.174	0.211	0.214	0.217

Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

margins, the number of stations that undercut the price of the market leader, and the length of the pricing cycle. We examine the relationship between leadership intensity and market outcomes by estimating

$$y_{it} = \alpha + \beta LI_i + \gamma_t + \eta_i + \varepsilon_{it}, \tag{1}$$

where y_{it} is an outcome variable in market i in week t, $LI_i \in [0, 1]$ is the leadership intensity of market i, γ_t is a week fixed effect, η_i is a fixed effect that captures the number of stations in market i, and ε_{it} is an error term that we cluster at the market level. The estimates in Table 2 show that, even when comparing markets with the same number of gas stations, leadership intensity is associated with higher margins, fewer stations undercutting the price of the market leader, and all stations setting their prices faster than in markets with lower leadership intensity. This indicates more than just a mechanical relationship between leadership intensity and the number of stations in a local market. We interpret these correlations as consistent with higher leadership intensity being associated with stronger coordination among the stations in a local market.

Table 2: Leadership and market outcomes: OLS regressions

	Margins		Number of prices below the leader's		Length of price cycle	
	(1)	(2)	(3)	(4)	(5)	(6)
Leadership intensity	19.177***	14.892***	-1.633***	-0.646***	-15.080***	-5.011***
	(4.496)	(4.920)	(0.297)	(0.084)	(1.842)	(1.523)
Week FE	Yes	Yes	Yes	Yes	Yes	Yes
Number-of-stations FE	No	Yes	No	Yes	No	Yes
Mean dependent variable	76.41	76.41	4.29	4.29	29.85	29.85
Observations	52641	52641	49671	49671	52585	52585
R^2	0.327	0.353	-	-	0.092	0.189

Standard errors, clustered at the market level, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In columns (1)-(2) and (5)-(6) correspond to OLS. Estimation in columns (3) and (4) corresponds to a Poisson model.

3 Theory: Impact of Mepco on Coordination Incentives

In this section, we propose a framework to examine how a policy such as Mepco could affect coordination incentives. Consider a market where n firms face a linear inverse demand $p = a - bq$

and an identical marginal cost, c_t, in period t. At the beginning of each period, firms observe the marginal cost announced by ENAP, and subsequently set simultaneously their prices. Firms play trigger strategies: if the announced marginal cost is c, firms set price $p(c) \in [c, p^m(c)]$, where $p^m(c)$ is the monopoly price; if at least one firm deviates from this pricing strategy, they play the static Nash equilibrium forever, setting prices equal to marginal cost each week, and earning zero profits.[13] Coordination is sustainable at time t if the net discounted coordination payoff is larger than the sum of the one-period deviation payoff plus the net discounted punishment payoff, i.e.,

$$\sum_{j=t}^{\infty} \delta^j \pi_j^{\text{coordination}} \geq \pi_t^{\text{deviation}} + \sum_{j=t+1}^{\infty} \delta^j \pi_j^{\text{punishment}}, \qquad \text{for all } t. \tag{2}$$

Policy Intervention. Mepco is, by construction, a filter that reduces the uncertainty about future wholesale prices. The policy constraints the absolute value of these changes to be smaller than Δ. To mimic the implementation of this policy, we define S_t to be the "stock of excess changes at time t." This variable is the cumulative wholesale price changes that were not passed to the firms due to Mepco, i.e., cumulative changes in excess of a change of magnitude Δ. We define $S_0 = 0$ and $S_{t+1} = c_t - c_{t-1} + S_{t-1} - z_t$, where the variable z_t corresponds to the weakly change in wholesale prices under Mepco and given by

$$z_t = \begin{cases} \Delta & , \text{ if } c_t - c_{t-1} + S_{t-1} \geq \Delta, \\ c_t - c_{t-1} + S_{t-1} & , \text{ if } |c_t - c_{t-1} + S_{t-1}| < \Delta, \\ -\Delta & , \text{ if } c_t - c_{t-1} + S_{t-1} \leq -\Delta. \end{cases}$$

Thus, the wholesale price at time t faced by firms under Mepco is

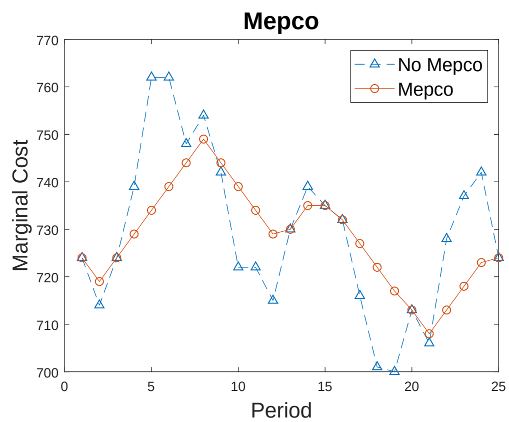
$$c_t^{\text{Mepco}} = c_{t-1}^{\text{Mepco}} + z_t. \tag{3}$$

To illustrate how Mepco operates, Figure 6 plots simulated wholesale prices that firms would face with and without Mepco for 25 periods after the implementation of Mepco. In the simulation, Mepco was implemented at $t = 1$ when the wholesale price was 724 pesos. We limit the variation of wholesale prices to $\Delta = 5$ pesos. Without Mepco, at $t = 2$ the wholesale price drops to 714 pesos, i.e., a change of 10 pesos. When Mepco operates, it limits this change in wholesale prices to $\Delta = 5$ (and $S_2 = 5$), so the effective wholesale price under Mepco at $t = 2$ is 719 pesos. In

[13] Firms can easily monitor rivals' prices by accessing the real-time price-disclosure government website.

period $t = 3$, without Mepco, the wholesale price increases by 10 pesos, from 714 to 724. Under Mepco, there is a 5 pesos increase from 719 to 724 (and $S_3 = 0$). In the next period, there is a large increase in wholesale prices, from 724 to 739, and after that from 739 to 762 in period 5. Under Mepco, the effective wholesale price increases by a magnitude of 5 until period 8. In the figure, we present the evolution of wholesale prices with and without Mepco for 25 periods and show that Mepco reduces the variance of wholesale price changes.

FIGURE 6: Simulated paths of marginal costs faced by firms with and without Mepco.



