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Pricing Coordination in a Spatial Context: Evidence from the Retail Vehicular Natural Gas Market of Lima, Peru

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Pricing Coordination in a Spatial Context: Evidence from the Retail Vehicular Natural Gas Market of Lima, Peru[1]

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ABSTRACT

This paper aims to assess the degree of market power in the Peruvian retail market for Vehicular Natural Gas (VNG) using a generalized spatial competition model proposed by Capozza and Van Order (1978). This model nests Loschian, Hotelling-Smithies, and Greenhut-Ohta models through a single coefficient, so-called the spatial conjectural variation parameter.

This paper exploits the fact that the marginal cost of natural gas is known and constant for all VNG stations due to the regulatory treatment in Peru, which ensures the proper identification of the conjectural variation parameter and gives information about the behavior of pricing coordination among firms.

Our database contains information on retail VNG prices, sold VNG quantities, and other characteristics of 34 counties in Metropolitan Lima and Callao in Peru from 2011 to 2015. The

[1] This paper is a subsequent research of Aurazo and Rojas's thesis to obtain the master's degree in economics at the Pacífico University of Peru, which advisor was Prof. Arturo Vásquez. We thank Francisco Galarza, Diego Winkelried, and the participants at the III Congress of the Peruvian Economic Association (Piura, Peru) for helpful comments. The views expressed in this paper are those of the authors and should not be interpreted as those of their host institutions. All errors and omissions are our own.

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results suggest the existence of some degree of coordination in prices associated with spatial collusion. This result is consistent with the Peruvian Antitrust Authority verdict that determined the existence of a case of price collusion in this retail market in 2019.

JEL Classification: C31 (Cross-Section and Spatial Models), C36 (Instrumental Variables Estimation, GMM), L11 (Pricing and Market Structure), L41 (Horizontal Anticompetitive Practices), L44 (Antitrust Policy), L95 (Gas Utilities, Pipelines), Q4 (Energy).

Keywords: Vehicular Natural Gas, Market Power Measurement, Spatial Competition, Peru, Oligopoly, Generalized Method of Moments, Collusive Behavior, Energy Cartel.

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Coordinación de precios en un contexto espacial: Evidencia del mercado minorista de gas natural vehicular en Lima, Perú[5]

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RESUMEN

Este artículo tiene como objetivo evaluar el grado de poder de mercado en el mercado minorista peruano de Gas Natural Vehicular (GNV) utilizando un modelo de competencia espacial generalizada propuesto por Capozza y Van Order (1978). Este modelo anida los modelos de oligopolio de Loschian, Hotelling-Smithies y Greenhut-Ohta a través de un único coeficiente, el llamado *parámetro de variación conjetural* espacial.

En este trabajo se aprovecha el hecho de que el costo marginal del gas natural es conocido y constante para todas las estaciones de GNV debido al marco regulatorio en el Perú, lo cual asegura la identificación adecuada del parámetro de variación conjetural y brinda información sobre el comportamiento de la coordinación de precios entre empresas. Nuestra base de datos contiene información sobre precios minoristas de GNV, cantidades de GNV vendidas y otras

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[5] Este trabajo es una investigación subsecuente de la tesis de Aurazo y Rojas para obtener el grado de magíster en economía en la Universidad Pacífico del Perú, cuyo asesor fue el profesor Arturo Vásquez. Agradecemos a Francisco Galarza, Diego Winkelried y a los participantes en el III Congreso de la Asociación Peruana (Piura, Perú) por sus comentarios útiles. Las opiniones expresadas en este artículo son las de los autores y no deben interpretarse como las de sus instituciones de acogida. Todos los errores y omisiones son nuestros.

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características de 34 distritos de Lima Metropolitana y Callao en el Perú entre los años de 2011 al 2015. Los resultados sugieren la existencia de cierto grado de coordinación en los precios asociados con a una situación de "colusión espacial". Este resultado es consistente con el veredicto de la Autoridad Antimonopolio del Perú (INDECOPI) que determinó la existencia de un caso de colusión de precios en este mercado minorista en el año 2019.

Clasificación JEL: C31 (Modelos de Corte Transversal y de Tipo Espacial), C36 (Estimación de Variables Instrumentales, GMM), L11 (Fijación de Precios y Estructura de Mercado), L41 (Prácticas Anticompetitivas Horizontales), L44 (Política Antimonopolio), L95 (Servicios Públicos de Gas, Gasoductos), Q4 (Energía).

Palabras clave: Gas Natural Vehicular, Medición del Poder de Mercado, Competencia Espacial, Perú, Oligopolio, Método Generalizado de Momentos, Comportamiento Colusorio, Cartel Energético.

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1. Introduction

Large-scale natural gas supply started in Peru in 2004, and since then, several households and industries (electric generation and manufacturing firms) use this fuel as an input of production. In 2006, this fuel was introduced into the automotive sector, representing a new and more convenient option for drivers and public transportation because it was cheaper than traditional petroleum-based fuels (gasoline or diesel) and favored greenhouse gas reductions. According to Tamayo et al. (2014), Vehicular Natural Gas[9] (VNG) accounted for 30% of total savings in fuel spending for automotive purposes in Peru.

The Peruvian government was interested in its promotion and established some subsidies for new VNG vehicle purchases or vehicular conversions to natural gas and established a promotional price at the wellhead for VNG until September 2012.[10] Besides, the government launched a tariff regulation scheme in non-competitive activities of the natural gas supply chain, such as transportation and distribution, which aimed at recovering costs and promoting efficiency for firms. This regulatory framework guaranteed that firms operating in the retail market (i.e., VNG stations) faced the same marginal costs: constant and known.

Regarding the retail market, in December 2016, the Peruvian Antitrust Authority (INDECOPI for its acronym in Spanish) started investigating some complaints of anticompetitive practices (price collusion) done by 66 VNG firms in Metropolitan Lima and Callao (the capital of Peru) between 2011 and 2015. INDECOPI made public the results of its investigation in 2019, finding evidence of the existence of a *cartel of VNG service stations*. The research also showed evidence of horizontal collusive practices to fix prices above the competitive level.

INDECOPI sanctioned 63 out of 66 VNG firms with a fine for an amount of US$ 145 million and penalized 29 managers for promoting the cartel. Also, it established a compliance program of the competition law among the infringing firms as a corrective policy to deter future collusive practices (INDECOPI, 2018).

