Trade flows in a spatial oligopoly: gravity fits well, but what does it explain?

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Abstract. Large distance and border effects on trade flows in some industries may result from the collusive division of geographic markets. In the Brazilian cement industry, traditional gravity equations fit the data well, yet limited regional flows are due to firms' strategic behaviour. Thanks to a unique institutional setting and an unusually rich data set, I directly control for trade costs, which – despite their importance – cannot account for the observed segmentation of local markets at current prices. The paper highlights how collusive behaviour can magnify the effects of distance, as firms use geography to coordinate on higher prices and less cross-hauling. JEL classification: D43, F12

Les flux de commerce dans un oligopole spatial : les équations de gravité s'ajustent bien aux données mais qu'est-ce qu'elles expliquent?. Les effets de grande distance et de frontières sur les flux de commerce dans certaines industries peuvent être le résultat d'une division collusive des marchés géographiques. Dans l'industrie brésilienne du ciment, les équations de gravité s'ajustent bien aux données, mais les flux régionaux limités entre régions sont attribuables au comportement stratégique des firmes. Grâce à un contexte institutionnel unique et à une base de données inhabituelles, l'auteur a pu prendre en compte directement les coûts du commerce qui – malgré leur importance – ne peuvent pas expliquer la segmentation observée des marchés locaux aux prix courants. Le mémoire met en lumière comment le comportement de collusion peut magnifier les effets de distance à proportion que les firmes utilisent la géographie pour assurer une coordination fondée sur des prix plus élevés et moins de transport transfrontalier.

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> Some intermediate goods industries like cement, wooden products, and forging rank among the highest border effects. We speculate that low volumes of trade in some of these industries may be the consequences of collusive industry practices, such as exclusive territories.
> Head and Mayer (2000, 303), on the magnitude and causes of market fragmentation in the EU

1. Introduction

The gravity equation of trade, by which trade flows decrease in distance and increase in market size, has been described as 'one of the greater success stories in empirical economics' (Feenstra, Markusen, and Rose 2001, 431), and 'one of the most important results about trade flows' (Evenett and Keller 2002, 282). Different theories that predict gravity have been developed,[1] yet the economic primitives that are backed out on estimating such models remain controversial. For example, researchers puzzle over the large magnitude of the estimated effect of distance on trade, and why it does not appear to be falling over time (e.g., Grossman 1998). Disdier and Head (2008) conduct a meta-analysis of the estimated distance effect, finding a mean effect of about (negative) 0.9, with 90% of estimates lying between 0.3 and 1.6, stating that 'Distance effects of this magnitude pose an important unsolved puzzle. They almost certainly do not arise solely from transport costs' (2). Similarly, recent research studies a large observed effect of border crossings on trade (e.g., Head and Ries 2001; Anderson and van Wincoop 2003).

This paper highlights the role that firms' oligopolistic behaviour can play in generating the observed gravity pattern of trade in some industries. I examine the case of the Brazilian cement oligopoly over the 1990s and provide evidence that, at the prevailing price levels, limited trade flows between regions resulted directly from the (tacitly or explicitly) collusive allocation of geographic markets among producers. The benefits of looking at a specific industry within a domestic setting are the richness of the data that might be observed by the researcher only at this level and the homogeneity of institutions across space. The Brazilian cement industry is unique in several respects. It operates in a country of continental dimensions, where public policy has historically pursued integration among its federative states. Brazil being a large developing economy, the construction sector is important. The good produced is quintessentially homogeneous, and its bulkiness relative to value makes transport a key component of cost. The industry uses simple, off-the-shelf (though capital intensive) technology, so a measure of plant marginal cost can reasonably be constructed from observed factor prices (e.g.,

1 In addition to the obvious role of transport (trade) costs, theories typically model either consumers' taste for variety (e.g., Anderson 1979; Bergstrand 1989; Anderson and van Wincoop 2003) or firm-level cost heterogeneity (as in the Ricardian model of Eaton and Kortum 2002). Deardorff (1995) criticizes the estimation of gravity equations to test among trade theories, on the grounds that gravity is 'not evidence of anything, but just a fact of life' (9).

the price of fuel oil) and plant characteristics (the fuel economy of the kiln). The industry exhibits high concentration of ownership and sales (i.e., the penetration of imports is low), and has operated in a fairly lax antitrust environment, which has favoured the compilation of data by the industry's trade association (spatial cement flows in particular, used in this study). From the cement industry's joint planning of capacity and prices with the government in the 1980s, to Brazil's introduction of antitrust policy in the 1990s, the Antitrust Authorities have most recently (starting in 2007) been prosecuting the cement industry for conspiring to divide markets and fix prices.[2]

I begin by spelling out the simple theoretical argument. I consider Brander and Krugman's (1983) homogeneous-good spatial Cournot oligopoly (as well as extensions) and point out that, were firms to coordinate to maximize joint profits rather than to compete in quantities, trade flows to 'home' markets would rise at the expense of trade flows to 'away' markets, given firms' desire to save on transport costs (Pinto 1986). (In a differentiated-product spatial oligopoly, Deltas, Salvo, and Vasconcelos 2009 show that inter-market trade flows similarly fall when firms switch from competition in *prices* to the fully collusive regime.) This 'home-market principle,' by which a firm is given preference in supplying its home region – where, say, its production facilities are located – at the expense of supplying other regional markets, has been identified in several real world cartels (Harrington 2006). Thanks to the allocation of territories, whether divided along jurisdictional or virtual boundaries, collusive behaviour can help account for large distance and border effects in certain industries.

Having framed the theoretical possibility, I then illustrate empirically. In a first part, I summarize firm-level spatial flows (both positive and zero-valued) in Brazilian cement by estimating a number of traditional gravity specifications. Cement flows from plants to local markets decay sharply in distance travelled *and* in state borders crossed. For example, on estimating a certain multiplicative gravity model using Poisson pseudo-maximum-likelihood (Santos Silva and Tenreyro 2006), a 1% increase in a firm's plants' average distance to a market is associated with a highly significant 1.7% reduction in flows. On top of that, reaching an out-of-state market is associated with shipments shrinking by 54% (also 1% significance) relative to serving an equally distant in-state market. The large state border effect is particularly puzzling in light of the institutions at hand, for example, the homogeneity of cement (any consumer home bias should be minimal) and the integration of Brazilian states (somewhat favourable tax treatment on inter-state flows relative to in-state shipments). At this point, any 'speculation' that the industry allocated customers or territories along verifiable state lines – consistent with the formatting of reports compiled privately by its trade association – seems quite real. It is hard to rationalize trade impediments

2 The findings of my paper predate – and so are not influenced by – the antitrust case in progress. I take no position as to whether any collusive arrangement was tacit or explicit.

of this magnitude at intra-national state borders, other than through strategic behaviour.

In a second, and final, part, I combine the cement flow data with local prices and (plant and transport) costs that I observe – and thus can directly control for – to examine the nature of firm competition. I base a structural test of firm-level conduct off the Cournot first-order-condition, allowing me to disentangle strategic behaviour from trade costs. Observed supply choices that are inconsistent with Cournot – for example, a firm's zero-shipment decision to a market located not too far from its plant that delivered marginal cost would still comfortably come in lower than market price – lead to rejection of a null hypothesis of Cournot behaviour in favour of the alternative of 'more collusive' behaviour.

The test identifies many instances in the data where a firm substantially undersupplied local markets (relative to the Cournot benchmark) in exchange for its rivals' giving it a large share in certain local markets. These large-share markets tended to be located around the firm's plants. This 'market-swapping' pattern is neatly illustrated by the supply of two firms – Votorantim and Brennand – to two small neighbouring markets – the states of Sergipe and Alagoas – in 1996. Votorantim owned a plant in Sergipe and Brennand owned a plant in Alagoas. Votorantim had an 89% share of the Sergipe market, where it had a plant, while commanding a low 7% share of the Alagoas market across the state border but still right next door to its Sergipe-based plant. In exchange, Brennand had an 83% share of the Alagoas market, where it had a plant, while not even shipping across the border to Sergipe. Importantly, at the prevailing price and cost, it would have been highly profitable, in a static sense, for Alagoas-based Brennand to serve buyers in Sergipe, but it chose not to. (Notice that the test conditions on observed plant location and ownership; it does not explain plant configurations.)

This paper thus presents solid evidence that large distance and border effects in some spatial industries may owe (directly) to collusion. To the best of my knowledge, no other empirical study has been able to go to such lengths in examining firms' spatial supply choices while directly controlling for trade costs. Many theories in the trade literature feature gravity in equilibrium, but they do not allow for strategic behaviour in oligopoly. Yet recent evidence indicates that cartels are an important phenomenon in the contemporary global economy. Levenstein and Suslow (2004), for example, selectively count 42 private and explicit international cartels in a wide range of industries that were successfully prosecuted by the U.S. or the European Commission during the 1990s for price fixing or dividing markets. Motta (2004, 141) and Kaplow and Shapiro (2007, 1099) describe market allocation schemes as prevalent. In the international methionine cartel, states Harrington (2006, 35–6), 'the home-market principle was, in fact, the instigating factor for cartel formation.' Examining European cement markets, Röller and Steen (2006, 324), like Head and Mayer (2000), conclude that 'competition is a multimarket game where credible threats to enter each other's markets prevent firms from entering other countries.' The Brazilian cement case suggests that borders, because of their verifiable nature, may play a central role in helping oligopolies coordinate on outcomes. The message of the paper is related to that of Blum and Goldfarb (2006), where a large estimated distance effect in the trade of digital goods over the internet leads the authors to conclude that distance may proxy for consumer tastes, or cultural similarity, and 'that trade costs cannot account for the entire distance effect found in previous gravity studies' (2). My findings suggest that strategic behaviour might help explain the prevalence of zeros in the trade flow data of certain oligopolistic industries.

In what follows, section 2 makes the theoretical argument and section 3 presents the empirical application: section 3.1 discusses data and institutions, section 3.2 (part A) shows that Brazilian cement flows exhibit gravity-like structure, and section 3.3 (part B) places a lower bound on the collusiveness of firm conduct. Section 4 concludes.

2. Theoretical argument

I consider a widely used partial-equilibrium spatial oligopoly model. My objective is to frame the theoretical possibility that I will subsequently illustrate empirically. I begin by laying out the simplest setting and then make it somewhat more general.

Consider two symmetric local markets (or regions), $l \in \{A, B\}$, with 'atomistic' demand for a homogeneous product given by $q_l = D(p_l)$, where p_l is the local price. Endow each region with $n_l = 1$ firm (and there are barriers to entry). Each firm incurs a constant marginal cost c to serve its home region and an additional unit trade cost $t > 0$ to cross-haul product to the 'away' region. Local market demand is atomistic in the sense that there is no further spatial differentiation within a region.

The top panel of figure 1 depicts, for a given local market, equilibrium quantities supplied by the home firm and the away firm in two benchmark models of oligopolistic behaviour: Cournot competition and full collusion (or monopoly, where producer establishments in the two local markets have the same owner). The flatter line represents the home firm's Cournot reaction function, given the away firm's supply to the local market. The steep line represents the away firm's Cournot reaction function, given the home firm's supply. As drawn, the Cournot equilibrium outcome, marked C, is an interior solution and there is cross-hauling by the away firm. Supply to the other local market is analogous, with the two firms reversing their market shares. Under Cournot competition – and assuming that the trade cost t is not too high, as raising t would shift the away firm's reaction function in – trade flows between the two regions are positive (Brander and Krugman 1983). Notice that, empirically, should we observe a local market outcome lying beneath the away firm's Cournot reaction function (i.e., in the shaded area), this can be taken as evidence that the away firm's supply decision toward the local market is 'more collusive' than is consistent with Cournot.

