Firm Networks, Borders and Regional Economic Integration*

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Abstract

While the presence of provincial border effects—the relative weakness of inter-provincial trade compared to intra-provincial trade—is well established, it remains unclear what underlies them. Networks of operating units controlled by the same enterprise lower the cost of trade by shipping goods between units as value is added through the production chain or via the use of common upstream and downstream supply chains. Higher costs of operating these networks in multiple provinces may act as a barrier to firm networks. Furthermore, higher costs of inter-provincial trade may induce firms to invest across provincial borders to overcome these barriers, rather than to extend their trading ties. By combining measures of regional trade and firm networks over a nine-year period (2004 to 2012), we test these propositions. We find that while many firms operate networks across multiple provinces, firm networks dissipate with provincial borders and that this has important implications for trade. Using a gravity model, we find that provincial border effects fall by about half after accounting for firm networks. This results both from provincial borders acting as a barrier to firm networks and that networks that cross provincial borders act less as a complement to than a substitute for trade.

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1 Introduction

Trade costs have proven to have a significant effect on the degree of economic integration between regions and countries (Anderson and van Wincoop, 2004; Chaney, 2008; Behrens and Brown, 2017). Although the magnitude of these costs can be estimated relatively easily, their sources are much more difficult to discern. Furthermore, while in Canada transport costs make a significant contribution to overall trade costs (Behrens and Brown, 2017)[1], the strong presence of provincial border effects suggests there are other factors at play that have yet to be taken into account (see Bemrose et al., 2016). Unlike in the United States where refined data and methods have reduced estimates of state-level border effects to zero (see Hillberry and Hummels, 2008), in Canada we continue to find evidence that provincial borders matter, measuring approximately 6.9% in tariff equivalent terms (Bemrose et al. (2016); see also (Agnosteva et al., 2014; Albrecht and Tombe, 2016)). The obvious next question is what trade costs lie behind these border effects or, perhaps more accurately in this instance, whether borders and the costs to firms that they entail intervene to reduce the ability of firms to mitigate trade costs.

One of the more important sources of trade costs are those that firms incur when engaging in market transactions (Williamson, 1979) that, in turn, influence the patterns of trade (Rauch, 1999). In order to minimize these costs, it is sometimes advantageous for the boundaries of the firm to extend across borders. As firms expand into new areas trade may be induced as the firm engages in lower cost, intra-firm trade and/or by extending their existing supply chain. Regarding the former about one-third of world trade occurs within firms (Antràs, 2003; Antràs and Helpman, 2004). Regarding the latter, there is evidence that firms that are taken over subsequently adjust their production technologies, including downstream shipment destinations and likely their upstream supply chains to more closely match that of the acquiring firm (see Atalay et al., 2014).

[1] Behrens and Brown (2017) find between 25 and 57% of distance related trade costs are attributable to transport costs.

While the role of intra-firm trade on the international stage is well known, relatively little is known of the role of intra-firm trade at the sub-national scale (see Anderson, 2011; Atalay et al., 2014) or, more broadly, the effect of firm networks on trade. In particular, a potentially important factor that underlies the integration of provincial economies through goods trade may be intra-firm linkages that extend across provincial borders, or a lack thereof (Helliwell, 1998). Hence, this paper investigates the nature of firm networks in Canada, their relationship with regional goods trade, and how much they account for the effect of provincial borders on trade flows. In particular, the analysis addresses the following questions:

1. To what extent is a provincial economy knit together by multi-location firms (firm networks)?

2. How easily do these firm networks spill across provincial borders? That is, as with trade, firm networks (i.e., operating locations controlled by the same firm) may be more prevalent within provincial borders as firms potentially incur extra costs when entering new provincial markets (e.g., adapting to a new set of regulations). Alternatively, they may be more prevalent if market access (e.g., eligibility to bid on government contracts) depends on demonstrating a physical presence in the province (see Chaundy (2016)).

3. How much do these firm networks influence provincial integration through goods trade? Specifically, how much do firm networks account for provincial border effects. Do firm networks enhance trade by reducing transaction costs or do they reduce trade by allowing firms to save on trade costs by producing goods in local markets?

To address these questions, we need information both on goods trade and firm networks across regions. Trade is measured using Statistics Canada's newly created Surface Transportation File (STF), which builds up from a set of geo-coded, transaction level records a coherent set of estimates of the value of trade across regions. Firm networks are measured using the Business Register (BR), which contains both information on the structure of firms [i.e., firms and the operating units they control (e.g., manufacturing plants)] and where the operating units are located. Using a common geography, these two data sets can be combined to provide both a measure of trading links between regions but also their firm-based links. Furthermore, both files cover a 9-year period (2004 to 2012), providing measures of firm networks and trade through time using a geographically consistent panel of regions.

This work contributes to two broad areas of research: borders and barriers to trade and firm networks.

Borders and barriers to trade. Accounting for firm networks may help us to parse the provincial border effect. Generic barriers to trade have been explored in several studies, and can be substantial (for an overview, see Anderson and van Wincoop, 2004) and quite naturally firms seek to minimize these costs. Multinationals, for example, may use affiliate ownership to reduce trade costs associated with contract enforcement problems (Yeaple, 2013). In this view, firms with vertically integrated supply chains expand and engage in intra-firm trade to minimize such costs, leading to the complementarity of investment and trade. However, recent research has shown this trade is not always part of a supply chain, even when the affiliate is in an industry that is upstream of the domestic firm (Ramondo et al., 2016), a result seems to also apply to domestic vertically integrated firms (Atalay et al., 2014). The implication of this stream of literature is that the impact of firm networks on trade may be less than originally thought.

Still, the relationship between firm networks and trade may go beyond this more limited view. Information asymmetries, for example, in the form of firm contacts in different trading destinations, have been used to explain the pattern of international trade (Chaney, 2014). Firm ownership is a way a firm can increase local knowledge of destinations, reducing these informational asymmetries, potentially inducing trade between regions. Furthermore, if firms maintain their network of upstream suppliers—i.e., their supply chain—as they extend their network of operating locations outwards, trade may be induced. Hence, whether it is through mitigating the costs of within firm transactions, the reduction of informational asymmetries, or the extension of supply chains, the expansion of firm networks is potentially complementary to trade.

On the other hand, firms may also use their local affiliates to circumvent trade barriers. They may do so to overcome transport costs, to tailor their products and services to local needs (e.g., to account for regulatory differences) and/or to meet local content requirements for some government contracts (Chaundy, 2016). From this perspective, trade and investment may be substitutes. If the primary influence of firm networks on trade is complementary, then they may help us to account for provincial border effects if firms are less likely to extend their operations across provincial borders. The opposite holds true, of course if they are substitutes.

This paper contributes to the study of trade barriers by investigating the association of firm networks with barriers to provincial trade in Canada. It is closely related to the literature that relates business and social networks of immigrants to aggregate trade, starting with Rauch (1999, 2001). The idea is that immigrants make connections between their contacts in the new and home countries, and the countries trade more than they otherwise would without these connections. Our focus is, however, on the specific channel of a firm owning operating locations in different regions, and the aggregate effect of those connections on regional trade. As such, this work has much in common with Combes et al. (2005), who find both firm networks and migration reduce measured intra-national barriers to trade and Garmendia et al. (2012) who examine the effect of networks and migration and find both reduce Spanish provincial border effects, with firm networks being more important. It, however, pushes beyond this paper augments the Combes et al. (2005) and Garmendia et al. (2012) by using panel methods to control for endogeneity and to address questions, as we will see, of complementarity and substitutability among investment and regional goods trade.

Firm networks. There is a large body of literature that examines firm networks, their characteristics, and impacts on productivity and trade. In this case, spatial characteristics are the object of interest, but this work also connects to these broader lines of research.