This paper aims to determine whether the VNG price data allows finding evidence of a (tacit) collusion in the retail VNG market in Metropolitan Lima and Callao from 2011 to 2015, to evaluate the verdict of INDECOPI, which determined that 63 out of 66 firms were conspiring to set prices in this market. The most common method for assessing collusive behavior is the *conduct parameter method* (Bresnahan, 1982, 1989). This methodology comes from a conjectural variations model and nests three oligopoly models through a conduct parameter: Collusion, Bertrand, and Cournot. The estimation of the conduct parameter gives us the

[9] Vehicular natural gas (VNG) is the name for natural gas used in the automotive sector by natural gas-powered vehicles. It has multiple economic and environmental advantages over other fuels, and its efficiency and sustainability make it an ideal alternative to oil-derived fuels such as gasoline and diesel. It is supplied as Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG). CNG is used by passenger cars, vans, lorries and city buses, while LNG is a fuel used by long-distance heavy lorries and coaches, and also for maritime and rail transport. See for further technical details the *Alternative Fuels Data Center* of the U.S. Department of Energy which is available at: https://afdc.energy.gov/vehicles/natural_gas.html (last access: 12/18/2020), as well as Ma et al. (2013).

[10] The Peruvian government enacted in 2006 the Supreme Decrees Nº 006-2005-EM and Nº 009-2005-EM to establish the rules of procedures to promote the consumption of VNG in the transportation sector. It also negotiated a regulated price of US$ 0.8 / MMBTU for VNG with the *Camisea Consortium* (the operator of the Camisea gas field that provides around 95% of the gas supply in Peru).

conjecture of firms that would yield the price-cost margin observed if firms played a conjectural variation game.

However, this approach is not appropriate for assessing collusive behaviors in the retail VNG market, which exhibits spatial patterns. Note that, despite VNG being a homogeneous product, positive transportation costs and high fixed costs cause differentiation between the VNG from one station to another. Capozza and Van Order (1978) developed a proper theoretical framework for assessing market power in differentiated goods markets. Their framework nests three different spatial competition models through a spatial conjectural variation parameter (SCVP): *Loschian* (a spatial collusive oligopoly), *Hotelling-Smithies*, and *Greenhut-Ohta* (both competitive spatial oligopolies). SCVP represents a firm's belief about its rival's reaction to changes in its price in a spatial market. Subsequent papers have continued developing the welfare analysis of these models (Villegas, 1982), have analyzed the interpretations of the spatial competition models (Watson, 1985), have deepened into the theoretical assumptions of these conjectures (Capozza and Van Order, 1980), and have analyzed the existence of optimal or consistent conjectures (Capozza & Van Order, 1989).

Additionally, several authors have performed some empirical studies for spatially differentiated products in several industries: automobiles (Bresnahan, 1987), instant cereals (Nevo, 2001; Reimer, 2004), gasoline markets (Houde, 2012), breweries (Pinkse & Slade, 2004), among others. Although most of these papers assume a Nash-Bertrand conjecture (firms do not react to rivals' actions), there is not a unique methodology to assess market power in differentiated products and multi-product firms. For instance, Bresnahan (1987) investigated the relations between neighboring products under the premise that only neighbors have any interdependence on the demand side by estimating an indicator so-called Matrix H to observe joint profits. Nevo (2001) calculated the exact economic price-cost margins and distinguishes three sources: the ability to differentiate, a portfolio effect, and price collusion. Similarly, Slade (2004) analyzed price-cost margins and decomposed them into unilateral and coordinated effects (tacit collusion). Despite the several studies for differentiated goods, to the authors' best knowledge, this paper is the first that applies Capozza and Van Order's approach (CVO) to an empirical case. This approach can be instrumental for antitrust cases in non-homogeneous goods markets like the one studied in this paper.

It is important to note that Corts (1998) criticized the conduct parameter method by emphasizing that this parameter fails to measure market power in practice. This critique relies on the argument that this method assumes that supply relations have the same intercept (the marginal cost), which is not necessarily true when firms' behavior follows a non-conjectural variations model. This problem is related to the impossibility of observing the real marginal cost function, which precludes estimating the relation of the margin to the quantity accurately. However, in this paper, the marginal cost's actual value is known *a priori*, and thus, Corts's critique no longer holds.

Recent literature that explores spatial competition in fuel markets focuses on finding the factors that affect firms' pricing behavior. For example, Bergantino et al. (2020) used the number of rivals within a certain length and the nearest neighbor's distance (proxies for spatial competition). They found that retail prices are affected by close rivals rather than far ones. Alderighi and Baudino (2015) found that gasoline and diesel prices are spatially dependent up to 1.1 km; in other words, gas stations react to their rivals' actions at this threshold distance. Pennerstorfer (2009), as well as Pennerstorfer and Weiss (2013) found a positive relationship between density (i.e., the number of stations per inhabitants at a district level) and prices of gasoline stations, while Firgo et al. (2015) found a positive relationship between the stations' degree of centrality and the reaction of retail prices. The methodologies these authors employed are usually IV regressions or spatial autoregressive and spatial error models.

However, the retail VNG markets have received relatively little attention in the literature, although this fuel represents an essential input for transportation activities, especially in Latin-American countries such as Argentina, Brazil, Peru, and Colombia. We can highlight few studies regarding the introduction of VNG in the transportation sector. For instance, Yeh (2007) conducted empirical research considering several countries (such as Argentina[11] and Brazil) adopting alternative fuels for transportation such as natural gas. Besides, Engerer and Horn (2010) evaluated the option to use VNG to substitute oil fuels in Europe, finding that the key reasons to promote the usage of VNG are the mitigation of air pollution in big cities and the exploitation of domestic gas reserves. The authors identified Italy's case as the most successful one in Europe regarding the introduction of VNG as a transportation fuel. Likewise, Ogunlowo, Bristow, and Sohail (2015) analyzed the introduction of compressed natural gas (CNG, which is a variant of VNG) as automotive fuel in Nigeria, finding different legal and regulatory barriers to achieve that goal in this country.

On the other hand, there is scarce research regarding the measuring of market power in VNG markets. One exception is Garcia et al. (2014), who found that the Lerner index in the Colombian VNG market was around 40%, and the retail prices were also affected by variables different from costs.