Now consider the behaviour of a perfect cartel. The solution that maximizes total industry profit clearly involves no cross-hauling, with each producer selling

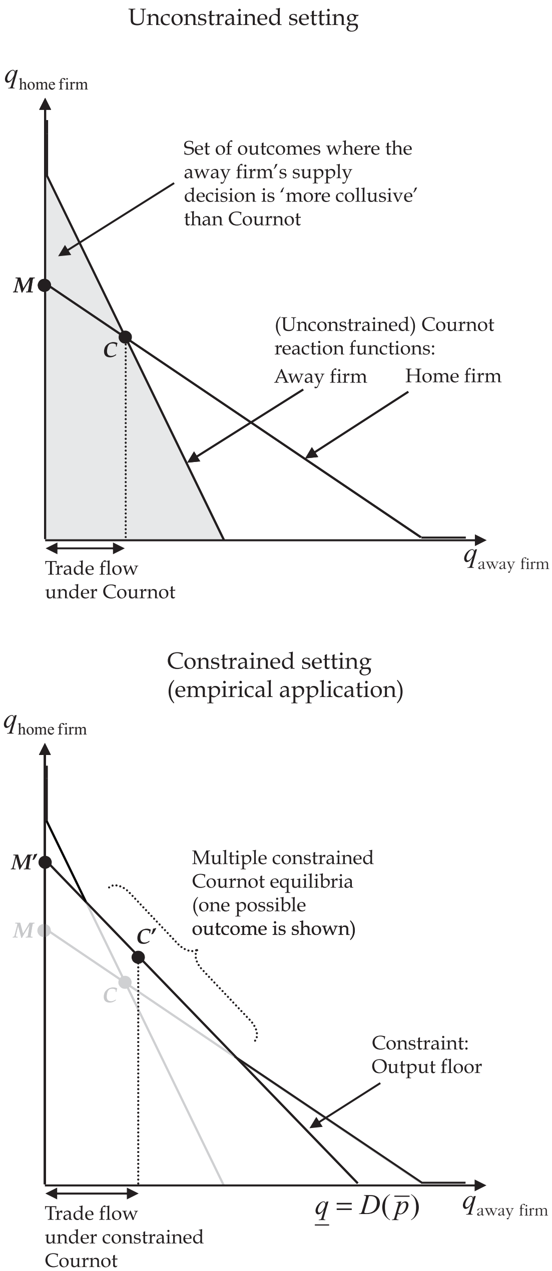


FIGURE 1 A region (local market) in the simple two-region model. Trade flows between regions are positive in the Cournot oligopoly (C or C') but zero in the fully collusive (joint profit maximizing, or monopoly) outcome (M or M'). Top panel (base setting): An (unconstrained) local market. Lower panel (extension): The local market is constrained by an exogenous price ceiling or, equivalently, output floor.

only to its home region (Pinto 1986). Trade flows are zero and there is complete market division. This is marked M ('monopoly') in the top panel of figure 1. With side payments ruled out (and independent producers), this fully collusive outcome can be sustained by pooling incentive constraints across the two regions. For sufficiently patient firms, a firm's share in its home region, where it enjoys low cost, can be increased at the expense of its share in the more distant region where its rival is located (Bernheim and Whinston 1990). Intuitively, invading a rival's allotted market today would trigger a costly tit for tat response in the home market in the future.[3]

I now extend this result of more collusive behaviour – M versus C – being associated with a higher prevalence of zeros (or less trade) in the trade flow data of certain oligopolistic industries. I do so in two directions. The first direction incorporates a specific feature of the subsequent empirical application, where I need to control for the presence of a price ceiling. Imagine that an 'external' constraint may bind on outcomes, say, owing to a regulatory threat or to an entry threat (I return to this point in the empirical illustration). In the bottom panel of figure 1, again for a given local market, this price ceiling $\bar{p}$ is drawn as an output floor $\underline{q} = D(\bar{p})$. As drawn, the limit output binds and aggregate quantity exceeds the earlier unconstrained Cournot quantity, thus also exceeding the unconstrained fully collusive quantity. However, even in this constrained setting, Cournot behaviour similarly involves higher trade flows relative to full collusion. To see this, notice that a Cournot firm's reaction function is given by the outer envelope to its earlier unconstrained reaction function and the output floor $\underline{q}$.[4] As such, there are now multiple Cournot equilibria C' associated with all but extreme market shares: again, there is cross-hauling by the away firm. The fully collusive outcome in this constrained setting, marked M', is again characterized by zero trade flows and complete market division. In sum, in both unconstrained and constrained settings, more collusive behaviour is associated with less trade between regions, thanks to the division of spatial markets.

The second direction in which I extend the unconstrained spatial oligopoly is to enrich the spatial distribution of consumers. Rather than having atomistic consumers sit atop plants, consumers are now distributed along a line segment – of unit length and with $l \in [0, 1]$ parameterizing the location along this line – that links two production clusters, A (located at $l = 0$) and B (at $l = 1$) (say that firms agglomerate in locations that are rich in resources, such as limestone in the case of cement). There are still barriers to entry, but I now allow more than one firm in each producer location, $n_A \geq 1$ and $n_B \geq 1$. Plant marginal cost

3 In contrast, if firms devise dynamic strategies that treat each market separately – that is, deviating in the away region no longer triggers retaliation at home – such pronounced spatial market division is not sustainable (Salvo 2005 illustrates with simple dynamic games). In a sufficiently asymmetric cartel (asymmetry being defined across space in terms of plant or transport costs), incentive compatibility may require less than complete market division (e.g., Harrington 1991).

4 In Gilbert and Vives (1986), for example, Cournot oligopolists deter entry by producing the limit output.

is still c, and the trade cost t is now incurred per unit of distance. Demand at each 'point,' or infinitesimal local market, l is given by the 'spaceless' demand function $q = D_l(p(l))$, where $p(l)$ is the local price and $q(p;l)$ is demand per unit distance; thus market revenue in the interval $(l, l + dl)$ is given by $p(l)q(p;l)dl$. Local markets can now generally vary in size; this can be parameterized in a simple way by specifying demand to be linear in a market size parameter a_l and in the price; that is, $q(p;l) = a_l - p$. Firms can still price discriminate across consumer markets.[5] A regularity condition $t < 2(a_l - c)$, $\forall l \in [0, 1]$ ensures that all consumers are served.

In Cournot equilibrium, one can show that supply to each local market depends on where its location l falls relative to two ordered thresholds,

$$l_A^C(l) := \max\left(0, \frac{n_A + 1 - (a_l - c)/t}{2n_A + 1}\right) < \frac{1}{2} \text{ and}$$
$$l_B^C(l) := \min\left(\frac{n_B + (a_l - c)/t}{2n_B + 1}, 1\right) > \frac{1}{2},$$

written in terms of (host) market size (a_l), technology (c, t), and (source) market structure (n_A, n_B). Local markets $l \in [0, l_A^C(l)]$ (i.e., when t is high) are served only from producer location A (at the left extremity) and the aggregate trade flow from each producer location is

$$\begin{array}{c}\text{case } 0 \le l \le l_A^C(l)\\ \text{producer } A \text{ markets}\end{array} = \begin{cases} q_A^C(l) = \dfrac{n_A}{n_A + 1}(a_l - c - tl) \\ q_B^C(l) = 0 \end{cases}.$$

Similarly, local markets $l \in [l_B^C(l), 1]$ (again when t is high) are served only from producer location B (right extremity) and aggregate trade flows are

$$\begin{array}{c}\text{case } l_B^C(l) \le l \le 1\\ \text{producer } B \text{ markets}\end{array} = \begin{cases} q_A^C(l) = 0 \\ q_B^C(l) = \dfrac{n_B}{n_B + 1}(a_l - c - t(1 - l)) \end{cases}.$$

In this setup, the strict ordering of the thresholds, which follows immediately from the regularity condition, ensures the existence of local markets that are served from both producer locations. For local markets $l \in [l_A^C(l), l_B^C(l)]$, there is cross-hauling or 'two-way trade,' in the sense that the market is served also by

5 This is realistic and common in both the spatial competition literature (e.g., Greenhut and Greenhut 1975; McBride 1983; Thisse and Vives 1988) and the trade literature (e.g., Brander 1981; Brander and Krugman 1983; Venables 1985; Feenstra, Markusen, and Rose 1998). In contrast, a more restrictive spatial pricing model à la Hotelling-Salop would allow firms to set only a 'mill' (or f.o.b.) price, with prices over space then given by the sum of this mill price and the trade cost.

the more distant set of producers;[6] the aggregate trade flow from each producer location is

$$\begin{array}{c}\text{case } l_A^C(l) < l < l_B^C(l) \\ \text{two-way trade markets}\end{array} = \begin{cases} q_A^C(l) = \dfrac{n_A}{n_A + n_B + 1} \\ \qquad \times\ (a_l - c - t\,((n_B + 1)\,l - n_B\,(1 - l))) \\ q_B^C(l) = \dfrac{n_B}{n_A + n_B + 1} \\ \qquad \times\ (a_l - c - t\,((n_A + 1)\,(1 - l) - n_A l)) \end{cases}.$$

Note that aggregate trade flows $q_A^C(l)$ and $q_B^C(l)$ exhibit gravity-like structure, increasing in market size a_l and decreasing in distance traveled (since $\partial q_A^C/\partial l < 0$ and $\partial q_B^C/\partial(1 - l) < 0$). (This also holds for firm-specific flows: to see this, divide aggregate flows by the number of firms n_A or n_B.) The top panel of figure 2 depicts aggregate trade flows over space, drawn with (i) equally sized local markets $a_l = a$ (increasing the size of a single local market, say, would result in a spike in at least one trade flow schedule), and (ii) $t > (a_l - c)/(n_B + 1) > (a_l - c)/(n_A + 1)$, such that all three supply cases occur.

In the fully collusive equilibrium, the efficient cartel again completely divides markets. Local markets to the left of $l_A^M := 1/2$ are served only from producer location A and local markets to the right of $l_B^M := 1/2 = l_A^M$ are served only from producer location B, with aggregate trade flows given by

$$\begin{array}{c}\text{case } 0 \le l \le l_A^M \\ \text{producer } A \text{ markets}\end{array} = \begin{cases} q_A^M(l) = \dfrac{1}{2}\,(a_l - c - tl) \\ q_B^M(l) = 0 \end{cases}$$

$$\begin{array}{c}\text{case } l_B^M < l \le 1 \\ \text{producer } B \text{ markets}\end{array} = \begin{cases} q_A^M(l) = 0 \\ q_B^M(l) = \dfrac{1}{2}\,(a_l - c - t\,(1 - l)) \end{cases}.$$

Trade flows again exhibit gravity-like structure, and are depicted in the bottom panel of figure 2 (drawn assuming local markets of equal size). As in the simple two-region model above (M in the top panel of figure 1), the presence of trade costs implies that the (perfect) cartel avoids cross-hauling from the more distant producer location.

Two comments are in order regarding this second extension. The first relates to the 'intensive margin.' Figure 2 shows that the slope of trade flows in the distance from a producer location (A, say) is steeper in the more competitive Cournot oligopoly: $-(n_A t)/(n_A + 1)$ over producer A markets followed

6 Two-way trade markets cease to arise in the limiting situation where $n_A, n_B \to \infty$ and equilibrium outcomes replicate those under (homogeneous) Bertrand behaviour, where no cross-hauling occurs and delivered price-cost margins are zero everywhere, though trade flows still exhibit gravity-like structure.