In descriptive terms, Atalay et al. (2011) show the prevalence of firm networks and their relationships to firm size (in customer-supplier relationship terms), and Lim (2016) showed the impact of fixed costs on establishing firm-firm relationships. One important result is that reducing trade costs within the supply chain has shown to increase firm productivity in Japanese firm networks (Bernard et al., 2015), supplementing previous work on Japanese keiretsus (Belderbos and Sleuwaegen, 1996, 1998; Head et al., 2004). These findings suggest provincial barriers that impede the establishment of firm networks and ultimately savings on trade costs may have an impact on productivity.

Drawing from this, we also take a step back to look at the networks themselves, and specifically how distance and borders matter there too. This is crucial because for networks to matter for trade across borders, firm networks also need to be less prevalent across borders. The existing literature does not address this, and therein lies an additional contribution. This relates to work on an MNE's choice to open a new foreign affiliate (greenfield investment) or acquire an existing location (M&A). The fact that M&A is the dominant form of foreign direct investment suggests an MNE uses acquisition to partially overcome regulatory and informational barriers that the border introduces (Nocke and Yeaple, 2007), since it must be easier to satisfy local regulations by acquiring something that already exists and already satisfies those regulations.

We show the intensity of firm networks declines with distance and across provincial borders, with the latter being an indication that firms incur additional costs when expanding their operation into other provinces. Furthermore, firm networks are positively associated with trade, but their effects dissipate with distance and borders. This suggests the additional costs associated with managing firm networks across provincial borders diminishes the complementary effect of firm networks on trade and, in some instances, switches it from positive to negative. After accounting for firm networks provincial border effects fall by about half, which is broadly consistent with the literature (Combes et al. (2005) and Garmendia et al. (2012)).

The remainder of this paper is organized as follows. Section 2 draws from the theoretical and empirical literature on multinationals to develop a set of hypotheses regarding the extension of firm networks across space and borders and the relationship between firm networks and trade. Section 3 describes the data sources and methods used to measure firm networks. Section 4 provides a description of provincial firm networks and an econometric analysis of the factors affecting firm networks at the province level and finer geographies. Section 5 presents the impact of firm networks on trade, which is followed by the Conclusion (Section 6) and the Appendix.

2 Multiunit firms and trade

To put this paper into context, it is necessary to return to the fundamental reasons why firms choose to operate multiple units, why sometimes it is advantageous to locate units across borders, be they national or sub-national, and what this implies regarding inter-regional trade. It is helpful to address these questions with their implied hypotheses in sequence, rather than all at once.

Why do firms have multiple units? There are three types of multiunit[2] enterprise (Caves, 1996): (1) horizontal (units produce the same goods/service), (2) vertical (units are related functionally through upstream-downstream links), and (3) diversified (are neither horizontally or vertically related; investments can be viewed as portfolio diversification strategy). Our focus here is on horizontally and vertically linked firms. Firms organise themselves horizontally to internalize the market for proprietary assets, while those that organize themselves vertically internalize markets for intermediates. Vertically linked firms, however, do not necessarily need to trade internally as

> "... [t]here can be transaction-cost economies in the procurement of raw materials that go beyond the input needs of a single plant's output. Economies can arise in

[2] Note that the terms "multiunit", "multi-location", and a firm's "operating locations/units" are used interchangeably throughout the text.

the transportation network for outbound shipments of finished goods that extend beyond the single plant's output"(Caves, 1996, pp. 6).

This is consistent with evidence on domestic (Atalay et al., 2014) and international (Ramondo et al., 2016) intra-firm trade patterns. Furthermore, the economies gained by developing a horizontally or vertically linked structure have to be traded-off against the costs of managing these operations. As those costs rise, firms are more likely to engage in more arms-length transactions. One dimension along which we would expect (Duranton and Puga, 2005) and find (Behrens and Sharunova, 2015; Baldwin and Brown, 2005) evidence of rising management costs is the distance between units. For instance, operating units of a multiunit firms are more geographically compact than a randomly drawn set of single unit firms in the same industry (Behrens and Sharunova, 2015). The implication, of course, is that the distance between potential units increases, the benefits of internalizing markets for proprietary assets are more likely to be outweighed by the cost of managing far flung operations. These leads to our first hypothesis.

H1: Facing a trade-off between economies gained from operating multiunit enterprises and the cost of managing these operations, the prevalence of firm networks ties will fall with distance between regions.

When do firms expand across borders? When crossing borders the entrepreneur incurs additional fixed costs of learning how to operate in a different jurisdiction, be it a country or province in this instance.

> "The typical entrepreneur, a native of some particular country, brings to his or her business activities a general knowledge of its legal and social system and its peculiar 'way of doing things'."(Caves, 1996, pp. 57–58)

The transaction cost advantage of the multiunit firm is required to counterbalance these costs. The same principles apply to national markets. "Indeed, the early process of expansion of firms to national-market status in the nineteenth-century U.S. economy was apparently quite similar to their evolution of multinational status more recently." (Kindleberger, 1969, pp. 33–35). This trade-off informs the second hypothesis.

H2: Firms are less likely to establish firm networks across provincial borders, because of the higher cost of operating in multiple provinces.

The opposite relationship could hold if government procurement rules stipulate firms must have a physical presence in a province to qualify for contracts (Chaundy, 2016). It is unlikely this specific form of contracting rule would determine the overall pattern of investment and so we maintain **H2** as our primary hypothesis.

How do firm networks influence trade? There are two relevant perspectives. The first is a basic model of trade and investment that can be applied to show that rising trade costs (e.g., tariffs or transportation costs) will result in declining exports corresponding with rising local production. Hence, rising trade costs shift the effect of firm networks from being a complement to trade to a substitute. This linear relationship holds with decreasing returns to scale, but not increasing returns, where production is either at home or abroad. Brainard (1997) shows sales of subsidiaries of U.S. MNEs (as a proportion of those sales plus U.S. exports) increased with transportation costs. The broader conclusion is that the higher the trade costs, the larger the proportion of the MNEs sales in the host country that is accounted for by local production. The following hypothesis draws on this point.

H3: Higher trade costs—associated with distance or borders—for a given firm switches the effect of firm networks on trade from positive to negative (*complement* to *substitute*).

The second perspective is more subtle but potentially as or more important. Based on the Transaction Cost Economics (TCE) framework, firms will organize themselves in order to minimize "...the cost of production and *associated logistics activities of the firm*"(Caves, 1996, pp. 2), *emphasis added*). One of the firm specific assets that contributes to firms expanding their operations horizontally or vertically is their logistics capabilities as expressed via their supply chain. For retail and wholesale enterprises, their ability to build and manage their supply chains is likely one of their more important assets. The TCE perspective suggests that even if there are no ownership ties, the need for some form of contractual arrangement means the switch between suppliers has a cost (Williamson, 2008). In fact, Atalay et al. (2014) find after a unit is purchased, its production technology and shipment destinations looks increasingly like the acquiring firm's. Hence, firms, regardless of their horizontal or vertical structures, will tend to maintain their supply chains.[3] As firms expand into new areas (or contract), so too do their supply chains. As a result, even if there is no input-output relationship between the units, trade between regions may rise, simply because firms have an established network of suppliers that move with them. However, once again, maintaining these networks across space has a cost and over longer distances it is less likely the will be maintained as the additional transportation costs outweigh the lower costs of utilizing an existing network of suppliers. This leads to the fourth and final hypothesis.

H4: The effect of firm networks on trade will decline with distance as the cost of maintaining supply chains out weight their benefits.

Of course, **H3** and **H4** are observationally equivalent. Hence, we will not be able to distinguish between both processes. We will, however, be able to establish whether trading relationships over space are consistent with both.

3 Methods

The analysis is based on the measurement of firm networks and trade across regions. The former requires detailed information on the structure of firms and their location, while the latter requires information on goods trade across a similar geography. Each of these data sources are described in sequence below, after we first define our measures of firm networks.