Our paper contributes to fill this gap regarding the assessment of spatial price coordination in the VNG market considering the experience of Peru as a case study. The article starts from a different perspective from the recent empirical literature. We use a microeconometric model derived from Capozza and Van Order (1978), which nests a parameter that reflects the degree of market competitiveness. We exploit the fact that natural gas's marginal cost is known and constant for all VNG stations due to the regulatory framework for setting gas tariffs in Peru, ensuring the SCVP's identification through the CVO approach. This result allows us to determine whether there exists evidence of collusive practices among VNG stations during 2011-2015.

Therefore, our methodology can be useful for antitrust agencies for determining the existence of price collusion in a spatial context by coordinated movements in prices among firms. We collect most of the data used in this paper from the "Facilito Website," a database managed by the Peruvian Energy and Mining Regulatory Commission (Osinergmin for its acronym in Spanish). On this website, VNG stations self-report their prices. We conduct the econometric analysis using Metropolitan Lima and Callao (the geographic areas that shape Peru's capital, the largest city of the country) as the relevant retail VNG market.

The rest of this paper is structured as follows. Section 2 explains the generalized model of spatial competition proposed by Capozza and Van Order (1978). Section 3 describes the industrial organization and regulation of the Peruvian VNG market, as well as the antitrust case. It also analyzes the database used and discusses the econometric strategy used to assess whether there exists spatial price coordination. Section 4 shows the main results and presents the interpretation of the values estimated for the spatial conjectural variation parameter under

[11] An in-depth analysis of the Argentine case regarding the introduction of VNG can be reviewed in Collantes and Melaina (2011).

different econometric specifications. Finally, we finish the paper drawing some concluding remarks in Section 5.

2. Spatial competition models

This section introduces the Capozza and Van Order's generalized model (CVO), which nests three spatial competition structures, i.e., Löschian, Hotelling-Smithies, and Greenhut-Ohta models, through a single parameter measuring a "spatial conjectural variation." The model considers that the location and the number of firms (i.e., VNG stations) are fixed in the short term. This assumption implies that firms compete in prices, but the zero-profit condition does not hold in the short run, given the market's monopolistic competitive structure.

Let us assume that firm i faces the demand function $q_i(p_i, R_i)$, where q_i is the quantity sold, p_i is the retail price, R_i is the market radius, and consumers face transportation costs $t > 0$. Thus, the indifferent consumer between the two firms is determined by:

$$p_i + tR_i = p_j + tR_j.$$

Let U be the distance between firms i and j, then the market radius of firm i is:

$$p_i + tR_i = p_j + t(U - R_i) \qquad \Rightarrow \qquad R_i = \frac{p_j - p_i}{2t} + \frac{U}{2}. \tag{1}$$

Therefore, a firm's market radius depends positively on its price relative to its rival's price and the distance to the competing firm, but it depends negatively on transportation costs.

From equation (1), three different spatial competition models can arise: a) Löschian, b) Hotelling-Smithies, and c) Greenhut-Ohta. The resulting model will depend on the spatial conjectural variation parameter (SCVP), denoted by $\phi_i = \partial p_j / \partial p_i$, which represents the belief of firm i about its rival's (firm j) reaction to changes in its price. Note that this belief determines the relation between the market radius of firm i and its price:

$$\frac{\partial R_i}{\partial p_i} = \frac{1}{2t}\frac{\partial p_j}{\partial p_i} - \frac{1}{2t} = \frac{1}{2t}[\phi_i - 1]. \tag{2}$$

A conjecture of $\phi_i = 1$ yields a non-competitive spatial oligopoly model, so-called *Löschian Competition*: as the market radius of firm i is fixed regardless of its pricing behavior ($\partial R_i / \partial p_i = 0$), the firm i acts as if it were not facing competition pressure. On the other hand, a conjecture of $\phi_i = 0$ yields the classical spatial competitive model known as *Hotelling-Smithies Competition*, in which the firm's pricing mechanism affects its market radius negatively ($\partial R_i / \partial p_i = -(2t)^{-1} < 0$), so it faces competitive pressure because of a demand loss when increasing prices. Finally, a conjecture of $\phi_i = -1$ yields a model known as *Greenhut-Ohta Competition*[12], in which the radius market of firm i depends negatively on its price, but in a more substantial way than in the previous case ($\partial R_i/\partial p_i = -1/t < 0$). This type of structure implies a more competitive scenario than the Hotelling-Smithies case[13].

The profit function of the firm i is defined as follows:

$$\pi(p_i, R_i) = (p_i - c_i)q_i(p_i, R_i) - F_i \,,$$

where c_i is the marginal cost and F_i is the fixed cost. The first-order condition (also known as the *conduct equation*) is:

$$\frac{\partial \pi_i(p_i, R_i)}{\partial p_i} = q_i + (p_i - c_i)\left[\frac{\partial q_i}{\partial p_i} + \frac{\partial q_i}{\partial R_i}\frac{\partial R_i}{\partial p_i}\right] = 0. \qquad (3)$$

Including equation (2) in equation (3), the conduct equation is:

$$q_i + (p_i - c_i)\frac{\partial q_i}{\partial p_i}\left[1 + \frac{1}{2t}\frac{\partial q_i/\partial R_i}{\partial q_i/\partial p_i}(\phi_i - 1)\right] = 0. \qquad (4)$$

Finally, note that the value of ϕ gives itself relevant information about the spatial market structure, regardless of whether it is equal to any specific value (1, 0, or -1). It gives information about the competition degree in the market. Thus, the parameter can adopt midpoint values among the three classical models. In the next section, we analyze the structure of the VNG industry in Peru, describe our dataset, and explain our econometric approach.