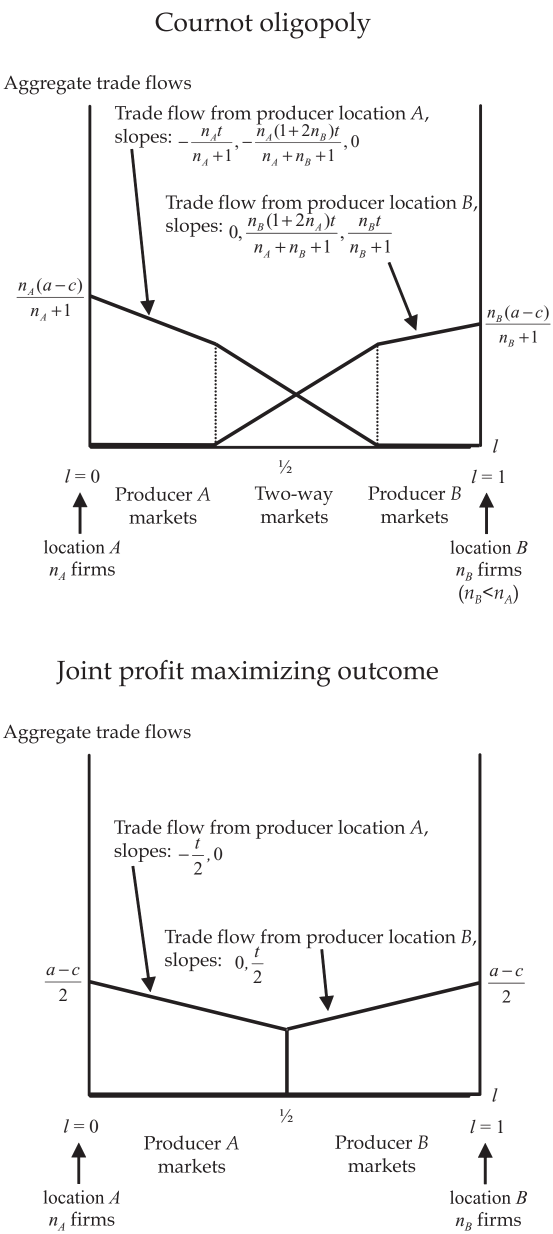


FIGURE 2 (Extending the simple two-region model) Trade flows to a unit line of consumers located between two producer locations. Drawn for $t > \frac{a_l - c}{n_B+1} > \frac{a_l - c}{n_A+1}$ and holding market size constant over space, that is, $a_l = a$ (increasing the size of, say, a single local market would result in a spike in at least one trade flow schedule). Top panel: 'Two-way trade' arises in the Cournot oligopoly. Lower panel: The fully collusive outcome again involves complete market division.

by $-(n_A(1+2n_B)t)/(n_A+n_B+1)$ over two-way trade markets, compared with a flatter $-t/2$ in the joint maximizing outcome. Intuitively, competition here generates greater cost pass-through, or less price discrimination in favour of distant buyers. The model suggests that, in the plant's vicinity, trade can decay more slowly if there is collusion rather than competition. (This result, however, is not robust: for example, in the differentiated-product spatial oligopoly of Deltas, Salvo, and Vasconcelos 2009, there is *less* cost pass-through under Bertrand competition than in the fully collusive regime, as Bertrand firms vie to offer variety at the expense of trade costs.)

The second comment highlights the core 'extensive margin' result. Since $l_A^C(l) < l_A^M = 1/2 = l_B^M < l_B^C(l)$, there are local markets to which the trade flow from the more distant producer location is zero in the collusive regime but positive under competition (and the prediction here *is* robust to the setup in Deltas, Salvo, and Vasconcelos 2009). Consider a numerical example. Say that in a (symmetric) economy, $a_l - c = a - c = 5,\ t = 2$ and $n_A = n_B = 2$. For markets $l \in [0.1, 0.9]$, zero-valued firm-specific flows arise under collusion but not under Cournot competition: while a Cournot firm hauls product over a maximum distance of 0.9, the distance travelled under collusion is no higher than 0.5. The cartel's market allocation scheme lowers the average distance travelled relative to Cournot: a firm's average distance to market is $(\int_0^1 lq_A(l)dl)/(\int_0^1 q_A(l)dl) \simeq 0.30$ in Cournot but 0.24 in the cartel. Now, in view of the coarseness of typical trade data, reinterpret the line segment of consumers (or 'micro-regions') as comprising two regions (or 'macro-regions') that share a frictionless border at $l_{Border} = 1/2$. Thus, consumers to the left of l_{Border} reside in region A and those to the right reside in region B. Only under Cournot does one region export to the other: the proportion of a region's output that is exported is $(\int_{l_{Border}}^1 q_A(l)dl)/(\int_0^1 q_A(l)dl) \simeq 20\%$ in Cournot but 0% under full collusion. Under collusion, trade flows jump discretely at the virtual border.

In sum, a simple spatial model and its extensions indicate that, while different oligopoly behaviours exhibit gravity features – consistent with Deardorff's (1995) critique that gravity is 'obvious' – the desire to save on transport costs may lead a cartel to divide markets and trade less between regions relative to a less collusive regime. When trade costs are held constant, collusive behaviour can thus magnify the effects of distance and borders, as firms can use geography to coordinate on outcomes. Notice that zero-valued flows arise naturally in the present framework, in contrast to the standard trade setup based on CES demand and monopolistic competition (where markups are space invariant).

3. Empirical application

I provide a clear-cut example of the theoretical argument above. Brazil's cement flows, from plants to local markets, decay sharply in distance and borders, but trade costs – in spite of their importance – cannot alone account for the observed market segmentation at prevailing prices. I discuss the industry and the available data. The illustration then follows in two parts. Part A uses gravity to describe flows. Part B uses flows, estimated demand, and observed cost (including transport) to test for oligopoly behaviour.

3.1. Industry and data

3.1.1. Setting

By the late 1990s, Brazil was the world's sixth-largest cement producer, with annual output of about 40 million tons. Though the country's land area was comparable to that of the United States, the location of cement plants (numbering 57 in 1999; see figure 3) was skewed east along an extensive Atlantic coastline, where the population lay, and away from the sparsely populated northwestern region, which remained largely covered with jungle. The cement industry was highly concentrated, having further consolidated from 19 firms in 1991 to 12 firms by 1999. In aggregate, the largest producer (Votorantim) accounted for about two-fifths of sales, but concentration at the disaggregate local market level was often substantially higher. For example, the one-firm sales concentration ratio C_1 averaged 61% across states over 1991–9; in certain states, such as Santa Catarina (SC) and Sergipe (SE), C_1 surpassed 80%. Barriers to plant entry were high and capacity was typically added to existing plants: over the 1990s, only four new plants had been set up, all by incumbents. Cement was primarily shipped from plants to buyers by road (90% of business) and in standard 50 kg bags (80% of business). Unlike developed countries, where bulk buyers such as ready-mix concrete firms were the norm, a Brazilian cement producer's representative customer was a local corner store (there were several hundred thousand of these retailers, known as 'resellers'), which then sold on to small-scale consumers. Because of the product's limited shelf life, inventories were low (around one week of sales at producer establishments, and one week at retail).

3.1.2. Plant-to-market cement flows

A feature of the data that distinguishes it from that typically available for other oligopolies is the observation of plant shipments by state of destination. Like the United States, Brazil is a federation of states, 27 in total. For the period 1991 to 1999, I observe detailed annual cement shipments, in tons, from each plant to each state. The data set is comprehensive, as it includes all producers (and Brazil's imports of cement were minimal – see below). To be clear, taking I_t to denote the total number of plants that are active in year t (I_t ranges between 56 and 60 in the sample) and L to denote the number of states ($L = 27$), nine $I_t \times L$ matrices are available, one for each year. A glance at these matrices indicates the degree to which trade flows in the industry were local, with the typical row (corresponding to an active plant in a given year) containing zeros in all but four elements, these

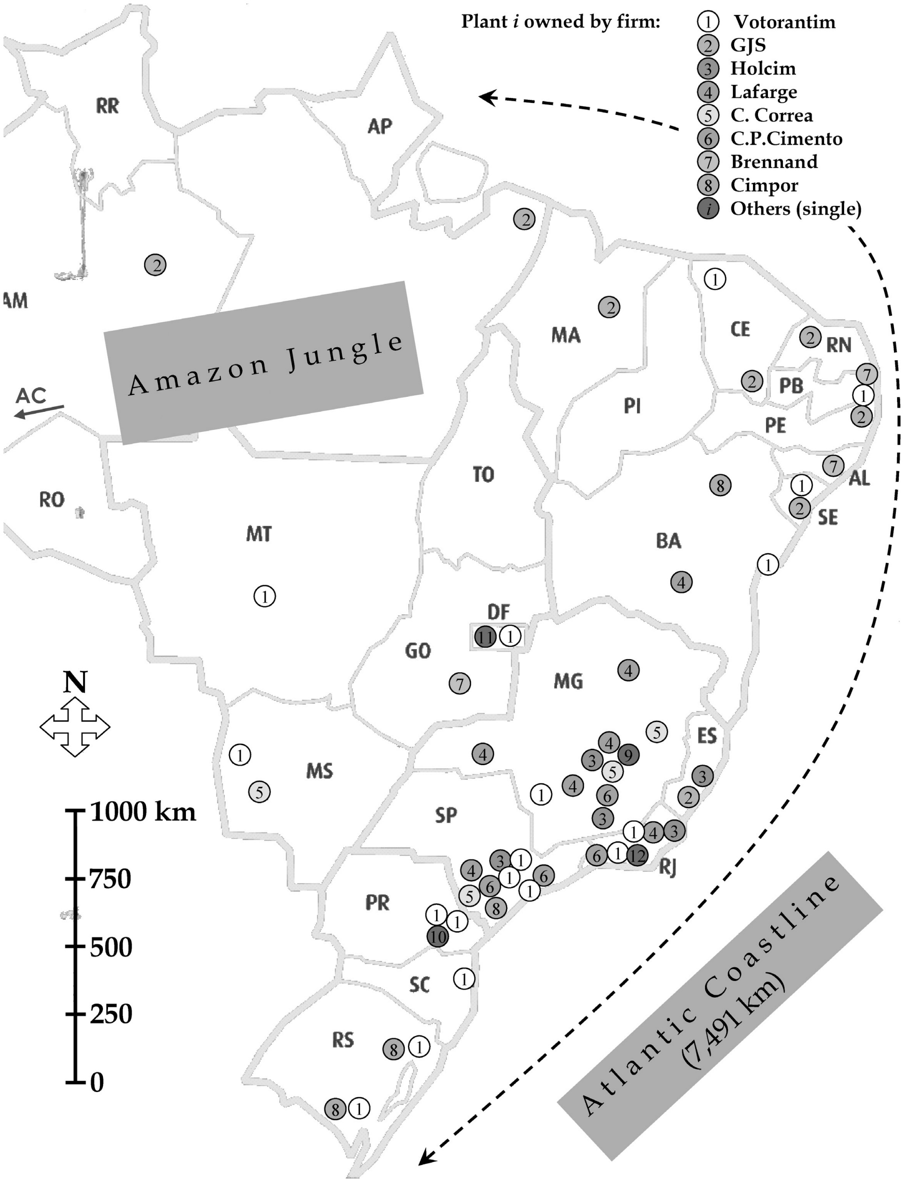


FIGURE 3 Active cement plants in 1999
SOURCE: SNIC

four non-zero elements pertaining to shipments to the state where the plant was located and to three nearby states. Aggregating across plants located within the same state, the average producer state traded only 40% of its cement production to out-of-state consumers (over three-quarters of which were located in bordering states). In the gravity exercise (part A), the steep decay of cement flows in distance *and* in the number of state borders crossed will be picked up by variables that are typically interpreted in the literature to proxy for trade costs. Since a state is the least aggregate unit for which deliveries are observed, I model each state as a local market.[7]

In analyzing cement trade flows, it is important to bear in mind that historically public policy in federal Brazil has pursued integration between states; crossing state lines is seamless, much as it is in the United States, but unlike the situation in India. For example, sales tax rules explicitly *favour* inter-state flows relative to within-state flows.[8]

3.1.3. Local market demand elasticities and interpretation

The test of behaviour in part B will require estimates of demand elasticities at the local market level. The following paragraphs draw on Salvo (2010), reproducing the essence of the discussion. For every state l over monthly periods t from Jan-1991 to Dec-2003 (i.e., 156 observations for each state), I use observed retail cement prices p_{lt}, cement consumption q_{lt}, and activity in the building and construction sector Y_{lt} to estimate a local market demand function for cement (here adopting a linear functional form as the baseline specification, including an interaction term $Y_{lt}p_{lt}$, which allows the demand curve to rotate as Y_{lt} varies):

$$q_{lt} = D\big(p_{lt}, Y_{lt}, \varepsilon^d_{lt}; \alpha_l\big) = \alpha_{1l} + \alpha_{2l} Y_{lt} + \alpha_{3l} p_{lt} + \alpha_{4l} Y_{lt} p_{lt} + \varepsilon^d_{lt},$$

where the mean-zero error term ε^d_{lt} captures the unobserved component of demand.[9] Since prices are potentially endogenous, I instrument for them using a mixture of domestic cement cost-shifters (e.g., domestic fuel oil and coal prices) and imported cement cost-shifters (e.g., the exchange rate and the world oil price), the latter owing to the entry threat of imports which may constrain prices (discussed below). For perspective, the table below reproduces average state-level demand elasticities $\eta(.) := (\partial D(p, .)/\partial p)(p/q)$ estimated in Salvo (2010, table 2, col. I), where robustness with respect to demand specification (e.g., functional form, choice of instruments) is also discussed.