Incentives to sustain coordination. When the current marginal cost is c, the deviation payoff from under-cutting the coordination price $p(c)$ is $\pi^{\text{deviation}}(c) = \dfrac{(p(c) - c)(a - p(c))}{b}$, and the punishment payoff is zero (price equal marginal cost) for every future period. Thus, the right-hand side of Equation 2 is equal to $\pi^{\text{Deviation}}(c)$. Note that the deviation payoff only depends on the *current* marginal cost and does not depend on *future* marginal costs. Without Mepco, if the current marginal cost is c, the expected payoff of coordination is

$$\Pi^{\text{Coordination}}_{\text{No Mepco}}(c) = \frac{1}{b}\sum_{\tau=0}^{\infty} \delta^{\tau} E_{c_{t+\tau}}\left[(p(c_{t+\tau}) - c_{t+\tau})(a - p(c_{t+\tau}))\Big| c_t\right]. \tag{4}$$

With Mepco, if the current marginal cost is c^{Mepco}, the expected payoff of coordination is

$$\Pi^{\text{Coordination}}_{\text{Mepco}}(c) = \frac{1}{b}\sum_{\tau=0}^{\infty} \delta^{\tau} E_{c^{\text{Mepco}}_{t+\tau}}\left[(p(c^{\text{Mepco}}_{t+\tau}) - c^{\text{Mepco}}_{t+\tau})(a - p(c^{\text{Mepco}}_{t+\tau}))\Big| c^{\text{Mepco}}_{t}\right]. \tag{5}$$

We define the gain from coordination when the current marginal cost is c with and without Mepco, respectively, by

$$G^{\text{Mepco}}(c) = \Pi^{\text{Coordination}}_{\text{Mepco}}(c) - \pi^{\text{deviation}}(c), \tag{6}$$

$$G^{\text{No Mepco}}(c) = \Pi^{\text{Coordination}}_{\text{No Mepco}}(c) - \pi^{\text{deviation}}(c). \tag{7}$$

The effect of Mepco on the incentive to sustain coordination is captured by the difference in the gain from coordination with and without Mepco, i.e., $G^{\text{Mepco}}(c) - G^{\text{No Mepco}}(c)$, which is in general analytically intractable. To gain intuition, we present a simplified setting that is analytically tractable and illustrates that Mepco reduce the incentive to coordinate.[14]

Reduced-form setting. Let the marginal costs evolve according to the stochastic process $c_{t+1} = \rho c_t + \varepsilon_{t+1}$, with $0 \leq \rho \leq 1$, $E[\varepsilon_{t+1}|t] = 0$ and $E[\varepsilon^2_{t+1}|t] = \sigma^2$. Suppose that firms coordinate on the pricing strategy $p(c) = \lambda p^m(c) + (1-\lambda)c$, where the parameter $\lambda \in [0,1]$ measures the strength of coordination. If $\lambda = 1$, firms set the monopoly price (the most-collusive agreement), and if $\lambda = 0$ firms play the static Nash equilibrium price (no coordination). When coordination is feasible, there is a cutoff value $\bar{\lambda}$ such that for any $\lambda \geq \bar{\lambda}$ coordination can be sustained. Under these assumptions, the incentive to sustain coordination at time t, when the marginal cost is c_t, is

$$G_t(c_t, \sigma^2) = \frac{\lambda(2-\lambda)}{4nb}\left[\frac{a^2}{1-\delta} - \frac{2c_t}{1-\delta\rho} + \frac{c_t^2}{1-\delta\rho^2} - n(a-c_t)^2\right] + \frac{\delta\lambda(2-\lambda)}{(1-\delta)(1-\delta\rho)4nb}\sigma^2. \tag{8}$$

The incentive to sustain coordination depends on the number of competitors (n), the discount factor (δ), the pricing strategy (λ), and the level of serial correlation (ρ). Importantly, the coefficient multiplying σ in Equation 8 is *always* positive, so *lower* uncertainty about future wholesale costs (measured by σ) creates *weaker* incentives to sustain coordination. This insight is not only true for a linear demand, but for any downward slopping demand. The intuition is easier to understand for the most-collusive agreement, where each firm sets the monopoly price after the common marginal cost is publicly announced (i.e., $\lambda = 1$). For any downward sloping demand monopoly, profits are convex in the marginal cost. The profit of a monopolist

[14] Online Appendix A contains numerical simulations for more complex specifications of the model (different stochastic processes for the cost and different pricing strategies) and shows that Mepco *reduces* the incentives to sustain coordination if future costs are expected to decrease.

that sets price p when faces a marginal cost of c is $\pi(p,c) = (p-c)D(p)$. The monopoly price $p^m(c)$ solves the first-order condition $\pi_p(p^m(c),c) = 0$. Let $g(c) \equiv \pi(p^m(c),c)$. We have $g''(c) = -D'(p^m(c))\frac{dp^m(c)}{dc} > 0$, so monopoly profits are convex in the marginal cost. When firms play trigger strategies by setting price equal to marginal cost following a deviation, they get a payoff of zero for all of the periods after the deviation occurred. The convexity of the monopoly profit in the wholesale price implies that the gain from coordination—defined as the difference between the expected continuation payoff of coordination minus the expected continuation payoff of a deviation—is also convex. This is reflected in the positive coefficient multiplying σ in Equation 8.

Note also that a reduction in σ reduces the incentive to sustain coordination by *less* in markets with a larger number of competitors, and by *more* in markets where λ is larger, because $\frac{\partial^2 G}{\partial\sigma^2\partial n} < 0$ and $\frac{\partial^2 G}{\partial\sigma^2\partial\lambda} > 0$. The impact of the current level of the cost (c_t) on the incentive to sustain coordination depends on the parameter values and, particularly, on the level of serial correlation. Without serial correlation ($\rho = 0$), the coefficient multiplying $(a-c_t)^2$ in Equation 8 is negative. Thus, a lower cost today (lower c_t) decreases the incentive to sustain coordination. This result is analogous to the result of Rotemberg and Saloner (1986): firms have less incentives to sustain coordination during booms. When we introduce serial correlation, however, this result can reverse. When $\rho = 1$ and $\delta > 1 - \frac{1}{n}$, the coefficient multiplying $(a-c_t)^2$ is positive, and therefore a lower cost today (lower c_t) increases the incentive to sustain coordination. This result is analogous to the conclusion of Green and Porter (1984), although the underlying mechanism is different. Similar to Haltiwanger and Harrington Jr (1991), with serial correlation, the incentive to sustain coordination is lower when firms expect future wholesale prices to decrease.

In our data, we find that $\rho \approx 0.989$, and the implementation of Mepco did not significantly change this value. Also, we find that $\sigma = 10.27$ before the implementation of Mepco, and that it fell to $\sigma = 7.37$ after the implementation of Mepco. In this reduced-form setting, we model the implementation of Mepco as reduction of the variance of the cost process σ^2. Let σ^2_{before} be the variance of the cost before Mepco, and let σ^2_{after} be the variance of the cost after Mepco, with $\sigma^2_{\text{before}} > \sigma^2_{\text{after}}$. The difference in the incentive to sustain coordination after and before Mepco is

$$\frac{\delta\lambda(2-\lambda)}{(1-\delta)(1-\delta\rho)4nb}(\sigma^2_{\text{after}} - \sigma^2_{\text{before}}). \tag{9}$$

Based on Equation 9 we formulate testable implications about the effect of Mepco on the incentive to sustain coordination.[15]

Hypothesis 1: If uncertainty about future wholesale prices decreases (i.e., $\sigma^2_{\text{after}} < \sigma^2_{\text{before}}$), the incentive to sustain coordination is smaller. Therefore, competition should intensify and margins should decrease after the implementation of Mepco.

Hypothesis 2: If uncertainty about future wholesale prices decreases (i.e., $\sigma^2_{\text{after}} < \sigma^2_{\text{before}}$), the incentive to sustain coordination decreases more in markets where λ is larger. Therefore, margins should decrease more in markets with higher λ.