3. Industry description, dataset, and econometric strategy

3.1. Industrial organization and regulation

The natural gas industry in Peru consists of five activities: exploration, extraction, transportation, distribution, and the retail market. The most relevant feature of this industry is

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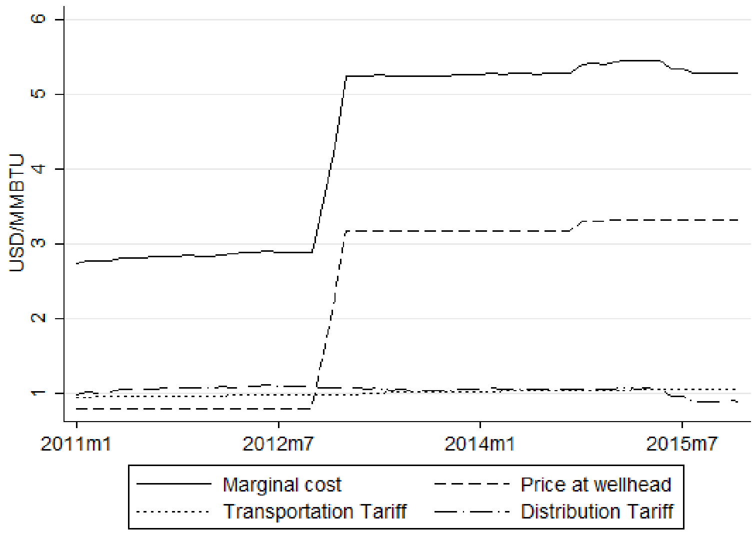
[12] Although the conjecture related to the Greenhut-Ohta Competition seems strange, Watson (1985) shows that this conjecture arises from a profit maximizing behavior, where firms react to a rival's price changes considering its impact on the price-demand elasticity.

[13] Villegas (1982) assessed the models' performance and shows that Hotelling-Smithies and Greenhut-Ohta match the perfectly competitive equilibrium in the limit as fixed cost or as transportation cost approaches zero.

the existence of economies of scale and costs subadditivity in transportation and distribution activities. The Peruvian regulatory framework considers each activity's vertical separation, and it establishes a tariff regulation scheme. The government, through a contractual arrangement with the gas producer (the *Camisea Consortium*), sets a cap on the price at the wellhead[14], and it determines the tariffs for the transportation and distribution activities using an efficiency cost-plus approach, considering a break-even constraint and an annual rate of return of 12%.

This regulatory scheme implies that the unit variable cost of natural gas (a *proxy* of the marginal cost of supplying gas in the VNG retail market) is the sum of three concepts. These are the price at the wellhead, the transportation tariff, and the distribution tariff (the so-called *unitary distribution tariff* or TUD for its Spanish acronym). Figure 1 shows the evolution of these three cost concepts for VNG stations from January 2011 to December 2015. This figure shows the impact of the expiration of the promotional gas price at the wellhead for the vehicular sector in September 2012 on the marginal cost (see note 9).

Figure 1: Evolution of the marginal cost and its components for VNG stations



Source: Osinergmin. Own elaboration.

Although the retail market is a competitive activity (i.e., there are not conditions for the existence of a natural monopoly), it tends to show collusive behaviors. Based on Motta (2004), some features ease this kind of behavior. For instance, the VNG stations exhibit homogeneous costs; their demand for gas from vehicles is continuous and exhibits high variability. Likewise, the stations' owners can inspect collusive deals through their gas price panels, and drivers have low bargaining power.

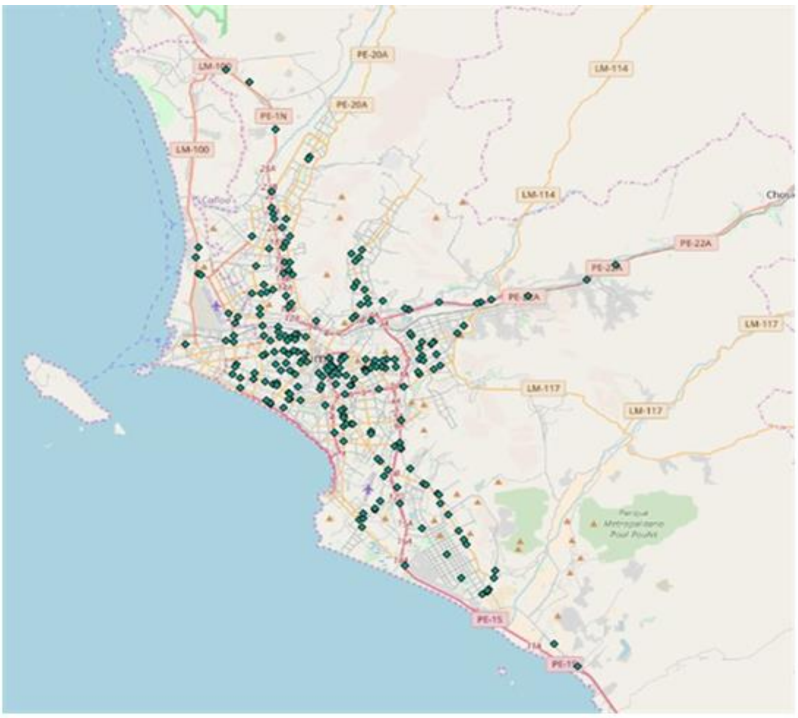
[14] To promote the use of natural gas in the vehicular sector, there was a promotional price of US$ 0.8 per MMBTU until September 2012, and afterwards the VNG price adjusted to the base value of US$ 1.8 per MMBTU, which is the price applicable to other customer categories (electricity generators, manufacturers, households). See for more details Radio Programas Peru (2013). *Gas stations claim that VNG rose because the promotional price ended*. Available at https://rpp.pe/economia/economia/grifos-aseguran-que-gnv-subio-porque-culmino-precio-promocional-noticia-556356 (last access: 05/20/2020).

3.2. The retail VNG market of Metropolitan Lima and Callao

The retail VNG market is an excellent example of spatial competition because of two features. First, VNG is a homogeneous product, which unique differentiation comes from stations' location due to positive transportation costs. Second, high fixed costs generate economies of scale, ensuring that drivers do not supply VNG by themselves. Given these special features, the VNG market provides a unique opportunity to apply the CVO approach to a specific industry for determining the existence of price collusion in spatial competition. As this framework applies to markets operating in the short run, VNG stations' location is exogenous. This proposition is consistent because VNG stations face high costs to move to new places in the short run.

The analysis of this market is relevant since the vehicular sector accounts for almost a third of total energy savings in the Peruvian economy generated by the introduction of natural gas. The main reasons for this result are the lower retail price compared to other vehicle fuels such as diesel or gasoline (around 80%) and the government subsidies for new VNG car purchases (Tamayo et al., 2014). In December 2015, there were 219 658 VNG cars, and the sold quantity of VNG reached a total of 685 million m^3 in Metropolitan Lima and Callao, which concentrates almost 100% of Peru's VNG demand.