7 The flow panel was privately compiled by the cement industry's trade association (SNIC). This was done along state lines. While rich, the data will still be too coarse to measure the decay of flows in the vicinity of a plant (i.e., flows to each city would be ideal). Price lists obtained from some producers, however, indicate that there was minimal variation in (delivered) cement prices within a state.

8 For perspective, Brazil's leading grocery distributors – Martins, Arcom, and Peixoto – are well known for having located warehouses in the city of Uberlândia, in the state of Minas Gerais, just across the border from the state of São Paulo, Brazil's largest consumer market, to take advantage of lower inter-state sales taxes.

9 Cement prices and construction activity were obtained from the Brazilian Institute for Geography and Statistics (IBGE). Cement consumption was obtained from the cement industry's trade association. I converted cement prices (as well as factor prices discussed below) into constant Real, denoted R$, Brazil GPI base Dec-1999, using the widely-used 'IGP-DI' published by the Fundação Getulio Vargas.

Mean estimated price elasticities of demand, in descending order of market size					
State l	$\hat{\eta}_{l\cdot}$ (robust s.e.)	State l	$\hat{\eta}_{l\cdot}$ (robust s.e.)	State l	$\hat{\eta}_{l\cdot}$ (robust s.e.)
SP	-0.36 (0.06)***	SC	-0.15 (0.08)**	RN	-0.28 (0.07)***
MG	-0.51 (0.06)***	PE	-0.34 (0.06)***	MS	-0.37 (0.06)***
RJ	-0.49 (0.05)***	CE	-0.50 (0.08)***	AL	-0.28 (0.05)***
BA	-0.41 (0.07)***	ES	-0.53 (0.05)***	PI	-0.40 (0.09)***
PR	-0.25 (0.08)***	MA	-0.58 (0.11)***	SE	-0.14 (0.05)***
RS	-0.28 (0.07)***	PB	-0.64 (0.08)***		

NOTE: Number of observations per 2SLS regression is 156. Significance: ***1%; **5%; *10%.

Estimated market price elasticities of demand, of the order of -0.5, are very low. This finding needs to be reconciled with the very high seller concentration observed in many local markets. One may wonder, for example, why the quasi-monopolist supplier in the state of Santa Catarina (SC), facing inelastic market demand at the prevailing price, did not restrict output to raise price to a point where demand was more elastic? Salvo (2010) attributes this to the threat of import competition. Though actual cement imports amounted to no more than 1%–2% of domestic consumption, the threat of imports placed a ceiling $\bar{p}$ on domestic prices (recall the discussion surrounding figure 1). Salvo (2010) models a highly elastic supply of cement imports on the world market, at the (exogenous and unobserved) sum of a world price and importation cost, which can constrain the domestic cement industry in equilibrium. Thus, while *market* demand could be inelastic at the limit price $\bar{p}$, the *residual* demand that the domestic industry faced at this price ceiling posed by high-cost imports was highly elastic. On estimating a regime-switching model – where markets switch between an unconstrained regime (say, when the local currency is weak or maritime freight rates are high so that imports are less competitive) and a constrained regime (e.g., the currency is strong and imports are cheaper) – Salvo finds that (in probability) the import price ceiling frequently constrained the domestic cement industry's prices. Intuitively, observed variables shifting the cost of cement imports significantly outperform observed domestic cement cost-shifters and demand-shifters in explaining observed variation in domestic cement prices.[10] As mentioned in section 2, this entry-constraint feature of the industry, while peripheral to the present paper, will still need to be controlled for in the test of part B.

As can be seen in the table, Salvo (2010) restricts the demand analysis to 17 states, the reason being that pricing data is unreliable in the remaining 10 states, which largely cover the vast Amazon region.[11] These sparsely-populated 'jungle'

10 Salvo (2010) provides further evidence – institutional and econometric – in support of this 'latent' imports discipline hypothesis; for example, cement prices were: (i) near uniform along the populated coastal states, (ii) increasing in distance from the nearest port of entry, and (iii) uncorrelated with firm concentration. Brazil's near absence of imported cement *quantities* contrasts with the United States, where cement imports from around the world have recently reached 30% of domestic consumption.

11 For example, price auditors working for the country's statistical agency may have limited their coverage to a few more accessible locations. As a point of comparison, despite being long established in Brazil, the global market research firm Nielsen does not audit jungle states, owing to their unusual geo-demographic characteristics (including low consumption).

states, while covering 60% of the country's land mass, accounted for only 12% of its cement consumption. I will drop these states from the (demand side of the) structural analysis in part B (following Salvo 2010), but retain flows to these states in the gravity analysis of part A (as this is based not on price audits, but only on flow data obtained from producers). Importantly, the gravity analysis is robust to the exclusion of these jungle states.

3.1.4. Delivered marginal cost

Another distinctive feature of the data is that, thanks to the simple fixed-coefficients technology, I observe the marginal cost of producing cement and delivering it to the buyer (irrespective of whether firms actually supplied). Like the demand elasticities, this cost data will be used in the test of part B. To be sure, it is the unusual richness of the micro data that enables me to directly examine oligopolistic behaviour, identifying firm conduct separately from (plant and trade) costs.

To calculate delivered marginal cost for every plant-market pair over time, I combine (i) observed plant-level characteristics (e.g., location, capacity, technology and age of kilns, and the type of fuel used); (ii) engineering parameters; and (iii) observed local factor prices (e.g., fuel oil, coal, electricity, wages, and freight rates). Take, for example, the main component of plant marginal cost: to calculate the cost of kiln fuel for a specific plant, I multiply the marginal kiln's fuel economy (e.g., 750 kcal/kg of clinker – an intermediate product – based on the kiln's technology) by the price of the specific fuel burned in the kiln (e.g., fuel oil). As for the plant-to-market specific freight, a key component of delivered marginal cost, I do not directly observe freight rates paid by cement producers. But I proxy for them using data on equivalent freight rates for agricultural commodities collected between 1997 and 2003 for thousands of different routes across Brazil.[12] Soares and Caixeta Filho (1996) discuss how the transport of farm products such as soybean and maize are close substitutes in the supply of cement freight. The substitutability of cement and farm products when it comes to road transport was confirmed in several field interviews. The appendix details how I construct a measure of cement freight. As such, for any plant to any local market at any point in time, I accurately predict the marginal cost of producing and delivering a truckload of cement.

In calculating price-cost margins, I observe not the cement producer's price to the reseller, but only the retail price. So my definition of marginal cost encompasses delivery all the way to the retail consumer, including the reseller's cost and sales tax. Based on interviews with salespeople at producers and buyers at resellers, I assume resellers were competitive. Based on tax legislation, I calculate sales tax, which was included in the producer's invoice to the reseller, but collected by the producer (tax authorities naturally favoured inspecting the

12 I am indebted to Professor José Vicente Caixeta Filho of ESALQ, at the University of São Paulo, for providing an extract of the SIFRECA freight database. Data pertaining to soyabean, maize, and (the mineral) limestone were kindly made available.

activities of dozens of producer establishments over that of several hundred thousand resellers).[13]

The appendix presents summary statistics on costs, prices, and margins, conditional on flow type. Price-cost margins were very high for firm-market pairs where shipments did take place: across producers, across states, and over time, the mean price-cost margin as a proportion of the producer price net of sales tax was 51% (the 10th percentile was 30% and the 90th percentile was 69%). In the data, I also find many firm-market pairs for which shipments did *not* occur and yet margins would be considerably high. I discuss robustness checks of these margins after using them in part B to uncover oligopoly behaviour.

3.2. *Part A: Using traditional gravity to describe flows*

I now show that gravity fits Brazilian cement flows 'well.' I use the observed (positive and zero) flows from plants (which I aggregate up to the firm level, since most firms owned multiple plants)[14] to local markets (identified with states) to estimate an equation that has a gravity flavour. I obtain large coefficients on distance and state border crossings, variables that the trade literature normally takes to proxy for trade costs. I interpret the exercise in a descriptive (or statistical) rather than a structural sense. Disentangling strategic behaviour from trade costs on the supply side is the task of part B.

In the data, flows are zero for many firm-market-year triples. Only one-third of the sample (1,290 out of 3,861 observations) exhibit positive flows; in other words, in any given year, each firm supplied, on average, only 9 of the 27 state markets (from either inside or outside the state). I first consider the Tobit estimator of the log-linear model:

$$\ln(q_{flt} + 1) = \max(0, \gamma_1 + \gamma_2 \ln D_{flt} + \gamma_3 \ln Y_{lt} + \gamma_4 B_{flt} + \epsilon_{flt}). \tag{1}$$

I adopt a log-linear specification, owing to '(its) near universal use (in) the gravity equation' (Disdier and Head 2008, 5) and, importantly, its better fit in the present data over other functional forms.[15] The limited dependent variable is the logarithm of (one plus) cement shipments (tonnage) q_{flt} from firm f's plants to state l in year t.[16] Following Head and Mayer (2000) and Chen (2004), D_{flt} is a

13 As mentioned in footnote 7, I was able to obtain price schedules directly from some producers. By comparing these producer prices to retail prices net of the reseller's cost (and producer's sales tax), I reassuringly cross-validate my calculations. (The reseller's cost totalled about 12% of the retail price.)

14 Importantly, interviews with producers revealed that spatial supply decisions were made at the firm, not plant, level. Inspection of plant-to-market flows confirms this institutional feature.

15 For brevity, these are not reported, since results – large distance and border effects – are not qualitatively different to what follows. Similarly, I do not report estimates based on more aggregated origin-state to destination-state flows, that is, where I aggregate from the establishment level up to the producing state. Though such aggregate data would more closely resemble that available in typical bilateral trade studies (e.g., Nitsch 2000), it is more natural in an oligopoly setting to take the firm (rather than the state of origin) as the unit of analysis.

16 As is common in the literature, I add 1 to q_{flt} to deal with zero flows. Since tonnage, when positive, tends to be a large number (see the summary statistics in the appendix), this is almost

weighted distance from each plant owned by firm f to each city in state l, constructed as follows: I first average the geodesic distance from each plant to each city in the state using city populations as weights;[17, 18] I then average these plant-to-state distances over the plants owned by firm f using (year-t) plant shipments as weights (or take the distance from firm f's nearest plant when the firm does not supply to the state). The market size variable Y_{lt} is the exogenous demand for cement in state l in year t, proxied by construction activity; alternatively, as I explain below, time-varying state fixed effects are used. (Both distance and construction activity are strictly positive.) The effect of state border crossings is captured using alternative specifications for B_{flt} (more below).

Tobit estimates are presented in the first five columns of table 1. Throughout the table, robust standard errors are displayed in parentheses, calculated with clustering around firm-state pairs (allowing for a same firm's shipments to a same state to correlate over time). Column (1) includes only distance ($\ln D_{flt}$) and market size ($\ln Y_{lt}$). Column (2) adds, as a parsimonious specification for B_{flt}, a dummy variable that takes on the value 1 when a firm needs to cross *at least* one state border to reach a market (i.e., the firm does not own a plant located within that state's boundaries in that year). Column (3) additionally controls for firm-and-year fixed effects (i.e., firm effects that vary by year). Estimated coefficients have the expected sign, but are surprisingly large. By the distance coefficient, a 1% increase in a firm's plants' average distance to a market is associated with a statistically significant 5.2% to 7.7% reduction in shipments. For comparison with the literature, recall that the distance effect on bilateral trade flows is typically estimated in the -0.3 to -1.6 range (Disdier and Head 2008). In column (3), the point estimate for the border effect, though imprecisely estimated for this specification, suggests that reaching an out-of-state market lowers shipments by $1 - \exp(-1.87) \simeq 85\%$ relative to serving a market from within its border, ceteris paribus. Column (4) replaces the market size variable by state-and-year fixed effects (i.e., market effects that vary by year). Relative to column (3), the distance effect increases in magnitude while the point estimate on the 'at-least-one-border' dummy variable is now positive, though statistically insignificant.