We test Hypothesis 1 in Section 4.1 and Hypothesis 2 in Section 4.2. Testing Hypothesis 2 is challenging because the strength of coordination, captured by the parameter λ in the model, is not observable. For this reason, we propose to index the strength of coordination in a local market by the *leadership intensity* in that local market (LI_i). This is motivated by the fact that price leadership has been recognized as a possible coordination device (see, e.g., Stigler, 1947; Miller, Sheu and Weinberg, 2018; McNamara, 2019), in particular, in retail-gasoline markets (see, e.g., Lewis, 2012; Byrne and de Roos, 2019). Further, Table 2 shows that markets with higher leadership intensity have, on average, higher margins. Therefore, we argue that the implementation of Mepco affected the effectiveness of price leaders as coordination devices.

4 Empirical analysis: The Impact of Mepco on Market Outcomes

4.1 The Impact of Mepco on Margins: Evidence from Chile and France

Mepco was implemented in Chile in August 2014. To causally identify the effect of the implementation of Mepco on margins, we use a group of stations that was not impacted by Mepco

[15] Our simulation results support this conclusion in more complex model specifications. See footnote 14.

as a control for stations in Chile. This is necessary for identification because concurrently with the implementation of Mepco, world oil prices experienced a sharp decrease during the second semester of 2014. During this period, world oil prices decreased from \$105 per barrel to around \$44 per barrel. This decrease in world oil prices is an identification threat that we cannot directly incorporate in our analysis relying exclusively on Chilean data.

To explicitly account for the change in world oil prices and to separately identify the effect of Mepco, we rely on data from the French retail-gasoline industry. There are a number of reasons for why we use these data as a control group. First, Montag and Winter (2020) also use France as a control country in their analysis, and they explain that the French retail-gasoline industry was not impacted by any policy that may confound with our analysis. Second, we are aware only of a few countries that tracked prices for the window of time in our analysis. Other countries with suitable datasets include Germany (since September 2013), South Korea (since 2008, but it restricts access and publication of their data), Australia (since 2001, but only for one city), and Austria (since 2011, but only partial reporting of price changes). Third, margins in France and Chile tracked each other well during the *entire* pre-Mepco period (see Figure 7). Therefore, we believe that the French industry is plausibly the best available control for the Chilean retail-gasoline industry.

To incorporate French data in our analysis, however, we need to make some assumptions and simplifications. In contrast to the Chilean retail-gasoline industry, wholesale prices change more often in France (even within the day), which results in French stations changing their prices more often than their Chilean counterparts. In our analysis, we follow Montag and Winter (2020) and compute margins at 5pm. We then define markets using the same criterion in Chile and France. Finally, because we have access to the French data only for the period between 2013 and 2015, in this section we restrict attention to this time period.

To examine how the implementation of Mepco impacted the Chilean retail-gasoline industry, we implement a differences-in-differences research design and estimate

$$y_{it} = \alpha + \beta_1 1\left[\text{Chile}_i\right] \times 1\left[\text{Mepco}_t\right] + \eta_i + \gamma_t + \varepsilon_{it}, \tag{10}$$

where y_{it} corresponds to the average margin in market i in week t, $1\left[\text{Chile}_i\right]$ takes the value one if market i is located in Chile and zero otherwise, $1\left[\text{Mepco}_t\right]$ is a binary variable equal to one if Mepco is operative in week t and zero otherwise (regardless of whether a station is located in Chile or France), η_i and γ_t correspond to market and week fixed effects, respectively, and ε_{it} is an error term that we cluster at the market level allowing for arbitrary correlations within a market.[16]

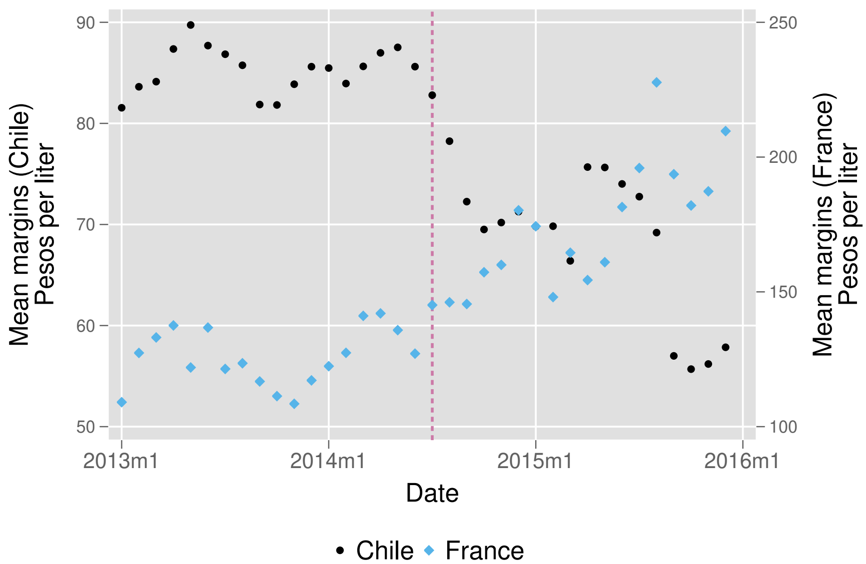
The identification assumption associated with this research design is that margins in Chile would have continued to follow the same trend as margins in France if Mepco had not been implemented. Though this assumption is not testable, it is possible to examine how margins evolved in each country before the implementation of Mepco. If margins in France and Chile tracked each other closely before Mepco was implemented, the French retail-gasoline industry is a plausible valid control for the Chilean industry. We thus expect that margins in Chile would have continued to track the evolution of margins in France in the absence of Mepco. Figure 7 presents the evolution of monthly average margins in Chile and France over the period 2013–2015. The figure shows that before the implementation of Mepco, the margin series tracked each other closely. Importantly, margins increased in France when world oil prices started to decrease.[17] Relative to France, however, margins in Chile decreased, which we attribute to the implementation of Mepco.

In Table 3, we present our estimates associated with Equation 10. In Column 1, we present estimates for a specification that does not include any fixed effects and instead report coefficients not only on the interaction of interest but also for the indicators that identify Chilean stations and the indicator that identifies the post-Mepco period. In this case, the interaction of interest, reported in the first row, shows that margins in Chile decreased significantly relative to margins in France. However, the absence of fixed effects prevents us from attributing a causal interpretation to this relationship. As an intermediate step, in Column 2, we introduce

[16]In our main specifications, we cluster standard errors at the market level. However, because the retail-gasoline industry is also exposed to temporal national shocks, we also report standard errors using two-way clustering at the market and week level. The statistical significance of our finding does not change under this alternative strategy. Finally, one could cluster standard errors at the city rather than at the market level to recognize that spatial correlation between markets within a city may be important. In our application, however, 60 percent of markets are located in municipalities that have a single market, and 25 percent in municipalities with two markets. Thus, very few cities are composed of more than two markets.

[17]Figure 2 in Montag and Winter (2020) reports the same pattern.

FIGURE 7: Retail margins in Chile and France



Note: The figure presents the evolution of the monthly average retail margin in Chile and France. The figure also identifies the implementation of Mepco (red vertical line).

a linear time trend, common to stations in both countries, to capture common elements in the evolution of margins across all stations in our sample. The estimate of the interaction effect is essentially unchanged. In Column 3 we introduce station fixed effects, thus dropping the indicator that identifies Chilean stations, but we retain the common trend. Again, the estimates are unchanged. Finally, in Column 4, the main specification in this section, we drop the time trend and introduce week fixed effects, which allow us to take into account shocks that affect all stations in a more flexible way. Again, the estimates remain essentially unchanged and show that the introduction of Mepco in Chile caused a significant decrease in margins relative to margins in France, which was also suggested by Figure 7. The estimated coefficient in Column 4 implies a 45 percent drop in Chilean retail-gasoline margins relative to the mean margin in the estimation sample. Finally, we also report two-way clustered standard errors and show that, though the standard errors increase, the significance of our estimates does not change.