Figure 2: VNG Stations located in Metropolitan Lima and Callao, 2011-2015



Source: Osinergmin – Facilito, Energy and Mining Map, INEI. Own elaboration.

From 2011 to 2015, there were approximately 246 VNG stations, which were located in Metropolitan Lima and Callao in 34 out of 50 counties. Those counties with many VNG stations are Lima and La Victoria, with 25 and 23 VNG stations. Also, there are five counties with only 1

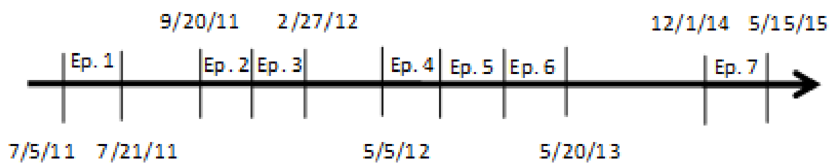
VNG station and three counties with two stations. See Figure 2. The five most significant brands[15] in this market are Primax, Pecsa, Gazel, Repsol, and the state-owned company Petroperu, which account for 69% of 246 VNG stations. These brands are not present in all the counties. The largest one, Primax, owns stations in 30 counties, while Petroperu owns stations only in 11 counties. There are only three counties (Ate, Lima, and San Juan de Lurigancho) where the five largest brands compete simultaneously (see Table 4 in the Appendix). In the next subsection, we describe the antitrust case study against the VNG cartel occurred in Peru.

3.3. Peru's Antitrust Case against a VNG Cartel

As we discussed before, the retail VNG sector has some features of a non-competitive market structure given the spatial distribution of VNG stations. In the case of Peru, the spatial competition induced VNG firms to establish a collusive agreement among them. The Peruvian Antitrust Authority (INDECOPI, for its acronym in Spanish) investigated horizontal collusion among VNG firms in Metropolitan Lima and Callao from 2011 to 2015. INDECOPI found evidence of pricing collusion and sanctioned 63 out of 66 VNG firms[16] imposing a penalty of US$ 145 million to the cartel.

INDECOPI's analysis relied on the inspection of more than 240 emails among VNG firms' managers in which they agreed to set prices in a collusive way. They set price ranges not to violate the collusive agreement and performed strategies to prevent INDECOPI from detecting the price coordination. In addition, emails allowed INDECOPI to establish seven periods between 2011 and 2015 where pricing collusion took place. The first period was from July 5th, 2011 to July 21st, 2011. The second and third periods were from September 20th, 2011 to February 27th, 2012. The three following periods occurred from May 5th, 2012 to May 20th, 2013. Finally the last period was from December 1st, 2014 to May 15th, 2015 (see Figure 3). Once INDECOPI identified these seven periods, it analyzed the existence of parallelism in retail VNG prices only on these dates, taking immediate previous periods as the competitive benchmark.

Figure 3: Collusion periods determined by INDECOPI



Source: Administrative Resolution Nº 104-2018/CLC-INDECOPI. Own elaboration.

The penalty imposed by INDECOPI was one of the largest fines in Peruvian history. Its calculation was based on the illicit benefit that VNG firms had during the collusive periods due

[15] In this paper, large brands are considered as those brands that have more than 10 VNG stations in Metropolitan Lima and Callao.

[16] INDECOPI analyzed the case using the VNG firms rather than VNG stations as the unit of analysis.

to the increase of retail prices. It is important to note that although the most of VNG investigated firms were sanctioned (63 out of 66), the collusive agreement was not perfect, i.e. the whole VNG firms were not necessarily colluding in all the periods. This will have implications in the expected results of our paper, as we should not expect a SCVP's value of 0 or -1. Moreover, the expected value should be greater than zero and lower than one. In other words, there should be observed in the data an imperfect price coordination.

Our paper aims to provide solid evidence of price coordination among VNG firms in Metropolitan Lima and Callao during 2011 and 2015. This econometric exercise constitutes an "after the facts" analysis that should be consistent with the INDECOPI's findings. The next sections describe our dataset and the econometric strategy that we used to analyze spatial price coordination in the VNG market.

3.4. Data

The database contains information on mean retail VNG prices and sold quantities of VNG in 34 counties of Metropolitan Lima and Callao from January 2011 to December 2015 (60 months). The mean price is the average of available retail prices obtained from the "Facilito" website,[17] a database managed by Osinergmin in which VNG stations report their prices. Likewise, we got data on sold quantities for each county from *InfoGas*, which is the entity that manages the National System of VNG loads.[18]

Also, we collected marginal costs directly from the regulatory contracts, which are available at Osinergmin's website.[19] On the other hand, to calculate variables that reflect spatial patterns, we calculated the average distance to the closest neighbor (in kilometers) and the number of rivals within a distance of 1.5km for VNG stations in each county. The geographic locations (i.e., the coordinates of VNG stations) were obtained from the database "Energy and Mining Map" at Osinergmin's website.[20] Finally, we collected data on counties' population and surface area from the National Institute of Statistics and Information (INEI).

Table 1 shows the descriptive statistics.

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[17] Available at: http://www.facilito.gob.pe/facilito/pages/facilito/menuPrecios.jsp (last access: 05/30/2020).

[18] The data on VNG quantities is only available by county and not for each VNG station. Moreover, those counties with only one or two VNG stations are reported into just one category, and we calculated the quantity of m3 for the whole group. See for further details: http://infogas.com.pe/ (last access: 03/17/2021).

[19] In order to convert marginal costs from MMBTU into m^3, a factor of 0,037 is used.

[20] Available at: https://gisem.osinergmin.gob.pe/ (last access: 03/17/2021).