[3] Furthermore, as Chaney (2014) shows, when firms invest in a new location they end up trading more with locations near by, because more is learned about those markets.

3.1 Defining and Measuring Firm Networks

We are seeking to measure the degree to which regions are linked via firm networks and the association between these networks and trade flows. Firm networks by their very nature are composed of multiunit firms, or what we will refer to here as multi-location firms to be consistent with naming conventions of the Business Register. Two geographic regions are linked if operating locations in each are part of the same (multi-location) firm. For instance, Toronto and Halifax are linked through a firm network if a supermarket chain has operating locations in both. Thus, a simple way to measure firm networks between two regions is to count the number of operating locations in a geographical unit that are part of the same multiunit firm operating in both.[4]

Figure 1a illustrates this conceptually. Firm a has 1 location in region i and 2 locations in region j, while firm b has 2 locations in i and j. Hence, from the perspective of region i, the number of locations linked j is 3, while the number of locations in region j linked to i is 4. Note that multi-location firm c has a location in i, but none in j, and so its locations are not counted when considering locations in i linked to j. In formal terms, we calculate the strength of firm network (N) connections from region i to region j over m firms as follows:

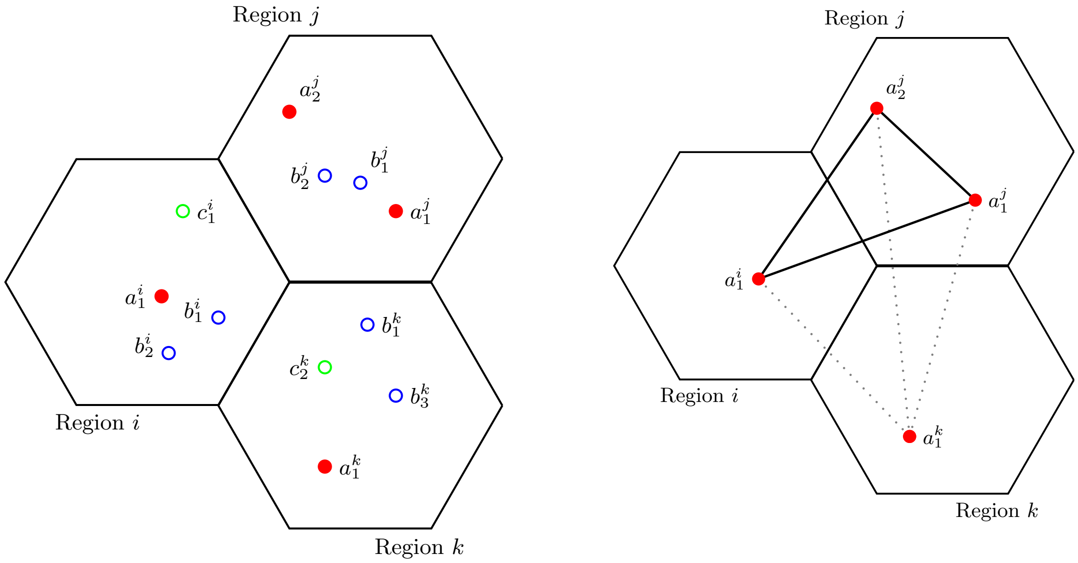
$$N_{ij} = \sum_{m} \mathbb{1}\{n_{mj} > 0\} n_{mi}, \tag{1}$$

where n_{mi} is the count of operating locations of firm m in region i. As is apparent from this equation, and the example described above, firm links are bidirectional but asymmetric.

Equation (1) is useful in the analysis of firms networks between geographic regions for two reasons. First, it can be derived from a reduced form model, the details of which are presented in subsection 4.1. Second, it forms the foundations for the analysis to the relationship between firm networks and trade flows that required networks be measured in

[4]There is, of course, a close association between the network measures described here and standard measures of networks (graph), where locations are vertices and the links between them are edges. As a result, the measures presented here are measures of network connections, but ones that are aggregated from the enterprise level to the region.

Figure 1: Conceptual firm networks.



(a) Several establishments belonging to several firms.

(b) Several establishments belonging to one firm, and the corresponding network.

a slightly different way. Based on (1), trade would be a function of whether there was a firm network present and weighting on the size of the firm as measured by the number of its operating locations in i. On a pairwise basis, however, the effect of networks on trade depends on the firm's locations in both regions. Thus, one simple way of capturing the bilateral firm links of regions i and j is to take into account the asymmetry implied by (1) to capture the j to i links as well:

$$\mathbb{N}_{ij}^{A} = \sum_{m} \mathbb{1}\{n_{mj} > 0\} n_{mi} + \sum_{m} \mathbb{1}\{n_{mi} > 0\} n_{mj} = N_{ij} + N_{ji}. \tag{2}$$

The aggregate additive measure $\mathbb{N}_{ij}^{A}$ thus represents total links between i and j, where A is a mnemonic for 'additive'. This additive measure likely captures whether firms have built a knowledge of markets in both regions, but it may not fully take into account the potential for internal firm trade.

Considering the ij geography pair once more, each location in i that has a firm link to region j is a potential trading partner of all the firm's locations in j. If the firm has two locations, potentially half of the output of each could be traded with the other, while if there are four locations the potential for trade is one-quarter between each, all else being held equal. This can be seen in Figure 1b. It illustrates the links (edges) between locations (vertices) controlled by enterprise a. It is the number of locations in i linked to j multiplied by the number of locations in j linked to i, divided by the number of locations controlled by the firm that determines the potential for intra-firm trade. In this instance, the locations in i and j account for half of the potential links: $(2 \times 1)/4 = 0.5$. Importantly, the strength of bilateral firm links depends on the number of units in the firm. Unlike in the additive case, the location in k matters. This multiplicative approach can be formalized as follows:

$$\mathbb{N}_{ij}^{M} = \sum_{m} \frac{\mathbb{1}\{n_{mj} > 0\} n_{mi} \times \mathbb{1}\{n_{mi} > 0\} n_{mj}}{n_m} = \sum_{m} \frac{n_{mi} n_{mj}}{n_m}. \tag{3}$$

It parallels the work of Combes et al. (2005) and Garmendia et al. (2012), however, these authors do not discount networks by the number of units in the firm, as in (14). Moving forward, for the analysis of firm networks, N_{ij} is the key dependent variable, while for the analysis of trade networks on trade flows the measures $\mathbb{N}_{ij}^{A}$ and $\mathbb{N}_{ij}^{M}$ are used (alternatively) as independent variables.

The number of units in a firm provides a straight forward measure of firm size, but one that may not be complete. For example, the question easily arises of whether it is appropriate to treat networks of convenience stores and supermarkets with the same number of units as equivalent. While both may have the same network ties between two regions, supermarkets are likely larger in terms of employment that, in turn, may also impact trade flows, with larger firms potentially generating more cross-region trade. We, therefore, take the additional step of weighting the counts by employment. When applied, however, we find no qualitative difference in the result. Hence, to simplify the exposition, we leave the development of the weighted measure and the associated results to the Appendix.

3.2 Data

These measures of firm networks requires a method to identify multiunit firms over subnational geographies. Statistics Canada's Business Register (BR) is an inventory containing all businesses in Canada, where firms are defined as multiunit if they have more than one operating location. For example, a manufacturing firm is considered to be multiunit if it has more than one plant (operating location). Measuring firm networks from the BR is possible since it provides information on a firm's operating structure, geographical location, and industry (6-digit NAICS). Using the geographical and industry information also available, we may then assess whether such a firm has operating locations within and across geographic units, by industry.

Over time, the BR has undergone changes that have improved the statistical coverage of businesses in Canada. Analytically, however, this is a challenge, as such changes to the frame of businesses potentially compromise its longitudinal consistency. For example, in 2009, the inclusion of additional detailed tax data (T4 tax filings) in the BR improved the coverage of multi-province firms. However, this results in many longitudinally inconsistent births of locations belonging to multiunit firms between 2008 and 2009. To improve the longitudinal consistency of the file, we used indicators available on the BR to exclude firms that are affected by such changes to the BR frame. We use the 2004 to 2012 time period to match that covered in our trade database.