Motivated by this empirical finding, in the next section we investigate why Chilean retail-gasoline margins fell. We argue that Mepco caused a disruption in the incentives to sustain tacit co-

Table 3: The effect of MEPCO on margins: OLS regressions with France as a control group

	(1)	(2)	(3)	(4)
$1[\text{Chile}_i] \times 1[\text{After Mepco}]$	-64.502	-64.338	-64.396	-64.704
	$(0.740)^{***}$	$(0.744)^{***}$	$(0.751)^{***}$	$(0.735)^{***}$
	$[3.548]^{***}$	$[3.542]^{***}$	$[3.552]^{***}$	$[3.557]^{***}$
$1[\text{Chile}_i]$	-42.464	-42.536		
	$(1.717)^{***}$	$(1.720)^{***}$		
	$[2.151]^{***}$	$[2.134]^{***}$		
1[After Mepco]	47.357	15.809	15.994	
	$(0.515)^{***}$	$(0.404)^{***}$	$(0.400)^{***}$	
	$[3.058]^{***}$	$[3.681]^{***}$	$[3.704]^{***}$	
Market FE	No	No	Yes	Yes
Week FE	No	No	No	Yes
Time trend	No	Yes	Yes	No
Mean dependent variable	143.98	143.98	143.98	143.98
Observations	248118	248118	248118	248118
R^2	0.430	0.464	0.814	0.892

Standard errors, clustered at the market level are in parentheses. Standard errors, clustered at the market and week level are in squared brackets. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. An observation is the average margin in market i week t.

ordination in the Chilean retail-gasoline industry. This disruption cannot be explained only from future expectations (fixing the underlying stochastic process dictating future uncertainty). In the period that follows the implementation of Mepco, world-wide wholesale prices were expected to decrease.[18] Borenstein and Shepard (1996) show that when firms expect future costs to decrease their (collusive) margins increase. While in France margins increased, in Chile we observe the opposite: margins fell even though future marginal costs were expected to decrease. Thus, the focus of our analysis is on the effect of Mepco on the underlying stochastic process governing the future wholesale prices, by reducing its variance.

4.2 Mepco, Leadership Intensity, and Margins

We now turn to the central question of our paper: does uncertainty about future wholesale prices affect the incentives to sustain coordination? In light of the discussion presented in Section 3, we implement a differences-in-differences research design to address this question. We identify each market's exposure to treatment based on our measure of leadership intensity LI_i, and we use the introduction of Mepco to define two time periods: before and after the implementation of Mepco. Formally, we estimate the following model:

$$y_{it} = \alpha + \beta_1 LI_i \times 1\left[\text{Mepco}_t\right] + \eta_i + \gamma_t + \varepsilon_{it}, \tag{11}$$

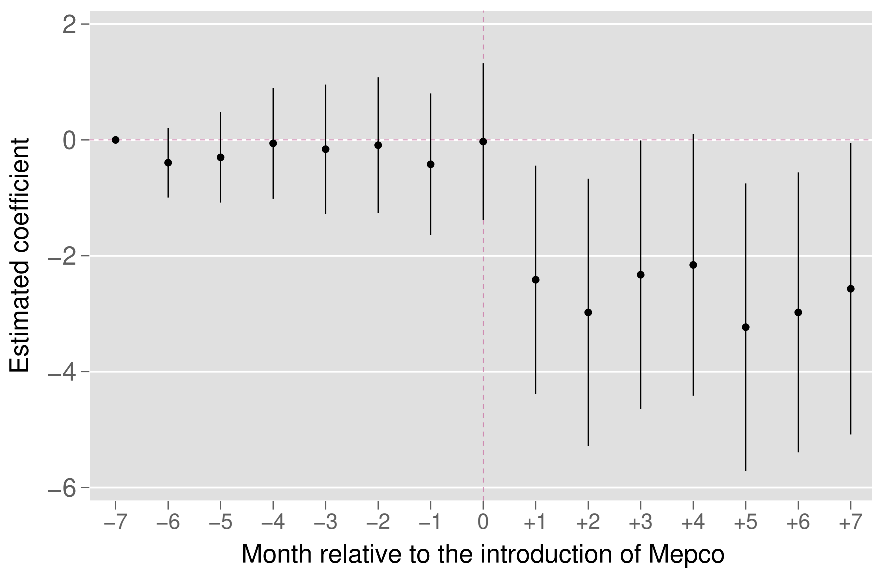
where $1\left[\text{Mepco}_t\right]$ is equal to 1 if Mepco was operative in week t and zero otherwise, $LI_i \in [0, 1]$ is the leadership intensity of market i (which is market specific), η_i is a market fixed effect, and γ_t is a time fixed effect. The interaction between LI_i and $1\left[\text{Mepco}_t\right]$ results in a continuous measure of exposure to treatment.

The identification assumption in this differences-in-differences research design is that, if not for Mepco, margins would have continued to follow the same trends across local markets with different exposure to the treatment. Figure 8 presents an event-study plot of the evolution of margins in markets with leadership intensity above the median of the distribution of LI, relative to markets with leadership below the median of the distribution of LI. This is, the figure presents the coefficients of the interaction between an indicator that identifies markets

[18]See, for example, https://voxeu.org/article/causes-2014-oil-price-decline

with high leadership intensity, with month fixed effects, for a window of seven months around the implementation of Mepco. The figure also shows that before the implementation of Mepco, margins followed parallel trajectories in the two groups of markets. Further, the figure also shows that after the implemention Mepco, margins decreased significantly in markets with higher leadership intensity relative to markets with lower leadership intensity. In what follows, we focus our analysis on the differential decrease in margins and interpret it as the causal effect of Mepco as it disrupted coordination. We return to this point, and to the discussion of the validity of the identifying assumption, in Section 4.4, where we present evidence based on weekly-level data that leads us not to reject the parallel-trends assumption not only for margins but also for the other outcome variables of interest.

FIGURE 8: Evolution of margins by level of leadership intensity



Note: The figure reports the estimated coefficients (and 95 percent confidence intervals) of an event-study around the implementation of Mepco. The figure normalizes the coefficient of January 2014 to zero and identifies the month in which Mepco was introduced. The figure shows that only after the introduction of Mepco margins decreased in markets with higher leadership intensity relative to markets with lower leadership intensity.

We now discuss the estimates associated with Equation 11, which are reported in Table 4. We present estimates for four specifications that differ on the controls included in the analysis in a way that resembles the analysis presented in section 4.1.