I thus enrich the specification of the border effect. In column (5), I replace the at-least-one-border dummy by a set of three variables that capture not only whether, but also how many, state borders are crossed: (i) a dummy that takes on the value 1 when the firm's closest plant is located in a state adjacent to the destination state, that is, when exactly one border is crossed; (ii) a dummy that takes

equivalent to taking as the dependent variable $\ln q_{flt}$ if $q_{flt} > 0$ and 0 otherwise. The Poisson estimator that I implement below treats zero flows in a more natural way.

17 Populations for the 5560 cities (i.e., municipalities) were obtained from the 2000 Census (IBGE). I did not use right-of-way (mostly road) distances, as these were not available for all municipalities (e.g., vast areas of the jungle were accessible only by barge).

18 Further describing the data, a probit regression of whether a firm supplies to a state on log distance, indicates that the probability that a positive flow is observed falls to 0.69 within 500 km and 0.28 within 1,000 km (the mean distance in the sample is 1,311 km and the standard deviation is 829 km).

TABLE 1
Traditional gravity equation estimates: Tobit, Poisson, and OLS

	Tobit					Poisson		Memo: OLS	
	(1)	(2)	(3)	(4)	(5)	(4′)	(5′)	(4″)	(5″)
Average plant-to-state distance	−7.74***	−6.76***	−5.20***	−7.09***	−3.39**	−1.67***	−1.17***	−3.33***	−2.34***
	(1.07)	(1.34)	(1.09)	(1.52)	(1.41)	(0.24)	(0.29)	(0.66)	(0.72)
State's market size (construction)	0.83*	0.76*	1.46***						
	(0.45)	(0.42)	(0.36)						
At-least-one-state-border-crossing dummy		−3.52**	−1.87	0.87		−0.77***		−2.00***	
		(1.61)	(1.21)	(1.39)		(0.22)		(0.70)	
Exactly-one-state-border-crossing dummy					−1.49		−0.89***		−1.81***
					(1.24)		(0.22)		(0.66)
Exactly-two-state-border-crossings dummy					−7.21***		−2.21***		−4.17***
					(2.13)		(0.47)		(1.04)
At-least-three-state-border-crossings dummy × Number of state borders crossed					−4.12***		−1.07***		−1.48***
					(0.87)		(0.28)		(0.41)
Constant	46.18***	43.19***							
	(9.39)	(9.71)							
Firm-and-year fixed effects	NO	NO	YES	YES	YES	YES	YES	YES	YES
Market-and-year fixed effects	NO	NO	NO	YES	YES	YES	YES	YES	YES
No. observations									
Uncensored	1290	1290	1290	1290	1290				
Total	3861	3861	3861	3861	3861	3861	3861	3861	3861
Log (or log pseudo) likelihood	−5514	−5494	−5127	−4822	−4607	−5.4E+07	−4.6E+07		
R^2								0.72	0.73

NOTES: Dependent variable is cement flow in ton (added to 1 and log transformation applied in the Tobit and OLS estimations). An observation is a (firm, market, year) triple. Heteroscedasticity-robust standard errors in parentheses, with clustering around firm-market pairs. (Two-tailed tests) ***Significant(ly different from zero) at the 1% level; **Significant at the 5% level; *Significant at the 10% level.

on the value 1 when exactly two state borders are crossed; and (iii) a variable that captures the linear effect of *each* state border crossing when three or more borders are crossed; that is, this is an integer with value of either 0 or 3, 4, 5, ... One would expect this alternative set of B_{flt} variables to correlate highly with distance and thus impact the distance coefficient. Indeed, the distance elasticity drops to (a still huge) -3.4. This richer border specification is picking up some of the variation in shipments that was previously accounted for by the distance variable. The border variables carry the expected sign (and are mostly significant). Compared with supplying a state from an in-state plant (a situation where all three variables are zero), I find that (i) crossing exactly one border to reach a market is associated with a $1 - \exp(-1.49) \simeq 77\%$ reduction in shipments; (ii) crossing exactly two borders is associated with a $1 - \exp(-7.21) \simeq 99.9\%$ reduction, or flows collapsing to virtually zero; and (iii) similarly, crossing three borders is associated with a $1 - \exp(3 \times -4.12) \simeq 100\%$ reduction (and so on). The log likelihood improves considerably. The combination of distance and border-related variables considerably explains – in a statistical sense – cement trade flows from plants to markets.

I then consider the Poisson pseudo-maximum-likelihood (PPML) estimator, recently recommended by Santos Silva and Tenreyro (2006) in the context of fitting trade flows (and constant-elasticity models more generally).[19] I estimate the multiplicative model:

$$q_{flt} = \gamma_1 (D_{flt})^{\gamma_2} (Y_{lt})^{\gamma_3} \exp\left(\gamma_4 B_{flt}\right) \epsilon_{flt},$$

where ϵ now denotes the mean-one multiplicative error on the flow level. Columns (4′) and (5′) of table 1 report the Poisson regression counterparts to the earlier Tobit regressions of columns (4) and (5) (where time-varying market effects were included). I obtain lower point estimates compared with using the Tobit estimator.[20] However, the estimated distance and border effects remain substantially large, have the expected sign, and are statistically significant at the 1% level. By the parsimonious border specification of column (4′), a 1% increase in distance is associated with a 1.7% reduction in shipments, and crossing at least one state border is associated with a $1 - \exp(-0.77) \simeq 54\%$ reduction in shipments. By the richer border specification of column (5′), a 1% increase in distance is associated with a 1.2% reduction in shipments, and shipments contract (i) by $1 - \exp(-0.89) \simeq 59\%$, when exactly one border is crossed; (ii) by $1 - \exp(-2.21) \simeq 89\%$, when exactly two borders are crossed; and (iii) by

19 See Flowerdew and Aitkin (1982) for an early suggestion in the regional science literature. Santos Silva and Tenreyro (2006, 646) argue that in trade applications the PPML 'emerges as a reasonable compromise' among the class of pseudo-maximum-likelihood estimators. On fitting the multiplicative model, PPML places equal weight on each observation, while non-linear least squares (NLLS) would give (even) more weight to observations where predicted trade is large (to be compared with log-linearized regressions, which downweight observations with large $\hat{q}_{flt}$).

20 Examining cross-sectional country-level bilateral trade data, Santos Silva and Tenreyro (2006) similarly report a reduction in the Poisson distance coefficient relative to that obtained under log-linear methods (Tobit and OLS).

$1 - \exp(3 \times -1.07) \simeq 96\%$, when exactly three borders are crossed (and so on). These large effects – and note that distance is controlled for – are puzzling on the basis of costs alone, since, as noted, trade frictions at intra-national state borders ought to have been minimal, particularly for a homogeneous good like cement. In all, the combined magnitude of the estimated distance and border-related variables suggest that they may be picking up more than fixed or variable costs of market entry. A market allocation scheme along state lines – a speculation à la Head and Mayer (2000, 303) – is plausible.[21]

Finally, for the sake of comparison with the literature, I use OLS to estimate the log-linear model:

$$\ln(q_{flt} + 1) = \gamma_1 + \gamma_2 \ln D_{flt} + \gamma_3 \ln Y_{lt} + \gamma_4 B_{flt} + \epsilon_{flt}.$$

Columns ($4''$) and ($5''$) of table 1 again replace $\ln Y_{lt}$ by state-and-year dummies and consider the alternative border specifications. OLS estimates of the distance effect are intermediate between Tobit and Poisson. OLS estimates of the border effect are mostly intermediate between (if not larger than) those of Tobit and Poisson.

3.3. Part B: Testing strategic behaviour controlling for trade costs

In this second part, I combine spatial cement flows with (observed or estimated) prices, demand slopes and marginal costs to examine the nature of firm competition. I show that the gravity pattern of flows reported above arises, at the current equilibrium, from the collusive division (or 'swapping') of geographic markets. I also discuss robustness checks of my cost (and demand) measures, as well as some anecdotal evidence.

The intuition for the test of firm behaviour was provided in the discussion surrounding figure 1. I adopt the Cournot oligopoly model as a benchmark and consider each firm's supply decision toward each local market to test the null hypothesis of Cournot conduct against the alternative of 'more collusive,' that is, output-restricting, behaviour. Under the null, the pricing condition for Cournot firm f is

$$D_l^{-1}(q_{lt}) + \frac{D_l^{-1}(q_{lt})}{\eta_l(q_{lt})} \frac{q_{flt}}{q_{lt}} \leq c_{flt}, \tag{2}$$

where c_{flt} is the firm's cost of increasing supply on the margin to market l in period t (and $D_l^{-1}(q_{lt}) = p_{lt}$). The inequality is strict in either of two situations that the null of the test needs to allow for (i) Cournot firm f's delivered cost to

21 Since I will drop 1,430 (= 3,861 – 2,431) flows to jungle states (1,100 of which are zero) in the structural analysis of part B, it is worth noting that the large effects estimated here survive the exclusion of these 1,430 observations: the Poisson estimates of column ($4'$) change to (distance) -2.07 (s.e. 0.12) and (at-least-one-border) -0.52 (s.e. 0.17), while those of column ($5'$) change to (distance) -1.74 (s.e. 0.16), (exactly-one-border) -0.55 (s.e. 0.16), (exactly-two-borders) -1.60 (s.e. 0.41) and (each-border-for-three-or-more) -0.73 (s.e. 0.25).

the market is so high, $c_{flt} > p_{lt}$, that there is a corner solution (e.g., the firm's nearest plant is too far from the market); and (ii) a price ceiling (output floor) binds (e.g., Cournot firm f does not cut output, since, rather than raising the market price, this would only open the door to imports). Now, rewrite (2) as the equality

$$D_l^{-1}(q_{lt}) + \frac{D_l^{-1}(q_{lt})}{\eta_l(q_{lt})} \frac{q_{flt}}{q_{lt}} = \varphi_{flt} + c_{flt}, \tag{3}$$

noting that $\varphi_{flt} \leq 0$ allows for the situations just described. The test is then given by

$H_0 : \varphi_{flt} \leq 0$ (Cournot behaviour allowing for a binding price ceiling)
$H_A : \varphi_{flt} > 0$ (More collusive supply, irrespective of price ceiling binding).

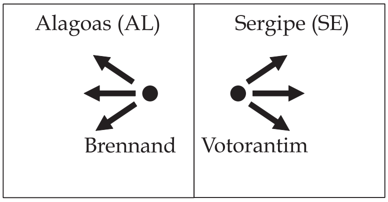
A negative test statistic φ_{flt} is consistent with Cournot behaviour by firm f toward market l: mindful of imports, the constrained Cournot firm does not cut output (as in Gilbert and Vives 1986). On the other hand, $\varphi_{flt} > 0$ rejects the null of Cournot in favour of the alternative of more collusive behaviour, no matter whether the output *floor* binds, as a Cournot firm would *expand* its supply to market l beyond the observed quantity. In the bottom panel of figure 1, consider a market observation at – or in the neighbourhood of – point M'. While this is consistent with Cournot behaviour for the home firm, the away firm is restricting supply to the local market relative to what a (constrained) Cournot firm would do: since the outcome lies below the steep line, it follows that $\varphi_{\text{away firm},lt} > 0$. Output choices that are too asymmetric for firms whose delivered costs are not that different are not consistent with Cournot. The point is to recognize that for no Cournot firm can perceived marginal revenue (the left-hand side of (2)) *exceed* marginal cost (the right-hand side); otherwise the firm would optimally expand supply, and this holds irrespective of whether the imports constraint binds or not, as this constraint is an output floor.