3.2.1 Sectoral Breakdown

We focus on the business sector and provide a subsector breakdown, defined as follows. A multiunit firm is said to be in the goods subsector if every one of its operating locations is goods-producing. Similarly, a multiunit firm is in the services subsector if all of its operating locations are in the services sector. Multiunit firms that have both goods- and services-producing operating locations are said to be in the hybrid goods subsector, since they are linked to both the goods and services subsectors. Note that the hybrid goods sector contains only locations belonging to multiunit firms by definition. On average over the 2004 to 2012 period, service only comprised almost 75% of the business sector operating locations. This is compared to 23.2% of operating locations that are in the goods only and 2.2% in the hybrid goods sectors (see Table 1).

Table 1: Business sector breakdown, operating locations

Sector	Percent share of operating locations
Goods only	23.2
Hybrid goods	2.2
Services only	74.6
Total business sector	100.0

This breakdown by industry is potentially important since firms are expected to behave differently within the business sector. For instance, goods producers have an incentive to keep their production facilities close by to minimize the cost of managing their facilities (Duranton and Puga, 2005) and/or to benefit from various localization economies (e.g., upstream-downstream links, labour market pooling, and knowledge spillovers). Service producers, on the other hand, do not face the same costs of managing multiple units across distances, since the production process is often (but not always) less complicated than goods production. Expansion of goods and service firms into new markets may also have a differential effect on trade. For many service firms, because they require customer contact (e.g., retail stores), expansion usually entails seeking new geographic markets, while attempting not to take customers away from existing facilities (substitution effect). Of course, service firm expansions may also induce trade if expansion into new areas involves the extension of pre-existing supply chains. The same incentives may also hold for goods producing firms, but expansion also has the potential to induce more trade through upstream-downstream trade within the firm (complementary effect). Finally, for the hybrid goods sector, since firms are multiunit by definition, they are likely larger than goods only or services only enterprises. Hence, while they also face costs of managing multiple units across distances, they are more likely to have the capacity to absorb these costs if they are fixed. As such, it is possible that these firms expand more easily across provincial borders. How multi-unit firm expansion relates to trade will depend on the relative concentration of goods and services producing units within the firm itself and so is an empirical question.

3.3 Trade data

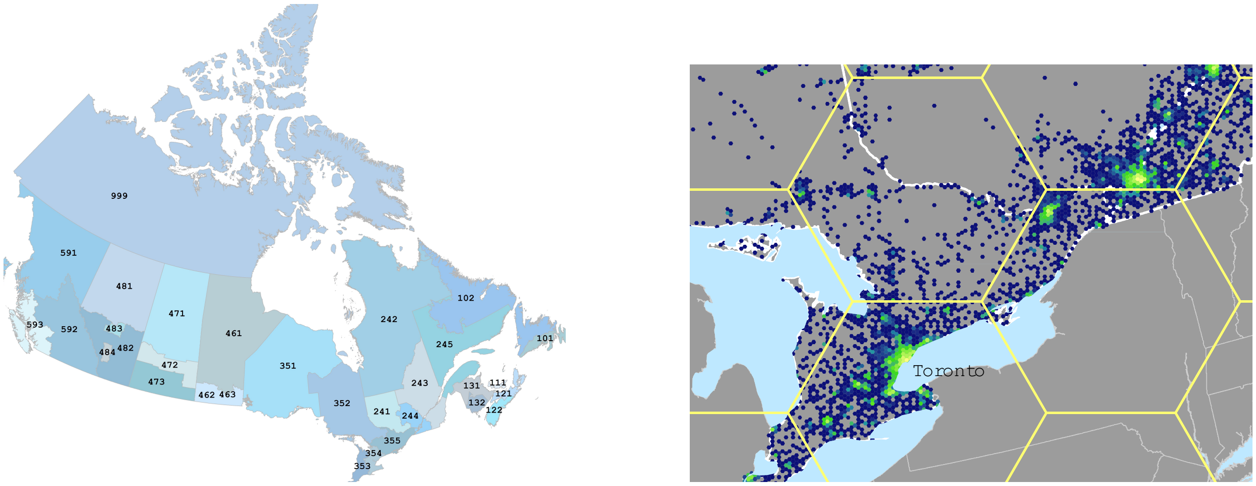
To measure regional trade flows, Statistics Canada's Surface Transportation File (STF) is used (please see Appendix 7.1 for more detail on the construction of the file). It is a shipment-level database on regional trade in Canada from 2004 to 2012, which covers goods moved by truck and rail. Trade flows are benchmarked to inter- and intra-provincial trade totals by commodity and year to better reflect total goods trade in Canada. The database contains shipments measured in terms of commodity, tonnage, value, distance, and cost between geocoded origins and destinations. The latter allows us to measure trade between a virtually limitless number of geographies. This is important in light of the problems associated with geographic aggregation, notably, the Modifiable Areal Unit Problem (MAUP). Generally speaking, how geographical units are specified, whether they are standard or non-standard, matters and can impact spatial interaction models like the gravity model employed here.

With this in mind, we use two standard geographies, provinces and Greater Economic Regions (GERs), and one non-standard geography, hexagonal lattices (see Figure 2) to measure trade flows.[5] We follow Bemrose et al. (2016) in using hexagonal lattices with 225km sides. Using postal codes of the operating locations, we construct the GER and hexagonal geographies. While not eliminating it completely, this strategy helps mitigate the sensitivity of our results to biases associated with geographic aggregation that plague standard geographies, since hexagons are identical and spatially independent (Arbia, 1989). Note that hexagons that cross provincial borders are split and treated as separate units.

We thus measure trade flows between origin and destinations measured at these different geographies. In a similar fashion, we are also able to measure firm networks between the

[5] Note that GERs are an aggregation of the standard Economic Region (ER) classification.

Figure 2: Geographies used to measure firm networks and trade.



(a) Greater Economic Regions

(b) 225km per side hexagons

Notes: Figure 1a presents the Greater Economic Regions' geography, constructed from standard Economic Regions. Figure 1b presents an overlay of hexagons with 225km sides on southern Ontario and Quebec. Hexagons respect provincial boundaries and so are split across provinces. Each 'point' is a 4km-sided (42km^2) hexagon with one or more origins/destinations (postal codes or railway terminals). The gradation in colour from blue to green to yellow denotes a greater number of origins/destinations. The 4km-sided hexagons are only used for illustration and are not used to determine which points fall into which hexagons in the econometric models.

different levels of geography due to the availability of geocoded postal code data on the BR. Therefore, the resulting dataset measures not only trade flows between a particular origin and destination pair, but also the number of operating locations in the origin that belong to firms with locations also in the destination from 2004 to 2012. In this way, we are also able to measure firm networks at different levels of geography.

Our data are limited in the sense that we cannot identify firms trading with each other, only regions. Identification stems from variation in firm network ties across region pairs and through time. This empirical strategy, however, has the potential to provide considerable insight. It provides a means to examine whether the well-documented trade border effect is also present in firm networks. These data also allow us to test whether networks matter for trade across regions, and whether they act as a complement or substitute on aggregate and by industry subsector. The next section (Section 4) begins the analysis by examining the extent to which firm networks are affected by distance and provincial border effects after taking into account the relative size of firm-linked region pairs, by industry subsector. This is follows by an analysis of firm networks on trade (Section 5).