In Table 4 (Column 1), we do not include any type of fixed effects, and so report not only the interaction of interest between our measure of leadership intensity and the period after the introduction of Mepco, but also the levels of these variables. The estimates show that after the introduction of Mepco margins decreased across all markets, that markets with stronger leadership intensity had higher margins on average–which is consistent with the estimates reported in Table 2–and that after the introduction of Mepco, margins decreased the most in markets with stronger leadership. In Column 2, we introduce a time trend that is common to all markets in Chile, and show that the estimates remain unchanged. In Column 3, we include market fixed effects and drop the level of leadership intensity as it is market-specific. In this case the magnitude of the interaction of interest increases in absolute value. Finally, in Column 4, we also include week fixed effects and drop the binary variable that identified the period after the introduction of Mepco. Again, we find that our estimates remain unchanged and show that after the introduction of Mepco, margins decreased the most in markets with stronger leadership intensity. Through the lens of the model presented in Section 3, we interpret these findings as being consistent with Mepco reducing the incentives to maintain tacit coordination and, thus, making price leaders a less effective coordination device. To give a sense of magnitude of our estimates, it is useful to compare what these mean for markets with weak and strong leadership. Specifically, our estimates suggest that while in markets in the 5th percentile of the distribution of leadership intensity margins decreased by 0.6 percent, margins decreased by 5.5 percent in markets in the 95th percentile of the leadership distribution, relative to the mean of 76.41 pesos (about 45 cents of a dollar per gallon). Finally, as we discussed above, the statistical significance of our estimates remains unchanged when using two-way clustering at the market and week level.

Robustness. In Online Appendix D, we examine the robustness of our findings along two dimensions. First, we implement a propensity-score matching differences-in-differences research design based on Imbens (2015) to take into consideration possible selection in that leadership intensity may be driven by market-level unobservables. Our findings are robust to this exercise.

Second, we recognize that there may be spatial spillovers across markets that are near each other. To take this into account, we re-estimate Equation 11 excluding markets that are within

Table 4: The effect of MEPCO on margins: OLS regressions

Dependent variable:	margin_{it}			
	(1)	(2)	(3)	(4)
Leadership intensity$\times$ $1[t \geq \bar{t}]$	-4.574	-4.625	-5.977	-4.981
	$(2.600)^{*}$	$(2.601)^{*}$	$(2.540)^{**}$	$(2.499)^{**}$
	$[2.575]^{*}$	$[2.577]^{*}$	$[2.586]^{**}$	$[2.522]^{**}$
Leadership intensity	20.571	20.683		
	$(5.357)^{***}$	$(5.363)^{***}$		
	$[5.347]^{***}$	$[5.355]^{***}$		
$1[t \geq \bar{t}]$	-17.604	-14.534	-13.200	
	$(1.185)^{***}$	$(1.184)^{***}$	$(1.177)^{***}$	
	$[1.310]^{***}$	$[1.566]^{***}$	$[1.557]^{***}$	
Market FE	No	No	Yes	Yes
Week FE	No	No	No	Yes
Common linear trend	No	Yes	Yes	No
Mean dependent variable	76.41	76.41	76.4093	76.41
Observations	52641	52641	52641	52641
R^2	0.245	0.247	0.787	0.859

Standard errors, clustered at the market level, are reported in parenthesis. Standard errors, computed using two-way clustering at the market and week level, are reported in squared brackets. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

one mile of other markets.[19] We report the results in Table D.2. The estimates are similar to those reported in our main specification, though noisier.

4.3 Mepco, the Length of the Pricing Cycle, and Price Undercutting

We now turn to examining how Mepco impacted the Chilean retail-gasoline industry on two additional dimensions: the length of time of the pricing cycles and whether followers changed the extent to which they undercut the prices set by the leaders. In other words, we want to examine whether Mepco impacted the effectiveness of leaders as a coordination device. To do this, we estimate Equation 11 with the dependent variable being both the length of time of the pricing cycle (in hours) and the number of prices that are set below the price of the leader. In the latter case, we estimate a Poisson model to take into consideration the nature of the data.[20]

Table 5 presents the estimates of Equation 11 when the dependent variable is the length of the pricing cycle (columns (1) and (2)) and the number of prices below that of the leader in each market (columns (3) and (4)). The specifications reported in odd columns do not include any type of fixed effects, while the specifications in even columns include market and week fixed effects. Across all specifications, the estimates show that both the length of the pricing cycle and the number of stations undercutting the price of the leader increased after the introduction of Mepco, and did so by more in markets with stronger leaders. These findings are also consistent with the implementation of Mepco decreasing the gains associated with coordination in markets with stronger leadership intensity.

[19] Fifteen percent of markets are excluded from these regressions as they are located at less than one mile of another market.

[20] In Online Appendix E, we present the evolution over time of the length of the pricing cycle and the number of prices below that of the leader, normalized by the number of stations in each market, for markets above and below the median of the distribution of leadership intensity. The figures show that there is a trend towards markets reacting faster over time, with some convergence in the long run. On the other hand, the number of prices below that of the market leader increased over time. The figures, however, do not show a break as clear for these variables as for the case of margins (Figure 8).

Table 5: The effect of MEPCO on the length of the pricing cycle and the number of stations undercutting the leader's price

	Length of the pricing cycle		Number of prices below the leader's	
	(1)	(2)	(3)	(4)
Leadership intensity$\times$ $1[t \geq \bar{t}]$	2.226	2.821	0.084	0.113
	(1.343)*	(1.325)**	(0.039)**	(0.030)***
	[1.405]	[1.365]**	[0.038]**	[0.031]***
Market FE	No	Yes	No	Yes
Week FE	No	Yes	No	Yes
Mean dependent variable	29.85	29.85	30.83	4.97
Observations	52585	52585	38892	38890
R^2/ log Likelihood	0.114	0.277	-74249.7	-64173.3

Standard errors, clustered at the market level, in parentheses. Standard errors clustered at the market and week level in square brackets. Two-way clustering in specifications (3) and (4) use the estimator proposed by Correia, Guimarães and Zylkin (2019). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Columns (1) and (2) are estimated by OLS, while column (3) is a Poisson model and in column (4) a Fixed Effects Poisson Model. Columns (1) and (3) also include the level of leadership intensity and the indicator for the post-Mepco period.

4.4 Market Outcomes Around the Implementation of Mepco

The results that we have presented so far suggest that Mepco decreased margins more in markets characterized by higher leadership intensity. This finding would be consistent with Hypothesis 2 if leadership intensity is a good proxy for the strength of market coordination (the parameter λ in our model). We now explore whether Mepco had an immediate effect on market outcomes. Because for a window of weeks before and after the implementation of Mepco the level of wholesale prices was relatively stable and high (ranging between 810 and 830 pesos), changes in market outcome during this time period are unlikely to be caused by the decrease in wholesale prices that took place in the months that followed. Rather, it is more likely that any changes that may have taken place during the weeks immediately after the implementation of Mepco were caused by the reduction of uncertainty associated with Mepco. Formally, we estimate

$$y_{it} = \alpha + \beta_t \, LI_i \times \gamma_t + m_i + \gamma_t + n_{it} + \varepsilon_{it}, \tag{12}$$

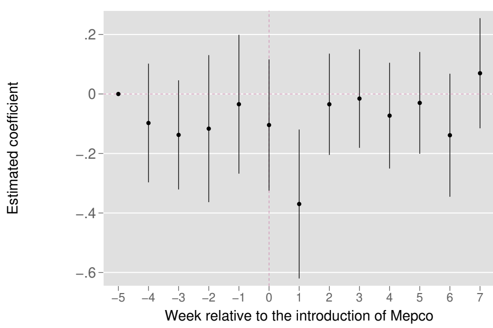
where the interaction $LI_i \times \gamma_t$ corresponds to the interaction between our measure of leadership intensity and the week fixed effects. In this section, we restrict to $t = -5, -4, ..., 6, 7$, where week 0 is when Mepco was implemented and week 1 is the first week after Mepco.[21]