Prior to testing the supply decisions of firms in space and over time for the entire sample, I consider two specific examples extracted from the data. These represent a broader trend, where in many instances Brazilian cement firms undersupplied local markets as benchmarked against the behaviour of a Cournot firm.

3.3.1. Illustration 1: The supply of two firms to two northeastern markets in 1996

Consider the two adjacent states of Alagoas (AL) and Sergipe (SE) in the country's northeast – see the picture below and recall figure 3. These states are equally small in terms of both market size and geography. Until 1996, each state was home to only one plant: the firm Brennand owned the plant located in AL and its rival Votorantim owned the plant in SE. Each firm owned further plants located in nearby states. Consider the year 1996. While Brennand commanded an 83% share in market AL, it chose not to supply the neighbouring SE market, next door to its plant in AL, despite the large price-cost margin it would enjoy were it to do so. Equally striking, Votorantim commanded an 89% share in market SE, while attaining only a 7% share in market AL, next door to its plant in SE. Retail prices were almost identical in AL and SE, respectively 9.46 R$ (per bag)[22] and 9.44 R$. I calculate Brennand's marginal cost (including sales tax and the reseller's cost) in supplying markets AL and SE to be respectively 5.37 R$ and 5.68 R$. As for Votorantim, delivered marginal costs were 5.54 R$ in AL and 5.28 R$ in SE.[23] These are reported in the table (where, for illustrative purposes, the market demand elasticities are the means stated earlier).

Example: 2 firms' supply to 2 small and adjacent markets



(Variable means for year 1996)	Price p_{lt}	Share $\frac{q_{flt}}{q_{lt}}$	Marginal Revenue Cournot $\mathrm{MR}^C_{flt} = p_{lt} + \frac{p_{lt}}{\hat{\eta}_{lt}}\frac{q_{flt}}{q_{lt}}$	Delivered MC c_{flt}	Reject Cournot? $\varphi_{flt} = \mathrm{MR}^C - \mathrm{MC} > 0$?
Local market of Alagoas (AL)					
Brennand	9.46	83%	$9.46 + \frac{9.46}{-0.28} 0.83 = -18.58$	5.37	No
Votorantim	9.46	7%	$9.46 + \frac{9.46}{-0.28} 0.07 = 7.10$	5.54	**Yes**
Local market of Sergipe (SE)					
Brennand	9.44	0%	$9.44 + \frac{9.44}{-0.14} 0 = 9.44$	5.68	**Yes**
Votorantim	9.44	89%	$9.44 + \frac{9.44}{-0.14} 0.89 = -50.57$	5.28	No

Relative to a Cournot firm (and short of estimation error – see below), Votorantim behaved more collusively toward (its 'away') market AL in 1996, since marginal revenue (as perceived under Cournot, 7.10) exceeds delivered marginal cost (5.54). Similarly, compared with a Cournot firm, Brennand restricted supply to its away market SE in 1996, and the 0% market share makes this conclusion robust to *any* econometric error in the estimation of the demand slope. (In this case, MR^C_{flt} collapses to the observed price and $\varphi_{\mathrm{Brennand,SE,1996}} = p_{lt} - c_{flt} = 3.76$ amounts to as much as 40% of price.) A multimarket arrangement where Votorantim agreed to give Brennand the upper hand in AL in exchange for the latter staying away from SE is consistent with observed flows. Tellingly, that same year, Brennand's plant in AL also hauled cement to the states of Paraíba

22 As noted (fn 7), price variation across cities within each state was also minimal. Divide prices denominated in Brazilian R$ (Brazil GPI base Dec-1999) by 2 for an approximate price in US$.

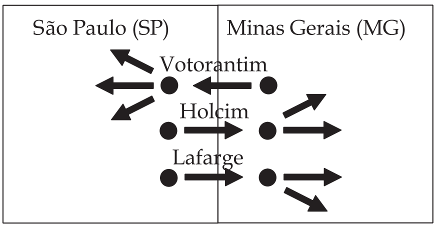
23 For perspective, the geodesic distance between the state-capital cities of AL and SE is 204 km (and 294 km by road). A higher freight cost to serve resellers in the more distance state (e.g., Votorantim's 0.90 R$ to AL relative to 0.44 R$ in SE) is partially offset by more favourable inter-state tax (2.04 R$ to AL relative to in-state tax of 2.23 R$ for SE).

(PB), Pernambuco (PE) and Bahia (BA), located no closer to AL than SE and where prices were similar to those in SE.[24]

3.3.2. Illustration 2: The supply of three firms to two southeastern markets in 1999

Now consider the supply decisions of Votorantim, Holcim, and Lafarge, three among the four largest firms nationwide, to the two largest markets, the southeastern and adjacent states of São Paulo (SP) and Minas Gerais (MG), in 1999. Each of the three firms owned plants in each of the two markets.[25] While Votorantim's share of the SP market amounted to 50%, its share in the MG market barely reached 8% (despite also having a plant there; in fact, somewhat unusually, Votorantim's MG plant shipped 3.5 times more cement to SP than it shipped to buyers within MG.) This pattern of shipments reverses when it comes to Holcim and Lafarge. Holcim and Lafarge, respectively, commanded single-digit shares of 9% and 5% in the SP market while enjoying respective shares of 24% and 25% in the MG market. Data are reported in the following table (where c_{flt} is the minimum marginal cost of serving market l across all firm f's plants at time t – see below).

Example: 3 firms' supply to 2 large and adjacent markets



(Variable means for year 1999)	Price p_{lt}	Share $\frac{q_{flt}}{q_{lt}}$	Marginal Revenue Cournot $MR^C_{flt} = p_{lt} + \frac{p_{lt}}{\hat{\eta}_{lt}} \frac{q_{flt}}{q_{lt}}$	Delivered MC c_{flt}	Reject Cournot? $\varphi_{flt} = MR^C - MC > 0$?
Local market of São Paulo (SP)					
Votorantim	8.67	50%	$8.67 + \frac{8.67}{-0.36} 0.50 = -3.37$	5.48	No
Holcim	8.67	9%	$8.67 + \frac{8.67}{-0.36} 0.09 = 6.50$	5.48	**Yes**
Lafarge	8.67	5%	$8.67 + \frac{8.67}{-0.36} 0.05 = 7.47$	5.87	**Yes**
Local market of Minas Gerais (MG)					
Votorantim	7.57	8%	$7.57 + \frac{7.57}{-0.51} 0.08 = 6.38$	5.62	**Yes**
Holcim	7.57	24%	$7.57 + \frac{7.57}{-0.51} 0.24 = 4.01$	5.10	No
Lafarge	7.57	25%	$7.57 + \frac{7.57}{-0.51} 0.25 = 3.86$	5.10	No

24 While outside this two-market illustration, here is a plausible explanation: Brennand owned a plant in PB, and thus a collusive scheme would have allocated a majority share of the PB market to Brennand. The firm's AL plant may have served (the 'home') market PB, while its PB plant was undergoing maintenance. (Consistent with fn 14, Brennand's AL→PB cement flow of 4 kilotons paled in comparison with the same firm's PB→PB flow of 174 ktons.)

25 Votorantim owned three plants in SP and one in MG, Holcim owned one plant in SP and two in MG, and Lafarge owned one plant in SP and four in MG. All three firms also owned plants in the neighbouring state of Rio de Janeiro (RJ), which could serve SP and MG.

Here, an arrangement where Votorantim gave Holcim and Lafarge the upper hand in MG (and, for that matter, also in the state of Rio de Janeiro (RJ), the third largest market) in exchange for Holcim and Lafarge staying away from SP explains the observed supply pattern. When benchmarked against a Cournot firm, Holcim and Lafarge's behaviour with respect to the SP market in 1999 was more collusive; similarly, Votorantim restricted supply toward MG.

3.3.3. Testing the full sample

As explained, I examine the (zero or positive) supply decision of each active firm in every year between 1991 to 1999 (recall flow data is available) to each of the 17 non-jungle states (due to pricing data). Firm f is active in year t if it owns at least one active plant that year; that is, if $\sum_l \sum_{i \in \mathcal{O}_{ft}} q_{ilt} > 0$, where $\mathcal{O}_{ft}$ is the set of plants owned (and located anywhere in the country). For every one of 2,431 active-firm-market-year combinations (f, l, t), the test statistic follows from (3):

$$\hat{\varphi}_{flt} = p_{lt} + \frac{p_{lt}}{\hat{\eta}_{lt}} \frac{q_{flt}}{q_{lt}} - c_{flt}. \tag{4}$$

I model $p,\ q$, and c as known (in fact, I subsequently argue that c is overstated, conservatively working against the rejection of the null of Cournot behaviour and the finding of restrictive firm supply). So I assume that the only source of error comes from the fact that demand elasticities $\hat{\eta}$ are estimated, and this error will be relevant only for positive flows ($q_{flt} > 0$; otherwise the inframarginal revenue term is zero, as in the Brennand-SE-1996 case), which I further discuss below. As for a firm's marginal cost of supplying a market in a given year (irrespective of whether it did supply), I take the minimum delivered marginal cost to that market from among the firm's plants, $c_{flt} := \min_{i \in \mathcal{O}_{ft}} c_{ilt}$. This cost is typically that of the plant $i \in \mathcal{O}_{ft}$ closest to the market, though this need not be so, recalling that cost also varies across plants, owing to variation in local factor prices and plant characteristics. Taking the minimum cost across the firm's plants reflects the cost of increasing supply to the market on the margin, since the data indicate that idle capacity was pervasive throughout the industry.[26]

Of the 2,431(f, l, t) observations, 1,471 correspond to zero supply decisions. Of these 1,471 observations where firms chose not to supply at all, a surprisingly low 324 of them correspond to situations where the firm's delivered marginal cost would exceed the market price, say because the firm's nearest plant was too far from the market. Recall that these supply decisions are consistent with Cournot; that is, $\hat{\varphi}_{flt} < 0$. For the remaining $1{,}471 - 324 = 1{,}147$ zero-shipment decisions, price exceeds marginal cost! Here $\hat{\varphi}_{flt} > 0$, with firms restricting supply to markets that were profitable, in a static sense, at prevailing prices. As the

26 Across producers and over time, capacity utilization has hovered about 65%. Consistent with this fact, Salvo (2010) documents how domestic cement producers were able to meet soaring demand during the unpredicted construction boom of the mid-1990s. For example, noting that capacity in this industry takes years to come on stream, firms managed to produce 37% more cement in 1996 relative to 1994.

summary statistics in the appendix indicate, the profitability of such forgone markets could be very high: the mean price-cost margin is \$2.40, equivalent to 21% of the mean (retail) price (or, as a proportion of the producer price net of sales tax, the mean margin is 29%). Another way of putting this is that, for the mean price-cost margin across these 1,147 zero-shipment observations to be zero, the transport cost would have to be $2.40/3.63 \simeq 66\%$ higher. The case of firm Brennand's zero flow to neighbouring SE, swapped for a comfortable lead in its home turf AL, comes to mind. For a good such as cement, sold by producers through a competitive spot market in an integrated country such as Brazil, it is hard to rationalize the flow discontinuity at the AL-SE border by way of trade costs of the informational or contract enforcement kind. The low number of corner solutions where supply on the margin was unprofitable (324) and the high number of zero flows where supply would have been profitable (1,147), already indicate behaviour that was more collusive than Cournot.