4 Analysis of Firm Networks

It is well-established in the trade literature that distance and provincial borders affect the degree of intra- and inter-provincial (or regional) trade in Canada (Agnosteva et al., 2014; Bemrose et al., 2016; Albrecht and Tombe, 2016). In a similar fashion, we ask here how easily firm networks spill across provincial borders, all else being held equal. As a first step, this entails the development of an estimatable model that, while not developed from explicit micro-foundations, provides some essential guidance as to how the spatial extent of networks across regions can be estimated.

4.1 Firm network model

The model is developed by beginning with a very simple counterfactual premise. That is, if there are no costs associated with the construction/purchase and operation of locations across space—i.e., no friction of distance—then the expected probability that an operating location in i is part of a firm operating in j should be a function the number of firms operating in j (q_j) and their underlying likelihood (p_j) of being a multiunit firm. This, in turn, will depend on a vector ($\mathbf{x_j}$) that characterises the population of firms in j (e.g., their industry, size, and managerial structure). Therefore, the expected share of operating locations in i that are part of a firm operating in j should be a function of j's $p_j(\mathbf{x_j})$ weighted share of all firms. In formal terms, this can be expressed as:

$$s_j = \frac{p_j(\mathbf{x_j})q_j}{\sum_j p_j(\mathbf{x_j})q_j} = \frac{Q_j}{Q}. \tag{4}$$

From (4) we can define the proportion of multiunit operating locations (N_i)[6] in i linked to j, N_{ij}/N_i, relative to the conterfactual as:

$$r_{ij} = \frac{N_{ij}/N_i}{Q_j/Q}. \tag{5}$$

Assuming no friction of distance across space, the expectation is that r_j=1. But, if there is a cost of developing firm networks across space, then the expectation would be that $r_{ij} < 1$.[7] Solving (5) for N_{ij} results in:

$$N_{ij} = (1/Q)N_i Q_j r_{ij}, \tag{6}$$

which can be estimated by log linearising and accounting for the unknowns Q, Q_j, and r_{ij}. This is accomplished by defining $\alpha = \ln(1/Q)$ and substituting fixed effects γ_j for Q_j and, to simplify matters, λ_i for N_i. r_{ij}, which accounts for variation in costs of managing networks across space, is defined as follows:

$$\delta \ln r_{ij} = \delta_{1_a} \ln d_{ij} + \delta_{1_b} (\ln d_{ij})^2 + \delta_2 B_{ij} + \delta_3 R_{ij} \tag{7}$$

where d_{ij} is the distance between i and j and B_{ij} and R_{ij} are inter-provincial and inter-regional dummy variables, respectively. Hence the strength of network links between i and j is a function of the propensity of i to generate and j to absorb network links conditioned on the costs associated with establishing and operating units across distance and borders. Following Head and Mayer (2014), we use Poisson-PML to estimate the above equation in cross-sectional form.:

$$N_{ij} = \exp(\lambda_i + \gamma_j + \delta \ln r_{ij})\varepsilon_{ij}, \tag{8}$$

[6]By definition $N_i = N_{ii}$.

[7]Note that 1 is not necessarily an upper bound, because if a location j were populated by firms that are national in scope N_{ij}/N_i would equal 1.

where ε_{ij} is a multiplicative error term. We estimate (8) across all three geographies—provinces, Greater Economic Regions, and hexagonal lattices (225km per side)—for the business sector as a whole and each of the subsectors. The analysis begins at the province level and then moves to the sub-provincial level.

model structure implies we do not have to include single plant firms

4.2 Provincial Firm Networks

The analysis at the provincial level of aggregation proceeds initially by developing a basic description of the pattern of network connections across provinces by sector. This provides some initial intuition for the model estimates that follow when we estimate (8), providing our first test of hypotheses **H1** and **H2**, namely that firm networks dissipate with distance and across provincial borders.

4.2.1 Describing Firm Networks

To begin, it is helpful to first look at the relative importance of multiunit firms in Canada. Table 2 presents the firm structure and subsector breakdown of operating locations across the business sector. The majority of operating locations in the business sector are part of single-location firms (90.9%) compared to multiple unit (9.1%). However, multi-unit firms comprise just over 40% of all employment, thus they are a large contributor to the Canadian economy.[8] The goods only subsector is primarily comprised of operating locations that are simple in nature (98.6%), while the services subsector has more locations that belong to multiunit firms (8.8%). By their definition, all operating locations in the hybrid goods subsector belong to multiunit firms.

As the analysis seeks to test the effect of provincial borders on firm networks, we also present the share of multiunit locations that are part with locations in two or more provinces. As a whole, 69.3% of operating locations belonging to multiunit firms in the business sector

[8]Note this number is derived for 2012 based on Canadian payroll tax data (PD7).

are also multiple province. This largely reflects the high share of hybrid goods, where 85.2% are multiple province, followed by the services only (65.7%) and goods only subsectors (33.3%).

Table 2: Operating locations by firm structure and sector

	Firm structure			
Sector	Total	Single	Multiple	Multiple province
Goods only	100	98.6	1.4	33.3
Services only	100	91.2	8.8	65.7
Hybrid goods	100	..	100.0	85.2
Total business sector	100	90.9	9.1	69.3

Notes: "Single" refers to locations belonging to single-location firms and "Multiple" refers to locations belonging to multi-location firms. For multi-location firms, "Multiple province" is the subset of locations belonging to a firm with locations in more than one province.

The intensity of firm network ties across provincial borders can be calculated by taking the number of operating locations in province i linked to province j as a share of all multiunit firm operating locations: N_{ij}/N_i. We use the number multiunit firm operating locations in the province to normalize its outward ties because these form the pool of units whose firms have the potential to have links to other provinces. To make this concrete, Table 3 presents provincial firm networks for Ontario, using the sectoral breakdown described above.

For the total business sector, a cursory look at the shares suggest that operating locations that belong to multiple-province firms tend to be concentrated close to the province of operation. That is, most multiunit enterprises do not have operations outside of the province and when they do there is a tendency, albeit not universally so, for their ties to dissipate with distance. For example, out of all operating locations in the business sector in Ontario, 30.9% also belong to firms with operations in Quebec. These links dissipate as one moves east, with 22.8% also belonging to firms in New Brunswick, 24.3% in Nova Scotia, 14.7% in Prince Edward Island, and 18.8% in Newfoundland and Labrador. There are stronger links to the Western provinces, with 30.9% of locations in Ontario also being linked to Alberta and British Columbia respectively.

These aggregate findings mask some important subsector differences. Note that the goods only subsector is highly concentrated, with few links crossing provincial borders. While Quebec remains the most linked province to Ontario, only 13.1% of operating locations in Ontario belong to firms with operations also in Quebec. These links drop quickly with distance. Other than Alberta and British Columbia, other provincial shares remain well under five percent. The services only subsector shows more provincial dispersion in firm networks than goods. Ontario is more connected to the Western provinces than anywhere else in this subsector, with just above 28% of locations in Ontario being linked to locations in Alberta and British Columbia. There are also strong links with Quebec as before (27.5%), but also with New Brunswick (20.9%) and Nova Scotia (22.3%). Finally, provincial firm networks in hybrid goods tend to concentrate around neighbouring provinces, but they are also dispersed across Canada. Notably, 50.4% of locations are linked to Quebec and 38% to its western neighbour, Manitoba.

Table 3: Provincial firm networks for Ontario by sector

	Share of own province: N_{ij}/N_i (%)									
Sector	N.L.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Goods only	2.3	1.0	3.5	3.2	13.1	100.0	4.4	3.1	9.3	9.2
Services only	17.3	14.4	22.3	20.9	27.5	100.0	24.9	21.8	28.3	28.5
Hybrid goods	28.2	18.6	37.3	35.3	50.4	100.0	38.0	34.6	47.0	45.9
Total business sector	18.8	14.7	24.3	22.8	30.9	100.0	26.6	23.5	30.9	30.9

Notes: Treating Ontario as the base, each element represents the share of these locations that are part of a firm with operations in the associated province. Note that the elements will not sum to 100% (own province totals) since links are asymmetric. By definition, $N_{ii} = N_i$ and so the total for Ontario will be 100%.