Figure 9 presents the estimated coefficient β_t for $t = -5, -4, ..., 6, 7$. This is, five weeks before and seven weeks after the implementation of Mepco. Our baseline estimate is the fifth week before the implementation of Mepco (i.e., we normalize $\beta_{-5} = 0$). Figure 9 (Panel a) reports that the probability of price matching decreased sharply in markets with higher leadership intensity, relative to markets with lower leadership intensity, in the first week after the implementation of Mepco. This mechanically led the range of prices to increase (figure not reported). Furthermore, Figure 9 (Panel b) shows that this finding is explained by more stations undercutting the price set by the price leader, which leads to a longer price cycle (Figure 9, Panel c). Finally, Figure 9, Panel (d) shows that starting two weeks after the implementation of Mepco, margins were lower than in the previous period, and that this effect was larger in markets with higher leadership intensity.

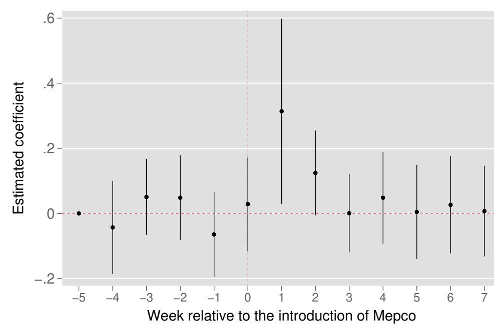
[21] Our results do not change if we consider a longer window in the neighborhood of the implementation of Mepco, but the interaction effects become less precise the longer the window we consider. We focus on the window of weeks specified above to examine whether Mepco had an immediate effect on competition.

These results, together with those presented earlier, suggest that Mepco disrupted market outcomes immediately after its implementation. We interpret this disruption as leaders becoming a less effective coordination device. This is consistent with the intuition from our model: reducing uncertainty about future wholesale prices decreases the incentives to sustain coordination. The undercutting of price leaders could have impacted the effectiveness of leaders in coordinating the market, leading to a more competitive equilibrium in the following weeks, reflected in lower margins.

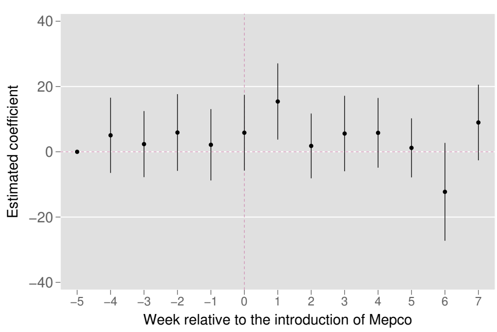
FIGURE 9: Wholesale prices over time



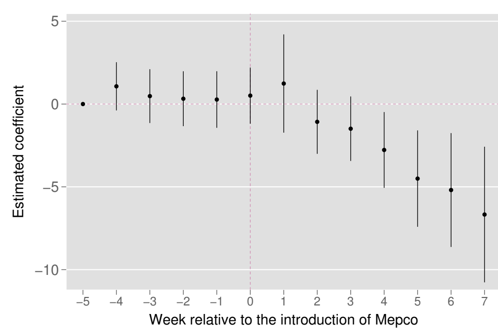
(a) Price matching



(b) Number of stations undercutting the leader



(c) Price cycle



(d) Margins

Note: The figures examine the impact of Mepco on four equilibrium outcomes using a window around the implementation of Mepco. The figures present the estimated coefficient associated with the interaction of our measure of intensity of leadership and the week fixed effect. The omitted week is the fifth week before the implementation of Mepco.

5 Conclusion

This paper examines whether uncertainty about future costs affects the incentives to sustain tacit coordination. In a simple repeated-game framework, we show that a reduction in the volatility of future wholesale prices hinders coordination incentives. Furthermore, this effect is bigger in markets with stronger price leaders. Based on these findings, we propose to empirically test two hypotheses: The effect of lower uncertainty about future wholesale prices (1) reduces margins; and (2) reduces margins more in markets with stronger coordination. For our empirical analysis, we exploit a policy intervention (Mepco) that reduced uncertainty about future wholesale prices in the Chilean retail-gasoline industry.

To test the first hypothesis, we implement a differences-in-differences research design in which we use data from the universe of French gas stations as controls for Chilean gas stations, and we show that Mepco sharply decreased margins of Chilean gasoline retailers.

Testing the second hypothesis is more challenging because the extent of coordination is unobservable. For this reason, we propose a measure of price leadership intensity as a proxy for the strength of coordination in each local market. We do this exploiting special features of the Chilean retail-gasoline industry which allow us to define price leaders and leadership intensity in each local market. Our measure of price leadership intensity positively correlates with higher margins, more price matching, and faster price adjustments following changes in wholesale prices, even across markets with the same market structure. We exploit this variation in leadership intensity across markets to implement a differences-in-differences research to examine how Mepco impacted local markets characterized by different levels of price leadership. Our findings show that in local markets with higher leadership intensity Mepco led to a larger decrease in margins, more firms undercutting the price leader, and longer price cycles.

These findings suggest that reducing uncertainty about future wholesale prices hinders coordination incentives, thus making price leaders a less effective coordination device.

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Online Appendix: Intended for Online Publication

Price Leadership and Uncertainty about Future Costs

Jorge Lemus and Fernando Luco

A Extensions to the Model

In this section, we present different model specifications that extend the basic setting presented in the main text (Section 5). With these extensions, we want to verify the robustness of the result in the main text: By reducing uncertainty about future wholesale costs, Mepco reduces the incentive to sustain coordination. The extensions presented here relax some of the assumption in the model of Section 5, adding more realistic features, at the expense of not being analytically tractable. For this reason, we rely on simulations to compute the gain from coordination with and without Mepco. We estimate Equations 6 and 7 in the main text by averaging over 2000 simulated paths of cost realizations for 200 periods in the future (instead of the 25 shown in Figure 7 in the main text). In subsection A.1, we explore the case of a stochastic process governing wholesale price changes with positive correlation subject to lower and upper boundaries (i.e., a stochastic process with reflecting barriers). Additionally, and as in the main text, we assume that firms employ linear price strategies, i.e., $p(c) = \lambda p^m(c) + (1 - \lambda)c$.

In our data, wholesale prices decreased shortly after Mepco, due to the sharp decline of international prices, so it is reasonable to assume that firms formed corrected beliefs and expected future wholesale prices to decrease. Also, the serial correlation of wholesale prices is high (about 0.98).

In subsection A.2, we explore a different stochastic process. We assume that the wholesale price takes a finite number of values and transitions from one value to another according to a transition matrix. This Markov process captures persistence by transitioning to values closer to the current value with a higher probability. In this section, we maintain the assumption that firms use linear pricing strategies. Finally, in subsection A.3, we use the same Markov process than in the previous section, but we assume that firms set a price equal to the current marginal cost plus a fixed margin $\mu > 0$.