For the remaining $2{,}431 - 1{,}471 = 960$ non-zero supply decisions, the inframarginal revenue term of (4) is no longer zero, and so error in the estimation of the market-year specific demand elasticity $\hat{\eta}_{lt}$ generates randomness in the test statistic $\hat{\varphi}_{flt}$. To test the null against the alternative, I take the upper bound to the 95% confidence interval for the demand elasticity $\hat{\eta}_{lt}$, as this maps onto the lower bound to the 95% confidence interval for the test statistic $\hat{\varphi}_{flt}$ (to see this, notice that increasing a negative $\hat{\eta}$ toward zero lowers $\hat{\varphi}$); I am going to reject Cournot in favour of more collusive behaviour when the 95% C.I. for $\hat{\varphi}_{flt}$ falls entirely on the positive domain. But there is an empirical issue I must overcome: of the $17 \times 9 = 153$ market-year pairs, 44 pairs have 95% C.I.s for the demand elasticity that cross over to the positive domain, suggesting (for η at the upper extreme of the interval) that the demand curve slopes upward! I deal with this in two alternative ways. One option is to drop from the analysis supply decisions that pertain to these 44 market-year pairs (and where shipments are non-zero, $q_{flt} > 0$; otherwise the demand elasticity is not relevant). This entails dropping 236 supply decisions, with $2{,}431 - 2{,}36 = 2{,}195$ observations remaining. Another option is keep the 236 observations and to truncate (for all market-year pairs) the 95% C.I. for the demand elasticity from above at -0.3. For example, the estimated 95% C.I. for $\hat{\eta}_{\mathrm{MA},1993}$ is $(-0.97, 0.14)$. The first option drops all (five) positive flows to the state of Maranhão (MA) in 1993 by firms that were active that year. The second option keeps these flows and computes the lower bound to $\hat{\varphi}_{f,\mathrm{MA},1993}$ using a truncated upper bound to $\hat{\eta}_{\mathrm{MA},1993}$ of -0.3.

Total number of active-firm-market-year flow combinations (f, l, t)	2431	
Drop (f, l, t) where upper limit to the 95% C.I. for η_{lt} is positive *and* $q_{flt} > 0$	−236	
	2195	100%
(f, l, t) where $\hat{\varphi}_{flt}$ is significantly greater than zero at the 5% level	**1470**	67%
(f, l, t) where $\hat{\varphi}_{flt}$ is positive and exceeds 20% of (retail) price	**733**	33%
(f, l, t) where $\hat{\varphi}_{flt}$ is positive and exceeds 20% of (net producer) price	**1088**	50%

The table above summarizes results for the first option. Of the 2,195 plausible active-firm-market-year supply decisions – that is, those where either the C.I. for the demand elasticity falls within the interval $(-\infty, 0)$ or shipments are zero – I find that the null hypothesis of Cournot behaviour, $\varphi_{flt} \leq 0$, can be *rejected at the 5% level of significance in 1,470 instances*. In other words, under the Cournot conjecture, one would expect firms to expand their supply to local markets in $1{,}470/2{,}195 \simeq 67\%$ of supply decisions vis-à-vis observed shares. Positive test statistics $\hat{\varphi}_{flt}$ can be sizable: the point estimate for $\hat{\varphi}_{flt}$ exceeds 20% of (retail) price in 733 or 33% of supply decisions (and exceeds 20% of the producer price net of sales tax in 1088 or 50% decisions). Further, if one disregards the 324 trivial supply decisions above for which delivered marginal cost would exceed the market price, since not much can be inferred here about the collusiveness of conduct, Cournot is rejected in $1{,}470/(2{,}195 - 324) \simeq 79\%$ of supply decisions.

As for the second option (not reported in the table) where I truncate the 95% C.I. for the demand elasticity from above at -0.3, of the 2,431 active-firm-market-year supply decisions, I reject the Cournot hypothesis in 1,712 decisions, or $1{,}712/2{,}431 \simeq 70\%$ of instances. It is clear from (4) that lowering the truncation threshold (i.e., increasing the magnitude of the elasticity to -0.5, say) would only reinforce this result.

3.3.4. Robustness

Any attenuation bias in the estimated market price elasticity of demand would conservatively work against my finding of restrictive firm supply.[27] Of more relevance, one might worry that my measure of delivered marginal cost understates the true cost and that the price-cost margins $p_{lt} - c_{flt}$ used to compute the test statistic (4) might then be overstated. Clearly, such a bias would work in the direction of rejecting Cournot when tested against collusion (a type I error).

With this concern in mind, on constructing 'true' marginal cost, in several instances I chose to err on the side of caution, somewhat *overstating* the true value. For example, I assume that cement is composed of 100% clinker – by far the most expensive (energy-intensive) ingredient – when in reality four-fifths of the industry's output was blended 'type 2' cement with a lower 70%–80% clinker content. To provide another example, cement producers were among the country's largest industrial buyers, whereas the factor prices I observe are those paid by average buyers, not reflecting quantity discounts. Similarly, my measure of plant-to-market freight is based on rates in the month of April, at the peak of the harvesting season (see the appendix). A supplementary data appendix, describing other examples of caution, is available from the author upon request.

Robustness checks bear out my argument that any systematic bias in cost is positive (and slight). A first check is offered by unusually detailed accounting

27 Say that one worries that the inelastic (market) demand that I estimated for such concentrated – including quasi-monopoly – local markets, may be due to attenuation bias rather than the threat of imports, as I have argued (and controlled for).

data reported by country of operation and line of business by the multinational firm Cimpor. The time series fit between my constructed data and Cimpor's reported figures (cement only) is good. For example, my calculated price-cost margin for Cimpor, as a percentage of net producer sales, rises from around 47% in 2000 to 56% in 2002. Cimpor reported a similar rise in its EBITDA margin over this period, from 44% to 55% of net sales. Importantly, my calculated price-cost margin, if unbiased, should be (substantially) higher relative to EBITDA, since EBITDA figures are net of costs such as plant overhead and sales and administrative expenses, which are not included as part of marginal cost. (I further verify my above calculations of the reseller's cost and the producer's sales tax by comparing the net producer sales, which I backed out from observed retail prices, to Cimpor's reported net sales.) Interestingly, Cimpor's Brazilian cement business was the most profitable among those in its many countries of operation: in 2002, for example, a 56% EBITDA margin in Brazil stood against an average 39% across all countries. Another check of constructed marginal cost based on census-like accounting data collected by the IBGE is further reassuring.

3.3.5. A recent anecdote

In 2007, Brazil's Antitrust Authorities brought a high-profile case against the cement industry, on charges of explicitly forming a cartel to divide regional markets and fix prices. The authorities claim to have gathered 'conclusive' direct evidence, including company documents seized during police raids, records of private meetings, and testimonies by whistleblowers (Agência Estado 2007).

4. Concluding remarks

This paper has documented the case of an industry in which trade flows exhibit gravity-like structure yet where the sharp decay of flows with respect to distance and borders is due to spatial collusion. Hummels (2001, 2) writes: 'we have remarkably little concrete evidence as to the nature, size, and shape of (trade) barriers.' My paper suggests that in some international oligopolies, certain barriers may not be barriers at all, but may simply reflect the outcome of firms' behavioural strategies. Transport costs may operate indirectly by prompting an oligopoly to divide geographic markets, allocating large shares in local markets to those firms with nearby facilities. In this sense, strategic behaviour can compound the effects of distance. The finding suggests that trade theory, in its mission to explain the pattern of trade flows, should advance in its modelling of strategic behaviour in oligopoly.[28] In the Brazilian cement case, the illustrations indicate that

28 Recall that the paper concerns supply behaviour in the product market conditional on firms' spatial entry decisions. Hummels (2001) makes a related point that trade theory should continue to advance in its modeling of supply with regard to entry. Hummels argues that because of an 'endogenous production response,' 'transport costs operate indirectly by placing the production

were the typical trade researcher to impose (rather than test) the supply model – Cournot, say – on the data, he would back out enormous trade costs.

Appendix

A.1. Summary statistics for shipments, prices, and costs

Table A1 provides (conditional) summary statistics on shipments q_{flt}, prices p_{lt}, and delivered marginal costs c_{flt} for the 2,431 observations (active-firm-market-year combinations) discussed in section 3.3. Delivered marginal cost is the sum of two components: (i) plant marginal cost, which is divided into the following subcomponents: kiln fuel, electricity, mineral extraction rights, and labour/packaging/other plant costs; and (ii) plant-to-market marginal cost, further categorized into the reseller's cost, sales tax, and plant-to-market freight. A supplementary data appendix is available upon request. In the following subsection, I detail the construction of plant-to-market freight, given its complexity relative to other components of delivered marginal cost (and its importance).

A.2. Constructing a measure of plant-to-market freight

In the cement industry, freight was a considerable component of cost. As mentioned, the vast majority of cement produced was shipped to buyers by road, and shipments were paid for by producers. Producers mostly outsourced trucking services on the spot market to independent truckers who were registered in their databases and simply turned up at the factory gate (or were hired through cooperatives or middlemen). I do not observe the exact freight rates paid by cement producers, but fortunately I do observe a good proxy for them based on freight rates for agricultural goods (recall fn 12). Due to product and market characteristics, cement and farm goods (such as soybean and maize) are close substitutes in the supply of transport services (Soares and Caixeta Filho 1996). This was confirmed in field interviews. For instance, an interview with the logistics director for a leading cement producer revealed that during the soybean harvesting season (March through May) his firm exceptionally encouraged the largest cement buyers to arrange for orders to be picked up at the plant, for fear of relying too heavily on the scarce supply of outside truckers during these months. This further suggests that cement freight and soybean freight, being close substitutes, were similarly priced.

I use a database containing about 30,000 observations on (predominantly road) freight rates for certain farm goods collected over the period 1997 to 2003

of specific varieties proximate to locations where these varieties are strongly preferred' (23). Not controlling for the migration of production in response to trade barriers then 'magnifies the effects of barriers on trade volumes and may explain the large estimates from aggregate (trade) models' (3).

TABLE A1
Conditional summary statistics for shipments, prices, and costs

	obs	mean	std. dev.	p1	p99
$q_{flt} > 0$					
Firm-to-market shipments, q_{flt}	960	262836	544691	26	1686184
Market retail price, p_{lt}	960	10.35	2.82	6.05	16.94
Delivered marginal cost, c_{flt}	960	6.70	1.41	4.25	10.36
Kiln fuel		0.84	0.11	0.69	0.99
Electricity		0.29	0.05	0.19	0.39
Mineral extraction royalties		0.14	0.04	0.08	0.22
Other		0.34	0.09	0.20	0.56
Freight		1.54	0.85	0.44	4.22
Sales tax		2.37	0.65	1.41	3.95
Reseller's cost		1.19	0.32	0.70	1.95
Price-cost margin, $p_{lt} - c_{flt}$	960	3.65	1.85	0.00	7.76
% of producer price net of sales tax	960	51%	16%	0%	75%
$q_{flt} = 0$ and $p_{lt} \geq c_{flt}$					
Firm-to-market shipments, q_{flt}	1147	0	0	0	0
Market retail price, p_{lt}	1147	11.60	2.70	6.63	16.97
Delivered marginal cost, c_{flt}	1147	9.20	1.93	5.42	13.44
Kiln fuel		0.87	0.09	0.69	0.98
Electricity		0.27	0.05	0.19	0.39
Mineral extraction royalties		0.15	0.04	0.09	0.23
Other		0.39	0.09	0.22	0.57
Freight		3.63	1.28	1.36	6.38
Sales tax		2.55	0.59	1.49	3.83
Reseller's cost		1.33	0.31	0.76	1.95
Price-cost margin, $p_{lt} - c_{flt}$	1147	2.40	1.63	0.04	6.81
% of producer price net of sales tax	1147	29%	16%	1%	65%
$q_{flt} = 0$ and $p_{lt} < c_{flt}$					
Firm-to-market shipments, q_{flt}	324	0	0	0	0
Market retail price, p_{lt}	324	8.58	1.44	6.45	11.91
Delivered marginal cost, c_{flt}	324	9.61	1.33	6.85	12.61
Kiln fuel		0.80	0.11	0.69	1.00
Electricity		0.28	0.04	0.23	0.36
Mineral extraction royalties		0.11	0.02	0.09	0.16
Other		0.29	0.05	0.22	0.40
Freight		5.27	0.88	3.29	6.89
Sales tax		1.86	0.32	1.39	2.57
Reseller's cost		0.99	0.17	0.74	1.37
Price-cost margin, $p_{lt} - c_{flt}$	324	−1.03	0.76	−3.34	−0.01
% of producer price net of sales tax	324	−19%	16%	−67%	0%

NOTES: p1 and p99 denote the 1st and 99th percentile respectively. Shipments in tons. Prices and costs in constant Reais per bag (Brazil GPI base Dec-1999).