As shown by the example of Ontario, provincial economies are connected by firm links. Those that cross provincial borders are more likely to be with neighbouring provinces, followed by those with larger markets (e.g., British Columbia and Alberta in the example of Ontario firm networks). While the descriptive analysis points to the importance of distance and provincial borders across the industry subsectors, it is a limited test focussing on one province with no control for the ability of the destination region (j) to absorb network ties, which (6) suggests is necessary.

4.2.2 Model estimates

Table 4 presents regression results at the province level across all sectors. Focusing first on the business sector (Model 1), firm network ties decline with distance and when crossing provicial borders, with the provincial border effect being 0.71; that is, firm networks are estimated to be 29% lower across provinces than within them. Adding a squared term on distance to take into account non-linear effects of distance results in insignificant distance estimates and a modestly stronger border effect. As the next section will demonstrate, measuring networks across finer grained geographies allows us to better test whether distance has a non-linear effect on trade, and whether border effects are sensitive to the geography chosen, which has proven to be the case when measuring border effects on trade (see, for example Hillberry and Hummels, 2008; Bemrose et al., 2016). Nevertheless, these results are a basic test of our first two hypotheses that distance has a negative effect on networks (**H1**) and so too do provincial borders (**H2**).

When disaggregated by sector, the results are expected to change, particularly with respect to the influence of distance. For goods producers (hybrid goods and goods only), the expectation is that firm networks will fall off quickly with distance, for the reasons posited above (e.g., the higher cost of organizing goods production across distances). This is borne out in the data. For the hybrid goods and the goods only sectors, the effect of distance was more strongly negative than service producers. In both instances, the provincial border effect was negative, but significant solely for the goods only sector. Services only, because it accounts for most of the business sector, produced results that were broadly similar.

4.3 Sub-Provincial Firm Networks

Table 5 presents regression results for firm networks between GERs and 225km-sided hexagons. Intuitively, these finer-grained geographies provide a stronger test of the effect of provincial

Table 4: Firm network (N_{ij}) Poisson regression results by sector, provinces

	Business sector		Hybrid goods		Goods only		Services only	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(ln)Distance	-0.146^a	0.407	-0.211^a	0.335	-0.586^a	-0.777	-0.114^a	0.440
	(0.0197)	(0.374)	(0.0172)	(0.338)	(0.0777)	(0.858)	(0.0213)	(0.388)
(ln)Distance^2		-0.0373		-0.0368		0.0131		-0.0373
		(0.0246)		(0.0224)		(0.0594)		(0.0255)
Inter-province	-0.347^a	-0.483^a	-0.00487	-0.139	-1.040^a	-0.998^a	-0.464^a	-0.600^a
	(0.0835)	(0.144)	(0.0705)	(0.120)	(0.161)	(0.242)	(0.0898)	(0.153)
Constant	8.514^a	6.609^a	7.641^a	5.765^a	7.311^a	7.971^a	7.937^a	6.032^a
	(0.138)	(1.290)	(0.133)	(1.166)	(0.584)	(2.915)	(0.144)	(1.343)
Observations	100	100	100	100	100	100	100	100
Border effect	0.71	0.62	1.00	0.87	0.35	0.37	0.63	0.55

Notes: All models utilize a Poisson-PML estimator and include fixed effects for origins and destinations. [a], [b], [c] indicate significance at the 0.01, 0.05, and 0.10 levels. Robust standard errors are in parentheses. The cross-section represents an average over 2004 to 2012.

borders on networks, because they better represent the actual pattern of network connections that tend to be smaller in scale, whereas provinces, particularly the large ones, tend to obscure these connections, possibly making within province networks look stronger than in reality. The use of smaller grained geographies also promises to provide a more nuanced perspective on how firms organize their production across space.

The effect of measuring firm networks across sub-provincial geographies is to substantially reduce the estimated border effect, but never to eliminate it altogether, regardless of the geography or model specification used. Focussing on the business sector, for GERs, networks across provinces tend to be about 18% weaker than within provinces. This result is qualitatively invariant across the two geographies and model specifications. In magnitude, this is less than the estimated border effect when provinces are used as units of analysis, but still economically meaningful.

Across the three subsectors—hybrid goods, goods only, and services only—provincial border effects tend to be weakest for hybrid goods and strongest for goods only, with services falling in the middle. This can be most readily seen when focussing on the results using the quadratic distance term (Model 2), which tends to consistently provide the lowest border effect for goods. Why this is the case is open to interpretation. A reasonable hypothesis is that if the cost of acquiring or building new operating locations across provincial borders is fixed (e.g., adapting to differing regulatory systems), larger firms may be better able to amortise these costs over a larger volume of sales. So, if we think of hybrid goods firms being the largest across the subsectors, the results would be consistent with this interpretation. More work is needed, however, to test this hypothesis more thoroughly.

As noted earlier, goods producing firms have an incentive to keep production close by, while service producers may be more inclined to seek new markets. Focussing on Model 1, distance has the most negative effect on networks for the goods only and hybrid goods sectors relative to services only. This holds irrespective of the geography chosen. Furthermore, for goods producers, the inter-regional networks are much weaker than intra-regional networks, which is not the case, in relative terms, for hybrid goods and services only. This is consistent with the hypothesis that only over longer distances would goods producers build facilities in order to expand into new markets. This can be seen for the goods only sector and measuring networks using the hexagonal geography. There the squared term on distance is positive, but weakly significant.

5 Firm Networks and Trade

We now turn to the heart of the analysis and ask two related questions. First, what is the magnitude and direction of the influence of firm networks on trade between regions? In other words, if networks matter, do they act as a complement or a substitute for trade? Second, is the magnitude and direction of the effect of firm networks on trade conditional on trade costs, be they associated with distance and/or provincial borders? As noted in the introduction, the intuition is that with rising trade costs associated with distance and borders, the cost savings to firms from maintaining existing supply chains (be they internal

Table 5: Firm network (N_{ij}) Poisson regression results by sector, Greater Economic Regions (GER) and Hexagons (225km per side)

Panel A: GER	Business sector		Hybrid goods		Goods only		Services only	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(ln)Distance	-0.131^a	0.442^a	-0.198^a	0.515^a	-0.392^a	1.518^a	-0.0996^a	0.407^a
	(0.00899)	(0.0911)	(0.00860)	(0.0719)	(0.0609)	(0.274)	(0.00941)	(0.103)
(ln)Distance^2		-0.0400^a		-0.0498^a		-0.141^a		-0.0353^a
		(0.00621)		(0.00493)		(0.0206)		(0.00698)
Inter-province	-0.206^a	-0.240^a	-0.0768^a	-0.119^a	-0.707^a	-0.674^a	-0.258^a	-0.289^a
	(0.0246)	(0.0260)	(0.0207)	(0.0191)	(0.116)	(0.0974)	(0.0280)	(0.0301)
Inter-region	-0.235^a	-0.493^a	0.00469	-0.319^a	-1.046^a	-1.770^a	-0.301^a	-0.530^a
	(0.0497)	(0.0632)	(0.0476)	(0.0468)	(0.123)	(0.154)	(0.0518)	(0.0711)
Constant	7.919^a	6.197^a	6.916^a	4.777^a	5.683^a	-0.173	7.406^a	5.880^a
	(0.0709)	(0.278)	(0.0749)	(0.224)	(0.379)	(0.870)	(0.0720)	(0.313)
Observations	900	900	900	900	900	900	900	900
Border effect	0.81	0.79	0.93	0.89	0.49	0.51	0.77	0.75
Panel B: Hexagon	Business sector		Hybrid goods		Goods only		Services only	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(ln) Distance	-0.154^a	-0.107	-0.214^a	0.126^c	-0.617^a	-1.224^a	-0.121^a	-0.184^b
	(0.00664)	(0.0844)	(0.00598)	(0.0707)	(0.0557)	(0.325)	(0.00736)	(0.0922)
(ln) Distance^2		-0.00320		-0.0235^a		0.0445^c		0.00434
		(0.00581)		(0.00490)		(0.0241)		(0.00634)
Inter-province	-0.218^a	-0.220^a	-0.100^a	-0.117^a	-0.507^a	-0.508^a	-0.271^a	-0.268^a
	(0.0181)	(0.0186)	(0.0144)	(0.0142)	(0.0824)	(0.0844)	(0.0217)	(0.0222)
Inter-region	-0.177^a	-0.197^a	0.0583	-0.0901^c	-0.734^a	-0.517^a	-0.247^a	-0.220^a
	(0.0442)	(0.0561)	(0.0421)	(0.0506)	(0.116)	(0.158)	(0.0457)	(0.0586)
Constant	4.094^a	3.954^a	3.128^a	2.104^a	1.666^b	3.425^a	3.545^a	3.735^a
	(0.0859)	(0.270)	(0.123)	(0.236)	(0.705)	(1.126)	(0.0858)	(0.295)
Observations	7,306	7,306	7,306	7,306	7,306	7,306	7,306	7,306
Border effect	0.80	0.80	0.90	0.89	0.60	0.60	0.76	0.76