Table 1: Descriptive Statistics

Variable	Description	Obs.	Mean Std. Dev.	Min Max
p_i	Average retail price of VNG stations in county i (PEN per m^3)	1168	1.387 0.18	0.86 1.71
p_j	Average retail VNG price of all counties $j \neq i$ (PEN per m^3)	1168	1.387 0.18	0.93 1.60
q_i	Sold VNG quantity in county i (in millions of m^3)	1353	2.0 1.15	0.2 6.8
c	Marginal cost (PEN per m^3)	2040	0,44 0.13	0.27 0.64
dis_i	Average distance to the closest neighbor (in kilometers) of VNG stations in county i	2040	1.25 0.68	0.31 3.13
$ve_{1.5}$	Average number of rivals within a distance of 1.5 km of VNG stations in county i	2040	2.89 1.56	1 6.75
$density$	Population density by county i	2040	11900 6778	6.0 10.2
$gnvden$	VNG station density by county i	1932	0.53 0.70	0.0 2.75
$grifoden$	Gasoline station density by county i	2040	1.15 0.94	0.02 4.33
$pg90$	Retail price of gasoline 90 at rival's counties	1969	13.13 1.22	9.5 15.2

Source: Osinergmin – Facilito, Google Maps ®, INEI, InfoGas. Own elaboration.

It is essential to point out that Facilito's data suffers from a high degree of missing values because most VNG station does not follow a stable reporting pattern (a report is voluntary). The distortion could suppose a problem because the average retail price of VNG stations can be biased. Therefore, it is necessary to know if the stations reported price quotations as if they came from a random and independent distribution.

For that purpose, we follow Firgo et al. (2015) to estimate a cross-sectional probit regression to explain which factors affect the probability of reporting prices. We describe this approach in detail in Annex B. Our results show that, although VNG prices are not sampled entirely at random, the deterministic factor plays an irrelevant role when we assess the data at a county level. In other words, the systematic patterns found in the selection process are not likely to affect the average retail prices and, thus, it would not bias our econometric analysis.

3.5. Econometric strategy

This paper aims to test whether the retail VNG market relates to a specific spatial competition model in Metropolitan Lima and Callao during 2011-2015. In the CVO approach, the critical parameter is ϕ which shows the belief on how rival firms react from variations in the price and, thus, associate it to a specific spatial competition model.

Let us assume the following demand function proposed by Claycombe (1991):

$$q_i(p_i, p_j, R_i) = 2dR_i(a - bp_i). \qquad (4)$$

This specific function is reasonable in a spatial context because the consumer makes her decision in two stages: first, she chooses the gas station which gives her the largest utility, and then, she selects the quantity of VNG, which depends entirely on the station's retail price, given that once in the station, the consumer perceives transportation costs as sunk. Therefore, transportation costs influence the demand only through the market radius. Thus, we obtain the demand function of interest by replacing equation (1) into (4):

$$q_i = d[aU - (\frac{a}{t} + bU)p_i + \frac{a}{t}p_j - \frac{b}{t}p_i p_j + \frac{b}{t}p_i^2]. \quad (5)$$

As our database contains retail prices and sold quantities of VNG by counties, we interpret the analysis unit as county representative firms competing in a spatial market. This outcome implies that VNG is a homogeneous good at some point (i.e., drivers are indifferent among VNG stations located in the same county).

Thus, the econometric specification of the demand function for the representative VNG station in county i in period t is defined by the following reduced form:

$$q_{it} = \beta_0 + \beta_1 p_{it} + \beta_2 p_{jt} + \beta_3 p_{it} p_{jt} + \beta_4 p_{it}^2 + \varepsilon_{it}, \quad (6)$$

where p_{it} is the mean price of the representative VNG station in county i in period t, p_{jt} is the mean price of all representative VNG stations in counties $j \neq i$ in period t, q_{it} is the sold VNG quantity of the representative VNG station in county i in period t and ε_{it} is the error term.

Then, replacing the first-order condition of (6) with respect to p_{it} in (3), we obtain the econometric specification of the conduct equation for the representative VNG station in county i in period t:

$$q_{it} + (p_{it} - c_t)\left[\beta_1 + \beta_2\phi + \beta_3 p_{jt} + \beta_3\phi p_{it} + 2\beta_4 p_{it}\right] + \eta_{it} = 0, \quad (7)$$

where η_{it} are the error terms. Note that the marginal cost in period t is taken as constant for all the VNG stations because the governmental regulation establishes it.

Notice that the parameters in equation (7) should hold some conditions derived from equation (5): i) the regressors of $p_j$and p_i^2 must be positive ($\beta_2, \beta_4 > 0$), and ii) the regressor of $p_{it}\, p_{jt}$must be negative ($\beta_3 < 0$). Besides, as a result of the aggregation of firms by counties, the distance U is no longer an absolute value, but a relative distance, so we cannot say anything about $\beta_0$and β_1. Regarding ϕ, it can take a value between -1 and 1 since those values are the extreme theoretical market structures (spatial collusion and spatial competition *a la* Greenhut-Ohta). However, as it was discussed above, the value of ϕ is expected to be greater than zero but less than 1, which implies that existence of a certain degree of price coordination in the period analyzed, which in turn means that the market was not competitive, but it did not exhibit a state of perfect collusion.

Because equations (6) and (7) are simultaneous and non-linear, we use Hansen's (1982) Generalized Method of Moments (GMM) to estimate our parameter of interest: ϕ. The reader could notice that p_{it}, p_{jt}, and q_{it} are simultaneously determined, so there is an endogeneity problem. To overcome this problem, we use instrumental variables, which should be orthogonal and relevant. For the demand function (Equation 6), instrumental variables should affect the quantity q_i only through p_i and p_j. The most commonly used instrumental variables are their lags and the retail price of a substitute fuel such as gasoline of 90 octanes (a widely used fuel in Peru that is a substitute of VNG). For the conduct equation (Equation 7), we must use instrumental variables on q_i and p_j that impact the price p_i only through those variables. In this case, variables that capture the number of consumers for each representative VNG station, as population density, VNG stations density, or gasoline stations density, should work fine as instruments for q_i, whereas variables that capture the degree of competition as the average number of rival VNG stations within 1.5 km in a county, or the average distance to the nearest VNG station in a county should work well as instruments for p_j. We perform Hansen's test to validate these instruments.

We employ a robust procedure to calculate our model parameters' standard errors to control the variability of the potential existence of spatial and serial correlation in our data, using a heteroskedasticity and autocorrelation consistent (HAC) covariance matrix estimation method proposed by Conley (1999).[21] Our approach allows obtaining consistent estimates even in the presence of arbitrary contemporaneous cross-sectional correlation, which is likely to encompass most forms of spatial correlations encountered in practice.