for thousands of different routes across Brazil. Table A2 summarizes the results of some auxiliary reduced-form regressions. These should be seen as hedonic regressions with the purpose of predicting the price of (farm or cement) freight. Since I do not observe quantities demanded and supplied in the market for freight,

TABLE A2
Auxiliary OLS regressions for plant-to-market freight cost

	(I)		(II)		(III)	
Specification	coef	s.e.	coef	s.e.	coef	s.e.
Intercept	1.45	(0.22)***	3.11	(0.32)***	5.41	(0.45)***
Distance of route	0.0393	(0.0005)***	0.0409	(0.0007)***	0.0433	(0.0008)***
Distance of route squared	−1.0E-06	(2.5E-07)***	−7.2E-07	(2.6E-07)***	−9.6E-07	(2.4E-07)***
Port destination dummy	2.01	(0.16)***	1.56	(0.26)***	1.72	(0.24)***
Water transport dummy	−17.59	(0.20)***	−13.40	(1.05)***	−11.52	(1.25)***
Rail transport dummy	−12.29	(0.30)***	−3.44	(0.58)***	−3.15	(0.54)***
Harvest season dummy	2.21	(0.11)***				
Port during harvest dummy	2.85	(0.29)***	2.37	(0.29)***	2.25	(0.28)***
Price of diesel oil	6.04	(0.35)***	5.84	(0.35)***		
Shipment in bags dummy			0.29	(0.20)	0.49	(0.20)**
Powdered soya dummy			1.94	(0.13)***	1.75	(0.13)***
Maize dummy			−0.71	(0.09)***	−0.98	(0.10)***
Limestone dummy			−2.18	(0.14)***	−1.82	(0.14)***
Monthly dummies			Included (except April)		Included (except April)	
Year dummies					Included (except 1997)	
Distance interacted with:						
Port dummy			0.0006	(0.0003)**	0.0006	(0.0003)**
Water transport dummy			−0.0064	(0.0016)***	−0.0086	(0.0018)***
Rail transport dummy			−0.0134	(0.0009)***	−0.0132	(0.0008)***
Monthly dummies			Included (except April)		Included (except April)	
Year dummies					Included (except 1997)	
No. observations	30367		30367		30367	
R^2	0.89		0.90		0.90	

NOTES: Dependent variable is freight price (in constant Dec-1999 R$ per ton of produce shipped). Estimated through OLS. Heteroscedasticity-robust standard errors. ***Significant(ly different from zero) at the 1% level; **5% level; *10% level.

I do not estimate a structural model of the market for freight. My objective is less ambitious: to predict the cost of hauling cement from plant i to state l based on observed data. Further, projecting freight prices onto freight cost-shifters is structurally appropriate to the extent that the market for freight was competitive. Using the farm freight data, I regress freight prices, in constant R$ per ton of produce shipped (Brazil GPI base Dec-1999), on explanatory variables such as the right-of-way distance of the route (road mostly), the square of distance, a shipment-to-port dummy (to capture exports), modal-choice dummies (by water or rail, as opposed to road), seasonal dummies or monthly dummies (to capture the harvesting cycle), the price of diesel oil (a key cost component), a packaging dummy (shipment of bagged produce as opposed to bulk), and product-type dummies (e.g., powdered soybean), in addition to interaction variables.

It is clear from the R^2 of the OLS regressions – around 90% – that the fit is very high. For perspective, Hummels (2001) reports R^2 in the order of 20%–45% for similar freight rate regressions using international shipping data. The heteroscedasticity-robust standard errors are low. Farm freight prices are increasing in distance (and concave, though slightly so over the relevant range). Consider the estimates for specification (II). At the sample means of the variables (a route distance of 735 km and a diesel oil price of 0.451 R$ per litre), the predicted price of freight for a ton of soybean shipped in bulk by road to a destination other than a port and in the month of April amounts to $3.11 + 0.0409 \times 735 - 7.2 \times 10^{-7} \times 735^2 + 5.84 \times 0.451 = 3.11 + 30.06 - 0.39 + 2.63 = 35.39$ R$ (with a standard error of 0.19 R$). Shipping to a port (possibly as a result of longer waiting times to unload) adds $1.56 + 0.0006 \times 735 = 2.01$ (s.e. 0.14) R$, and when this shipping to a port takes place during the harvest season freight prices are predicted to increase by a further 2.37 (s.e. 0.29) R$. Shipping by waterway costs $13.40 + 0.0064 \times 735 = 18.12$ (s.e. 0.23) R$ less than by road, while shipping by railway costs $3.44 + 0.0134 \times 735 = 13.28$ (s.e. 0.27) R$ less than by road. Shipping in bags as opposed to in bulk raises the price of freight by only 0.29 R$ (this difference is not statistically significant, probably because such heavy goods fill up a truck's weight capacity long before its 'cube' capacity binds and the form of packaging matters most for cube). Compared with April, the peak month of the harvesting season, shipping in any other month of the year are cheaper (all coefficients on monthly dummies and their interactions with distance – not reported – are negative). Shipping in January is the least expensive: prices are 4.64 (s.e. 0.23) R$ lower compared with shipping in April. Note that the variation in diesel oil prices over the period is 0.464 R$, accounting thus for a $5.84 \times 0.464 = 2.71$ (s.e. 0.16) R$ variation in freight prices; this appears somewhat low.

I then predict the plant-to-market freight cost for cement using the coefficients of specification (II) and cement plant-to-market observables. These observables include the price of diesel oil and a proxy for the average road distance from the plant to all cities in the market (state). Since road distances to all cities are not available (recall fn 17), I take the average geodesic distance (weighted by city population, as explained in section 3.2) adjusted upward by a plant-to-state specific factor to account for the fact that road distances exceed geodesic distances. Because road distances from each plant to the capital city of each state *are* available, this upward plant-to-state specific factor of adjustment is the *road* distance from each plant to each state's capital divided by the *geodesic* distance from the plant to the state's capital. (It is worth noting how Brazil's population concentrated in state capital cities: in 2000, for example, a state's capital – including the wider metropolitan area – was its most populous city in 26 out of the 27 states; in total, state capitals were home to 42% of Brazil's households.) For the reason explained in section 3.3, it is important that any bias in my measure of plant-to-market freight be upward, that is, in the direction of overstating the true cost c_{flt}. So I ignore seasonality and predict cement freight year-round based on rates at the peak month of the harvesting season, that is, April (as well as based on soybean rather than limestone).

References

Agência Estado (2007) 'Secretaria de Direito Econômico investiga criação de cartel no setor de cimento,' (Secretariat for Economic Law investigates cartel formation in the cement sector), edition of 02/02/2007

Anderson, James E. (1979) 'A theoretical foundation for the gravity equation,' *American Economic Review* 69, 106–16

Anderson, James E., and Eric van Wincoop (2003) 'Gravity with gravitas: a solution to the border puzzle,' *American Economic Review* 93, 170–92

Bergstrand, Jeffrey H. (1989) 'The generalized gravity equation, monopolistic competition, and the factor-proportions theory in international trade,' *Review of Economics and Statistics* 71, 143–53

Bernheim, B. Douglas, and Michael D. Whinston (1990) 'Multimarket contact and collusive behavior,' *Rand Journal of Economics* 21, 1–26

Blum, Bernardo S., and Avi Goldfarb (2006) 'Does the internet defy the law of gravity?' *Journal of International Economics* 70, 384–405

Brander, James A. (1981) 'Intra-industry trade in identical commodities,' *Journal of International Economics* 11, 1–14

Brander, James A., and Paul R. Krugman (1983) 'A reciprocal dumping model of international trade,' *Journal of International Economics* 15, 313–21

Deardorff, Alan V. (1995) 'Determinants of bilateral trade: does gravity work in a neoclassical world?' NBER Working Paper 5377; reproduced in J.A. Frankel, ed. (1998) *The Regionalization of the World Economy* (Chicago: University of Chicago Press)

Deltas, George, Alberto Salvo, and Helder Vasconcelos (2009) 'Welfare-enhancing, collusion and trade,' mimeo, University of Illinois at U.-C., Northwestern University, and Universidade Católica Portuguesa

Disdier, Anne-Celia, and Keith Head (2008) 'The puzzling persistence of the distance effect on bilateral trade,' *Review of Economics and Statistics* 90, 37–48

Eaton, Jonathan, and Samuel Kortum (2002) 'Technology, geography and trade,' *Econometrica* 70, 1741–79

Evenett, Simon J., and Wolfgang Keller (2002) 'On theories explaining the success of the gravity equation,' *Journal of Political Economy* 110, 281–316

Feenstra, Robert C., James A. Markusen, and Andrew K. Rose (1998) 'Understanding the home market effect and the gravity equation: the role of differentiated goods,' mimeo, University of Michigan

— (2001) 'Using the gravity equation to differentiate among alternative theories of trade,' *Canadian Journal of Economics* 34, 430–47

Flowerdew, Robin, and Murray Aitkin (1982) 'A method of fitting the gravity model based on the Poisson distribution,' *Journal of Regional Science* 22, 191–202

Gilbert, Richard, and Xavier Vives (1986) 'Entry deterrence and the free rider problem,' *Review of Economic Studies* 53, 71–83

Greenhut, John G., and M. L. Greenhut (1975) 'Spatial price discrimination, competition and locational effects,' *Economica* 42, 401–19
Grossman, Gene (1998) 'Comment on Deardorff,' in *The Regionalization of the World Economy*, ed. J. A. Frankel (Chicago: University of Chicago Press)
Harrington, Joseph E. (1991) 'The determination of price and output quotas in a heterogeneous cartel,' *International Economic Review* 32, 767–92
— (2006) 'How do cartels operate?' *Foundations and Trends in Microeconomics*, Vol. 2, 1–105
Head, Keith, and Thierry Mayer (2000) 'Non-Europe: The magnitude and causes of market fragmentation in the EU,' *Weltwirtschaftliches Archiv* 136, 285–314
Head, Keith, and John Ries (2001) 'Increasing returns vs national product differentiation as an explanation for the pattern of US-Canada trade,' *American Economic Review* 91, 858–76
Hummels, David (2001) 'Toward a geography of trade costs,' mimeo, Purdue University
Kaplow, Louis, and Carl Shapiro (2007) 'Antitrust,' in *Handbook of Law and Economics*, Vol. 2, ed. A. M. Polinsky and S. Shavell (Oxford: North-Holland)
Levenstein, Margaret C., and Valerie Y. Suslow (2004) 'Contemporary international cartels and developing countries: economic effects and implications for competition policy,' *Antitrust Law Journal* 71, 801–52
McBride, Mark E. (1983) 'Spatial competition and vertical integration: cement and concrete revisited,' *American Economic Review* 73, 1011–22
Motta, Massimo (2004) *Competition Policy. Theory and Practice* (Cambridge: Cambridge University Press)
Nitsch, Volker (2000) 'National borders and international trade: evidence from the European Union,' *Canadian Journal of Economics* 33, 1091–105
Pinto, Brian (1986) 'Repeated games and the "reciprocal dumping" model of trade,' *Journal of International Economics* 20, 357–66
Röller, Lars-Hendrik, and Frode Steen (2006) 'On the workings of a cartel: evidence from the Norwegian cement industry from 1955–1968,' *American Economic Review* 96, 321–38
Salvo, Alberto (2005) 'Price competition, mergers and structural estimation in oligopoly,' PhD thesis, London School of Economics
— (2010) 'Inferring market power under the threat of entry: the case of the Brazilian cement industry,' *RAND Journal of Economics*, forthcoming
Santos Silva, João M.C., and Silvana Tenreyro (2006) 'The log of gravity,' *Review of Economics and Statistics* 88, 641–58
Soares, Marcelo G., and Jose Vicente Caixeta Filho (1996) 'Características do mercado de frete para cargas agrícolas,' (Characteristics of transportation markets for agricultural goods), *Preços Agrícolas* 121 (Piracicaba, Brazil), 21–5
Thisse, Jacques-François, and Xavier Vives (1988) 'On the strategic choice of spatial price policy,' *American Economic Review* 78, 122–37
Venables, Anthony J. (1985) 'Trade and trade policy with imperfect competition: the case of identical products and free entry,' *Journal of International Economics* 19, 1–19