For all these different specifications, our simulation results show that Mepco reduces the incentive to coordination, when the implementation of Mepco occurs during a period of high costs. In other words, when firms foresee that costs in the future will decrease. This result is consistent with Haltiwanger and Harrington Jr (1991). Also note that, in fact, this is case in the data (see

FIGURE A.1: Normal shocks with barriers and persistent cost (positive correlation).

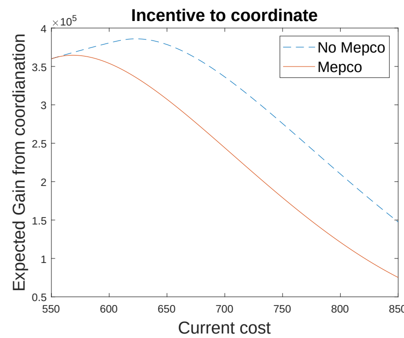


Figure 2 in the main text).

A.1 Persistence and Reflecting Barriers

We use linear coordination strategies $p(c) = \lambda p^m(c) + (1 - \lambda)c$, and a stochastic process with persistence and reflecting barriers with a lower and upper bound of c_L and c_H, respectively. This is, the marginal cost follows the process

$$c_{t+1} = \min\{\max\{\rho c_t + \varepsilon_t, c_L\}, c_H\}.$$

We simulate Equation 6 and Equation 7 under the following specification: $c_L = 550$, $c_H = 850$, $\lambda = 0.5$, $n = 3$, $\delta = 0.95$, the inverse demand is $p = 950 - q$, $\Delta = 5$, $\sigma = 5$, $\rho = 0.9$. Figure A.1 shows the expected gain from coordination. The figure shows that regardless of whether Mepco is in place or not, the incentive to sustain coordination is lower when the current marginal cost is larger, i.e., when firms expect lower future costs. The figure also shows that the incentive to sustain coordination when Mepco is in place is *lower* than the incentive to sustain coordination without Mepco. This is, the minimum value of $G(c)^{\text{Mepco}}$ is lower than the minimum value of $G(c)$ and this minimum occurs at the highest possible cost.

A.2 A Markov Process with Persistency

In this section, the marginal cost can take values in $c^1 = 550 < 551 < 552 < ... < c^M = 850$. The evolution of the marginal cost is governed by a Markov process with transition matrix A, i.e., $\mathbf{c}' = A\mathbf{c}$, where $\mathbf{c} = (c^1, c^2, ..., c^M)$ and $(\mathbf{c}')_k = E[c_{t+1}|c_t = c^k]$. The transition probability from $c_t = c^i$ to $c_{t+1} = c^j$, denoted by α_{ij}, is

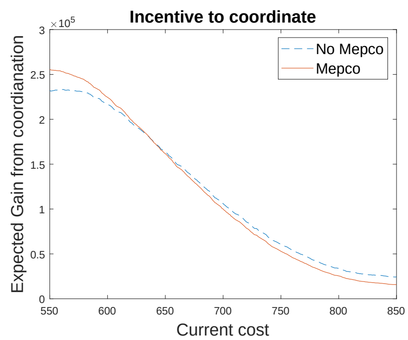
$$\alpha_{ij} = \begin{cases} \frac{s_{ij}}{S_i} & , \text{if } |c_i - c_j| \leq 30 \\ 0 & , \text{if } |c_i - c_j| > 30 \end{cases}$$

where $S_i = \sum_{|i-j|\leq 30} s_{ij}$ and $s_{ij} = \dfrac{1}{1 + 0.5 \cdot |c_i - c_j|^{0.5}}$. This transition matrix captures persistency: it is more likely to transition to values closer to the current value. The other parameters used in our simulations are $n = 3$, $\delta = 0.95$, the inverse demand is $p = 950 - q$, $\lambda = 0.5$, and $\Delta = 5$.

Figure A.2 plots the expected gain from coordination conditional on the current marginal costs faced by firms with and without Mepco. We again obtain that, regardless of whether Mepco is implemented or not, the gain from coordination is lower when costs are expected to decrease. Mepco decreases the incentive to sustain coordination even further when costs are expected to decrease. However, Mepco increases the incentives to sustain coordination when costs are expected to raise. Mepco provides "brakes" to price changes so it has the effect of increasing the payoff from coordination when the current marginal cost is low (i.e., future costs are expected to raise) and it decreases it when the current marginal cost is large (i.e., when future costs are expected to decrease). This is driven because the cost is persistent and there is discounting: under Mepco, firms will stay in longer in states with lower/higher costs.

To see this intuitively, consider first the incentive to sustain coordination at the lowest possible cost $c = 550$. At this cost, the gain from deviation is the largest possible. Under our assumptions on the transition matrix, in the next period the cost will increase but it cannot be above 580. Mepco slows down the price increase because it cannot be more than Δ. Without Mepco, there is a positive probability that the cost increases by more than Δ. Therefore, under Mepco the marginal cost will likely increase by *less* than it should in the next period, the payoff from coordination is *larger* under Mepco relative to the case of No Mepco. At the other extreme, consider the highest possible marginal cost $c = 850$. Here, the profit from deviation is the lowest possible. In the next period, the cost will decrease but under Mepco it will decrease *less*. Thus, the profit from coordination will increase *less* under Mepco than without Mepco. Therefore, Mepco increases (decreases) coordination profits in the next period when the current marginal cost is low (high). When firms compute the expected discounted payoff of coordination, the profit of the next few periods receive less discounting than periods far away in the future. Thus, as shown in Figure A.2, the expected discounted profit of coordination will be larger (smaller) under Mepco, compared to the case without Mepco, when the current marginal cost is low (high). This intuition is similar to the findings in Haltiwanger and Harrington Jr (1991).

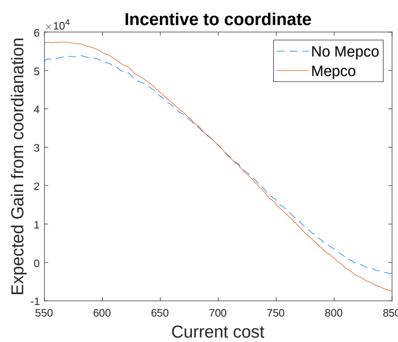
FIGURE A.2: Simulated expected gain from coordination conditional on the current marginal costs faced by firms with and without Mepco.



A.3 Pricing at marginal cost plus a constant margin

We also evaluated the effect of Mepco on coordination when firms use a different pricing strategy for coordination: firms set a constant margin μ, so they price according to $p(c) = c + \mu$. For this specification, we use the same transition matrix as in the previous section, and we assume that firms set a constant margin equal to $\mu = 60$. Figure A.3 shows the incentive to sustain coordination with and without Mepco in this case. The interpretation of the analysis in this case is similar to the one given in the previous section.

FIGURE A.3: Simulated expected gain from coordination conditional on the current marginal costs faced by firms with and without Mepco.