4. Results

To address serial and spatial correlation's potential existence, we run the regressions using a HAC weighting matrix using the Bartlett kernel proposed by Newey and West (1984). Table 2 exhibits six separate regressions for our econometric specification, with several instrumental variables to check robustness. The results show that the conjectural variation ϕ is around 0.55, which seems to be robust to different instrument specifications, and it is a statistically significant value. Since the estimation considers average prices and quantities at the county level, ϕ can be interpreted as the average conjectural variation parameter of VNG stations in Metropolitan Lima and Callao during 2011-2015.

Our results also show that some of the remaining parameters are statistically significant at 10% or 5% for specifications (5) and (6). To validate the instruments used in the regressions, we run the Hansen's test. Table 2 shows that the six regressions instrument sets are valid to identify the demand and supply equations.

[21] Conley's GMM approach to control cross sectional dependence is based on Kraay and Driscoll's (1995) research who proposed a method to calculate robust standard errors to correct for spatial correlation in panel data econometric models. The spatial covariance estimator proposed by Conley is an application of Hansen's (1982) generalized method of moments estimator (GMM) to spatial error autocorrelation. This estimator involves minimizing a quadratic form in the sample moment conditions, where the covariance matrix is obtained in non-parametric form using a Bartlett window estimation following Newey and West (1984).

*Table 2: Estimations Results**

	(1)	(2)	(3)	(4)	(5)	(6)
β_0	-11.686+	-11.377+	-6.567+	-6.277+	-14.733*	-14.585*
	[6.490]	[6.518]	[3.631]	[3.667]	[6.011]	[6.023]
β_1	-23.807	-24.752	-15.087	-15.582	-24.599	-26.09
	[18.452]	[17.914]	[12.353]	[12.405]	[21.862]	[21.617]
β_2	43.232+	43.767+	26.799+	26.909+	48.801*	50.133*
	[22.412]	[22.466]	[14.301]	[14.569]	[23.424]	[23.560]
β_3	-26.731+	-26.979+	-14.473+	-14.426+	-31.627*	-32.481*
	[14.917]	[15.127]	[8.517]	[8.735]	[15.105]	[15.291]
β_4	19.973	20.366	10.566	10.654	23.032	23.937+
	[12.856]	[12.879]	[7.607]	[7.748]	[14.187]	[14.231]
ϕ	0.545**	0.559**	0.548**	0.558**	0.497*	0.514*
	[0.198]	[0.182]	[0.188]	[0.183]	[0.235]	[0.220]
Instruments Demand Eq.	L.pi L.pj	L.pi L.pj pg90	L.pi L.pj	L.pi L.pj pg90	L.pi L.pj	L.pi L.pj pg90
Instruments Conduct Eq.	density dis	density dis	gnvden ve15	gnvden ve15	grifoden dis	grifoden dis
Hansen's test (p-value)	0.765	0.945	0.744	0.946	0.491	0.751
Obs.	729	715	729	715	729	715

Estimations are based on HAC standard errors. Standard errors are in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05, + p<0.1. L.pi and L.pj are lagged prices in one-month. Source: Own elaboration.

It is important to point out that the results are consistent with our priors, as $\beta_2, \beta_4 > 0$, $\beta_3 < 0$ and $\phi \in (-1, 1)$. Even when at first hand it is not possible to associate the retail VNG market of Metropolitan Lima and Callao to a specific spatial competition model, the values of ϕ indicate some degree of price coordination, which in turn suggest the existence of a non-competitive market. It is possible to validate this proposition by calculating the confidence intervals of ϕ at a 95% level.

As Table 3 shows, the intervals of ϕ never take the zero value, which means that we can reject the existence of a Hotelling-Smithies competition structure in Lima and Callao's VNG market. We also can reject the presence of Greenhut-Ohta competition in this market since the intervals do not cover the value of -1. However, it is essential to note that the upper bounds of the confidence intervals for different instruments' configurations are close to one, which means that it is more likely that a Loschian collusive oligopoly existed in Lima and Callao's VNG market during the period 2011-2015. This empirical evidence is consistent with the Peruvian Antitrust Commission's (INDECOPI) findings regarding the discovery of a cartel of VNG stations in Metropolitan Lima and Callao during that period.

Table 3: 95% Confidence Intervals for the Spatial Conjectural Parameter

	(1)	(2)	(3)	(4)	(5)	(6)
ϕ	0.545**	0.559**	0.548**	0.558**	0.497*	0.514*
95% Confidence interval	[0.157, 0.934]	[0.203, 0.916]	[0.179, 0.917]	[0.200, 0.916]	[0.036, 0.958]	[0.083, 0.945]
Instruments Demand Eq.	L.pi L.pj	L.pi L.pj pg90	L.pi L.pj	L.pi L.pj pg90	L.pi L.pj	L.pi L.pj pg90
Instruments Conduct Eq.	density dis	density dis	gnvden ve15	gnvden ve15	grifoden dis	grifoden dis
Obs.	729	715	729	715	729	715

The estimations of confidence intervals are based on HAC standard errors. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, + $p<0.1$. L.pi and L.pj are lagged prices in one-month. Source: Own elaboration.

5. Concluding remarks

This paper applies the framework developed by Capozza and Van Order (1978) to determine the existence of collusive behaviors among VNG stations in Metropolitan Lima and Callao from 2011 to 2015. Given that VNG is a homogeneous product, which unique differentiation comes from the location of the stations that sell it and the high fixed costs to supply it, the VNG market matches a spatial competition model's structure.

The paper aims to estimating the spatial conjectural variation parameter that reflects the belief of how rival firms react to changes in a firm's price over the space and approximately measures the pricing behavior of VNG stations. The value of the conjecture can be associated with Loschian (value of 1), Hotelling-Smithies (value of 0), or Greenhut-Ohta (value of -1) competition structures, as well as with a midpoint among these market structures. The first structure relates to a collusive market. The other ones relate to competitive oligopolistic markets.

The results show an estimated value of the spatial conjectural variation parameter around 0.55, which suggests some degree of a collusive behavior among VNG stations during 2011-2015. Our results are robust to using different instruments sets. We also control for the presence of heteroskedasticity and spatial autocorrelation in our dataset using HAC standard during the estimation of the spatial conjectural variation parameter and the rest of our model's coefficients. In addition, these results are obtained considering a representative firm at a county level, so our findings must be interpreted as the existence of intercounty price coordination rather than coordination among VNG firms.