Notes: All models utilize a Poisson-PML estimator and include fixed effects for origins and destinations. ^{a}, ^{b}, ^{c} indicate significance at the 0.01, 0.05, and 0.10 levels. Robust standard errors are in parentheses. The cross-section represents an average over 2004 to 2012.

or external to the firm) may be exhausted, inducing firms to seek out new, closer by suppliers. Hence, our expectation is that with longer distances between regions and borders the effect of firm networks on trade will turn from positive (a complementary effect) to negative (a substitution effect).

Econometrically, we approach this in two steps. In the first, we maintain the cross-sectional approach used above. This provides a basic test of the relationship between networks and trade. While useful, the cross-sectional analysis may be biased due to missing variable bias and/or reverse causality. ***We address these issues, in part, using a first-difference estimator, which accounts for missing variable bias, but not necessarily reverse causality.***

5.1 Cross-sectional estimates

As is now standard in the literature, we estimate a trade model that takes into account the capacity of geographic units to generate and absorb trade and a measure of trade costs between them. The model is specified as follows:

$$\ln X_{ij} = \psi_i + \omega_j + \beta \ln \phi_{ij} + \varepsilon_{ij}, \tag{9}$$

where X_{ij} is the value of goods shipments between region i and j, and ψ_j and ω_j take into account the i's output and market potential and j 's size and level of competition, respectively. Trade costs (ϕ_{ij}) are accounted for by the distance between i and j (d_{ij}) and a set of binary variables that account for inter-provincial (B_{ij}) and inter-regional (R_{ij}) trade effects:

$$\beta \ln \phi_{ij} = \beta_1 \ln d_{ij} + \beta_2 B_{ij} + \beta_3 R_{ij} + \ln \beta_4 \mathbb{N}_{ij}. \tag{10}$$

Since firm networks are also expected to reduce trade costs, their bilateral measure ($\mathbb{N}_{ij} \in \{\mathbb{N}^A_{ij}, \mathbb{N}^M_{ij}\}$) is also included with the other measures of trade costs. We test the effect of firm networks in the business sector on trade.

While it is, of course, unknown whether the association between either network measure and trade will be positive or negative, both provide a different, albeit related, perspectives.

Namely, $\mathbb{N}_{ij}^{A}$ better captures the presence of firms in both i and j weighted by the number of operating locations, since $\mathbb{N}_{ij}^{M}$ tends to discount the effect of large firms with locations outside of the region. Hence, $\mathbb{N}_{ij}^{A}$ likely better captures the ability of firms in both locations to gather information and establish supply chains, be they within the firm or between firms. On the other hand, $\mathbb{N}_{ij}^{M}$ better measures the firm's internal capacity to generate and absorb trade. This is for two reasons. First, for $\mathbb{N}_{ij}^{A}$ there is no difference between an instance where a firm's units are heavily weighted towards one region or evenly spread between the two. For the latter, there is more potential for within firm trade. Second, even if the firm's operating units were evenly spread across regions, if the firm has many operations outside of the region pair, $\mathbb{N}_{ij}^{A}$ would not take this into account, while $\mathbb{N}_{ij}^{M}$ does.

The model is estimated for the 225km sided hexagons (Table 6). The baseline model, which excludes networks, is Model 1. As expected, it shows distance has a strong negative effect on trade. The effect of provincial borders on trade, as expected, is negative and indicate inter-provincial trade is about 37% $(1 - \exp(-4.64))$ less than the level of intra-provincial trade. Although using a more parsimonious model, this is a result that is qualitatively similar to Bemrose et al. (2016).

Model 2 adds the additive measure of business sector firm networks. The effect of firm networks on trade is positive suggesting, at least based on the cross-sectional evidence, that firm networks on balance tend to complement, rather than act as a substitute for, trade. Their inclusion, however, reduces the effect of provincial borders on trade by about half. Model 3 adds the multiplicative measure of firm networks resulting in a similar positive and significant estimated effect of networks on trade. The provincial border effect is reduced further when this measures is added. Also the coefficient on distance falls considerably and there is a concomitant rise in the distance and inter-region parameter estimates. We, therefore, view this result with some caution.

Table 6: The impact of business sector firm networks on trade flows (X_{ij}), cross-sectional regression results for 225km-sided hexagons

	Model 1	Model 2	Model 3
(ln) Distance	-0.828^a	-0.792^a	-0.325^a
	(0.0635)	(0.0673)	(0.0383)
Inter-province	-0.466^a	$-0.236b$	$-0.147b$
	(0.0875)	(0.101)	(0.0631)
Inter-region	0.120	0.0948	1.062^a
	(0.128)	(0.130)	(0.0778)
(ln) $\mathbb{N}^A_{ij}$		0.585^a	
		(0.111)	
(ln) $\mathbb{N}^M_{ij}$			0.562^a
			(0.0264)
Constant	17.13^a	14.10^a	15.61^a
	(0.763)	(1.031)	(0.428)
Observations	7,306	7,189	7,189

Notes: All models utilize a Poisson-PML estimator and include fixed effects for origins and destinations. ^{a}, ^{b}, ^{c} indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Robust standard errors are in parentheses. The cross-section represents an average over 2004 to 2012

5.2 Panel estimates

As we have noted, due to missing variable bias and reverse causality, the cross-sectional estimates may be endogenous with respect to the network measure. Reverse causality may be a concern, because rising trade might provide an incentive for firms to build operating locations in these new markets. However, to date, much of the empirical and theoretical evidence suggests trade flows follow the expansion of networks—that is, firms use their contacts (e.g., their network) to find new markets (see Chaney, 2014). Missing variable bias may result from unaccounted differences in industry structure. Assuming these are fixed over short periods, first differencing accounts for this source of bias. First differencing also allows us to test further the effect of trade costs on firm networks. As trade costs rise, the expectation is that the effect of networks on trade will shift from complementing trade (positive) to substituting for trade (negative). Testing for this addresses hypotheses **H3** and **H4**. Because trade costs are expected to be positively related to distance and provincial borders, we condition the effect of network growth ($\Delta \ln \mathbb{N}_{ij}$) on trade growth by the distance between regions (d_{ij}) and whether the flow crosses provincial borders (B_{ij}). Formally, the model is specified as follows:

$$\Delta \ln X_{ijt} = \alpha + \beta_1 \ln X_{ijt-1} + (\beta_{2_a} + \beta_{2_b} \ln d_{ij} + \beta_{2_c} B_{ij}) \Delta \ln \mathbb{N}_{ijt} + \zeta_t + \epsilon_{ijt} \tag{11}$$

with the lagged level of trade (X_{ijt-1}) included to account for regression to the mean. To reduce the effect of noise in the data, we divide the 9-year panel into three sub-periods (t): 2004 to 2006, 2007 to 2009 and 2010 to 2012, with the mean of the variables calculated across years within each period.[9] Finally, period fixed effects (ζ_t) are included to account for inflation and macro shocks. The periods are then differenced to obtain (11), which is estimated using OLS.