B Summary statistics

Table B.1: Summary statistics

	Mean	Median	Standard deviation
Leadership Intensity	0.381	0.334	0.228
Margins (CLP)	76.409	75.326	21.285
Range (CLP)	7.510	4	11.057
Price matching	0.261	0	0.439
Length of price cycle (Hours)	28.85	22.31	16.12
Number of prices below the leader's	4.294	3	4.005
Number of stations in the market	5.178	4	4.795

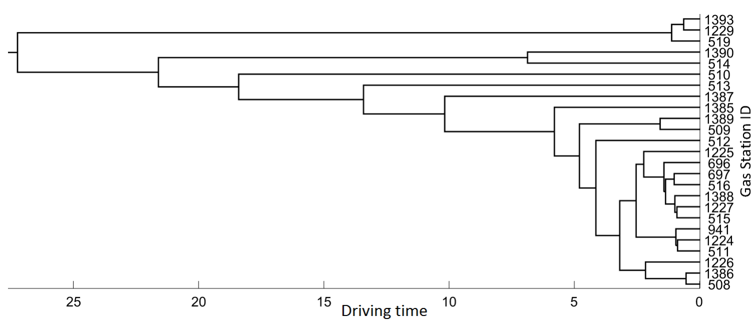
Summary statistics for all variables, but for the number of stations in the market, are computed based on market–week observations. The number of stations in the market is reported based on one observation per market. CLP stands for Chilean pesos per liter.

C Clustering Algorithm

The clustering algorithm begins with each gas station in a different cluster. The algorithm then selects the two closest clusters and links them into a new cluster, which is characterized by a "representative gas station" located at the average distance between the stations that form the new cluster. The algorithm then continues clustering gas stations according to the representative gas station of each new cluster. Based on these clusters, the algorithm constructs a "tree" indicating clusters that have been merged, and also the "height of a link," which corresponds to the distance required to merged two clusters. Eventually, when the distance is large enough, all gas stations are grouped in a single cluster.

Figure C.1 shows part of the hierarchical clustering tree constructed by the algorithm applied to our dataset. In the figure, gas stations 1393 and 1229 are merged into a cluster at a height equal to the driving time between them, which is around 1 minute. That cluster is then merged with gas station 519, located at around 1 minute in driving time from the cluster's representative gas station. Finally, the resulting cluster of three gas stations is merged with another cluster at around 25 minutes in driving time from the 3-station cluster.[22]

FIGURE C.1: Hierarchical Clustering tree from part of our dataset.



In some clustering algorithms, the total number of clusters is set by the researcher (e.g., k-means). In our approach, we do not define the number of clusters ex-ante. Instead, after the hierarchical clustering algorithm builds the hierarchical clustering tree, we need to decide where to "prune" this tree to determine the number of clusters. This "pruning" is based on

[22] An exposition of the hierarchical clustering algorithm can be found in: http://cda.psych.uiuc.edu/multivariate_fall_2012/matlab_help/cluster_analysis.pdf

an *inconsistency measure*, which captures the difference in heights of the clusters below a link in the tree.[23] The larger the inconsistency threshold, the fewer the clusters formed by the algorithm. We chose an inconsistency threshold that pruned the tree at the 90th percentile of the distribution of inconsistency, which creates markets with stations that are both close to each other, but are not artificially small.[24]

[23] For example, gas stations 1393 and 1229 are at the same height, and it takes one minute in driving time to merge them. Adding gas station 519 to this cluster requires one additional minute of driving time. But merging this cluster with the next closest cluster requires around 25 minutes of driving time.

[24] We experimented with different inconsistency thresholds, around the 90th percentile, and our results were robust to these other market definitions.

D Robustness Analysis

In this Appendix, we report the outcome of two exercises meant to examine the robustness of our findings. First, we report the estimates associated with a blocking regression approach in which we first create two indicators to classify markets into categories according to their leadership intensity. One indicator identifies markets with leadership intensity above the median, and the other indicator identifies markets with leadership intensity above 75th percentile. Then, we estimated the likelihood of each market's leadership intensity being above the median or above the 75th percentile, as a function of market characteristics (those used as covariates in Table 1) and average margins before the implementation of Mepco. We then classified markets into bins using the predicted propensity score, and identified whether markets were treated (treated meaning in the top 50 or top 25 percent of the distribution of leadership intensity). When doing this, we take into account that both the propensity scores and covariates must be balanced within each bin. Finally, we estimate Equation 11 within each propensity score bin, and compute the overall effect of the implementation of Mepco as the weighted average of the bin-specific effects. Table D.1 presents the results, which are similar to those reported in Table 4, though slightly smaller and noisier.

Second, we replicate our analysis excluding markets that have competing markets nearby (within one mile). We do this to take into consideration potential spillovers across nearby markets. As with the first robustness exercise, the estimates reported in Table D.2 are similar to those reported in the main text, though noisier.

Table D.1: The effect of Mepco on margins: Propensity-score matching (Logit)

	Above/below median		Top quartile	
	(1)	(2)	(3)	(4)
Leadership	8.707*		14.239***	
	(3.943)		(3.038)	
Leadership intensity$\times$ $1[t \geq \bar{t}]$		-5.147		-6.024**
		(3.115)		(2.704)
Week FE	Yes	Yes	Yes	Yes
Market FE	No	Yes	No	Yes
Observations	48005	48005	49834	49834

Standard errors, clustered at the market level, in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The regressions are estimated restricting the sample to ensure common support, which results in a smaller number of observations in the estimation sample. An observation is a market–week combination.

Table D.2: The effect of Mepco on market outcomes, excluding markets with close neighboors: OLS regressions

	(1)	(2)
Leadership intensity$\times$ $1[t \geq \bar{t}]$	-3.486	-4.138
	(2.686)	(2.568)
Market FE	No	Yes
Week FE	No	Yes
Mean dependent variable	79.07	79.91
Observations	44654	44654
R^2	0.282	0.868

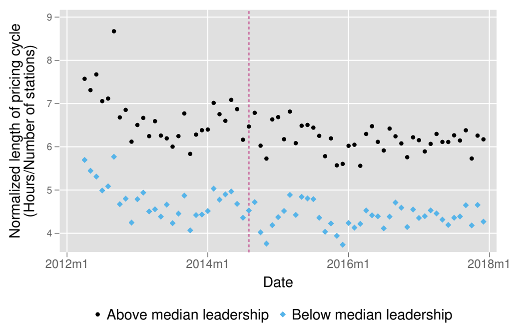
Standard errors, clustered at the market level, in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

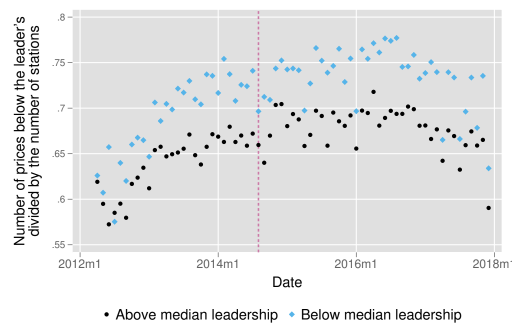
E Evolution of other market outcomes

In this appendix, we report the evolution of the length of the pricing cycle and of the number of prices below that of the market leader (which we normalize by the number of stations in each market), for markets above and below the median of the distribution of leadership intensity.

FIGURE E.1: Length of the pricing cycle and number of prices below the leader's



(a) Normalized length of the pricing cycle



(b) Normalized number of prices below the leader's

Note: The figure presents the evolution of the length of time of the pricing cycle (in hours) for markets above and below the median of the distribution of leadership intensity. The figure also identifies the implementation of Mepco (red vertical line).