Our empirical results indicate some degree of collusive behavior in the retail VNG market in Metropolitan Lima and Callao. This outcome is consistent with the Peruvian Antitrust Authority's finding that determined the existence of collusive practices in the retail VNG market. However, it is essential to mention that our results should not necessarily be interpreted as the existence of explicit agreements among VNG stations, as the price coordination detected in our econometric exercise can be the result of firms following the pricing behavior of the most significant leader firms. In this case, the agents could have used the "Facilito" website as a focal point for coordinating prices. Antitrust authorities can only prove an explicit collusion case when they find hard evidence of a cartel such as emails, written agreements, chats, phone calls, or coordination meetings.

In sum, our paper shows the validity of Capozza and Van Order's (1978) general model of spatial competition to detect evidence of coordinated price movements during the initial stages of an investigation about collusion in energy markets. We use a real-world antitrust case study involving an energy market that occurred in Peru to demonstrate the usefulness of the CVO approach. This framework can be a useful tool for antitrust authorities at the early stages of a cartel investigation in energy markets because it allows assessing pricing behaviors when a well-defined spatial structure characterizes the markets of interest (such as the ones of gasoline or LPG) and when the competition authorities can know the marginal cost of production of the market (e.g., this can occur in energy markets subject to some price regulation).

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7. Appendix

7.1. Annex A: Supplementary Table

Table 4: VNG Stations by County and Brand

County / Brands	Others	Petroperu	Repsol	Gazel	Pecsa	Primax	Total
Ate	4	2	3	1	4	4	18
Breña	3	-	-	1	2	1	7
Callao	8	-	2	1	1	2	14
Chaclacayo	-	-	-	-	-	1	1
Chorrillos	1	-	2	1	-	2	6
Comas	1	1	-	-	-	2	4
El Agustino	-	1	-	-	-	-	1
Independencia	3	-	1	-	-	2	6
Jesus Maria	-	-	-	-	-	2	2
La Molina	1	-	-	1	1	2	5
La Victoria	8	-	2	3	4	7	23
Lima	9	4	1	2	3	6	25
Lince	-	-	-	-	1	1	2
Los Olivos	3	1	1	3	2	-	10
Lurigancho	-	-	-	1	1	2	4
Lurin	1	-	-	2	-	-	3
Magdalena del Mar	2	-	-	-	2	4	8
Miraflores	-	-	-	-	1	1	2
Pachacamac	-	-	-	-	-	1	1
Pueblo Libre	5	-	-	-	1	1	7
Puente Piedra	1	-	-	-	1	1	3
Rimac	-	-	-	1	-	-	1
San Borja	-	-	-	-	1	-	1
San Isidro	-	-	-	-	-	3	3
San Juan de Lurigancho	5	2	3	2	3	2	17
San Juan de Miraflores	-	2	2	-	-	4	8
San Luis	5	-	-	-	1	2	8
San Martin de Porres	4	1	-	1	1	3	10
San Miguel	1	-	-	1	2	4	8
Santa Anita	1	1	-	-	1	-	3
Santiago de Surco	2	-	1	2	3	3	11
Surquillo	3	-	2	2	2	1	10
Villa El Salvador	3	-	2	1	-	1	7
Villa Maria del Triunfo	3	1	2	-	-	1	7
Total	77	16	24	26	38	66	246

Source: Osinergmin – Facilito, Google Maps ®, INEI, InfoGas. Source: Own elaboration.

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7.2. Annex B: Analysis of data on retail prices of VNG

Following Firgo et al. (2015), we estimate a cross-sectional probit regression where the binary dependent variable, p, takes a value of 1 if the retail price at a VNG station is observed in a specific month and zero otherwise. We include variables as independent variables of a VNG station's different characteristics, such as the distance to the nearest neighbor, the number of rivals within several kilometers, the existence of a convenience store, dummies for the five largest brands, among others.

The results show that the nearest neighbor's distance and being branded as Gazel are statistically significant (see Table 5). The marginal effect of this variable increases the probability of reporting retail price by 10%. Despite this marginal effect, Gazel's market share of VNG stations within each county is not relevant, which is crucial for our econometric technique. Our estimations are done by county instead of by VNG station. The rest of the brands and variables, except for the number of rivals within 0.5 kilometers, are not statistically significant.

Table 5: Selection Model of reporting VNG Prices (marginal effects)

	(1)	(2) k = 0.5km	(3) k = 1km	(4) k = 1.5km	(5) k = 2km
dis	-0.04*** (0.01)	-0.05*** (0.01)	-0.04*** (0.01)	-0.04*** (0.01)	-0.04*** (0.01)
$lnden$	0.23 (0.24)	0.24 (0.24)	0.23 (0.24)	0.23 (0.24)	0.23 (0.23)
$store$	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)	0.01 (0.00)
ve_k		-0.05** (0.02)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
PETROPERU	0.04 (0.05)	0.05 (0.04)	0.04 (0.05)	0.04 (0.05)	0.04 (0.05)
REPSOL	0.00 (0.03)	0.00 (0.03)	0.00 (0.03)	0.00 (0.03)	0.00 (0.03)
GAZEL	0.10*** (0.03)	0.10*** (0.03)	0.10*** (0.03)	0.10*** (0.03)	0.10*** (0.03)
PECSA	0.04 (0.03)	0.04 (0.03)	0.04 (0.03)	0.04 (0.03)	0.04 (0.03)
PRIMAX	0.04 (0.02)	0.03 (0.02)	0.03 (0.02)	0.03 (0.02)	0.04 (0.02)
Dummy for missing values	yes	yes	Yes	yes	yes
Dummy for counties	yes	yes	Yes	yes	yes
Time-period fixed effects	yes	yes	Yes	yes	yes
Obs.	14646	14646	14646	14646	14646
Pseudo R^2	0.2411	0.2443	0.2414	0.2412	0.2411

* p < 0.10, ** p < 0.05, *** p < 0.01. t-statistics in parentheses; standard errors clustered by station. Source: Own elaboration.

Therefore, although prices are not sampled entirely at random, the probit model allows us to conclude that the deterministic factor plays an irrelevant role in assessing the county level. In other words, the systematic patterns found in the selection process are not likely to affect the predictions of the generalized model of spatial competition, and the estimations using this database will not be biased.

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