Turning to the results, we begin by estimating the effect of business sector (goods and services) additive ($\mathbb{N}^A_{ij}$) and multiplicative ($\mathbb{N}^M_{ij}$) firm network measures on trade across two geographies—Greater Economic Regions (GERs) and 225km sided hexagons, presented in Tables 7 and 8. In contrast to the cross-sectional results, the effect of the multiplicative firm networks measure is insignificant for most specifications. We interpret this as being due to unobserved variable bias in the cross-section (e.g., input-output links) that are eliminated in the panel estimation, the change in the multiplicative measure is picking up dynamics within the firm population that are not necessarily related to the effect of networks on trade[10], and/or the multiplicative measure being more sensitive to error, leading to errors

[9]The BR provides an excellent snapshot of industrial organization of the economy in any given year. However, because it is an administrative file, it is subject to periodic updates. These can result in large year over year shifts that are not necessarily reflected in changes in true economic activity on the ground in that year. Furthermore, because the structure of multiunit firms on the BR is only updated periodically (on average about every three to five years) it can become stale. While we have dealt with a number of issues affecting the consistency of the file, we likely do not account for all of these effects. Nevertheless, as Baldwin et al. (2002) demonstrate, using longer periods (i.e., 5 years) to measure firm dynamics (e.g., entry and exit rates) BR-based estimates tend to converge with other sources that are updated annually (e.g., the Annual Survey of Manufactures, which is a *defacto* census). As a result, we believe using three-year periods, changes in firm networks will be more likely to reflect real shifts in firm networks through time.

[10]For instance, the multiplicative measure will rise if a firm is eliminating operating units that are not in

in variable (attenuation) bias. As such, we will focus our discussion on the results of the additive measure (Table 7) and relegate the results of the multiplicative measure (Table 8) to Appendix 7.2.

The impact of firm networks in the business sector on trade is only negative and significant for the GERs (see Table 7, Panel A: Model 1). The relationship between networks and trade becomes much clearer when its effect is conditioned on distance and provincial borders. Focussing on the business sector results for GERs, the effect of firm networks on trade is positive. However, its effect falls with distance and provincial borders (see Table 7, Panel A: Model 2). This holds also for the subsectors—hybrid goods, goods only, and services only—across both geographies, which runs counter to our expectation that goods networks should have a stronger complementary effect than services. Using the GER results, at just over 3,300km, the effect of business sector firm networks on trade turns negative, switching from a complement to a substitute for trade.[11] This is a little under the driving distance from Toronto to Calgary, which obviously implies trade must cross provincial borders. The conditioning effect of provincial borders on the influence of networks on trade is also negative and significant for both geographies. According to the GER estimates, if trade flows cross a provincial border, the effect of firm networks on trade turns negative at just over 1,200km. Hence, taking a page from Engel and Rogers (1996), the provincial border effect is equivalent to adding 2,100km to the journey between provinces, which is equivalent to incurring an ad valorem transportation cost of 5.7% (Behrens and Brown, 2017). The implication is that for many important inter-provincial region pairs (e.g, Ontario-Alberta), the effect of firm networks on trade is negative. These results are consistent with hypotheses **H3** and **H4**. That is, as trade costs rise—from distance and borders—firm networks move from being a complement to being a substitute for trade flows as production (**H3**) and sourcing of inputs (i.e., supply chains) (**H4**) shift towards the destination.

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i and j, and so it may be capturing the effect of firm decline. Of course, the opposite holds true as well.

[11] The equivalent distance for the hexagonal results is 3,900km.

Table 7: The impact of additive firm networks on trade flows (ΔX_{ij}), by geography, first difference panel model

Panel A: GER	Business sector		Hybrid goods		Goods only		Services only	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(ln) Trade value, $(t-1)$	-0.300^a	-0.420^a	-0.278^a	-0.332^a	-0.196^a	-0.223^a	-0.310^a	-0.408^a
	(0.0444)	(0.0527)	(0.0425)	(0.0475)	(0.0304)	(0.0328)	(0.0450)	(0.0516)
$\Delta ln\mathbb{N}_{ij}^{A}$, (t)	-5.263^a	35.35^a	0.145	16.58^a	-0.156^c	2.138^a	-4.284^a	31.74^a
	(1.260)	(5.014)	(0.500)	(3.021)	(0.0817)	(0.496)	(1.261)	(4.923)
Inter-provincial $\times\Delta ln\mathbb{N}_{ij}^{A}$, (t)		-4.467^a		-1.761^b		-0.355^c		-4.293^a
		(1.213)		(0.743)		(0.182)		(1.188)
(ln) Distance $\times\Delta ln\mathbb{N}_{ij}^{A}$, (t)		$-4.363a$		-1.923^a		-0.256^a		-3.733^a
		(0.582)		(0.396)		(0.0660)		(0.559)
Observations	1,740	1,740	1,740	1,740	1,206	1,206	1,740	1,740
R-squared	0.190	0.245	0.173	0.199	0.176	0.194	0.194	0.237
Panel B : Hexagon	Business sector		Hybrid goods		Goods only		Services only	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(ln) Trade value, $(t-1)$	-0.349^a	-0.372^a	-0.353^a	-0.367^a	-0.235^a	-0.248^a	-0.353^a	-0.379^a
	(0.0156)	(0.0177)	(0.0160)	(0.0166)	(0.0302)	(0.0305)	(0.0159)	(0.0177)
$\Delta ln\mathbb{N}_{ij}^{A}$, (t)	0.0768	10.40^a	0.772^a	6.615^a	-0.204^a	1.089^b	-0.474	9.856^a
	(0.344)	(3.927)	(0.269)	(1.565)	(0.0673)	(0.483)	(0.306)	(2.927)
Inter-provincial $\times\Delta ln\mathbb{N}_{ij}^{A}$, (t)		$-1.644b$		-0.984^c		-0.324		-1.994^a
		(0.663)		(0.563)		(0.226)		(0.678)
(ln) Distance $\times\Delta ln\mathbb{N}_{ij}^{A}$, (t)		$-1.256b$		-0.670^a		-0.143^c		-1.221^a
		(0.540)		(0.236)		(0.0816)		(0.404)
Observations	5,389	5,389	5,241	5,241	1,736	1,736	5,337	5,337
R-squared	0.210	0.223	0.209	0.213	0.179	0.187	0.214	0.230

Notes: All models include a constant, fixed effects for origin-destination pairs, and period, and are estimated via OLS. ^{a}, ^{b}, and ^{c} indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Robust standard errors are in parentheses. The sample covers the mean of variables across three equal periods, 2004-2006, 2007-2009, and 2010-2012.

6 Conclusions

This paper provides a picture of firm networks and intra- and inter-provincial trade patterns in Canada. Firm networks, like trade flows, are negatively influenced by both distance and borders. This is apparent in the descriptive statistics and perhaps more so in their estimated effects. These patterns are consistent with higher costs associated with managing operating units across longer distances and establishing operations in a different provinces. In turn, firm networks tend to be positively associated with trade flows—that is, they act as a complement to trade. However, the effect of firm networks on trade is conditional on variables associated with higher trade costs. Namely, with rising distance and provincial borders, the complementary effect of firm networks on trade falls and, at sufficiently long distances and when crossing borders, networks switch from being a complement to trade to being a substitute instead. Hence, provincial borders appear to both reduce the degree to which the economy is knit together through firm networks and the degree to which these networks are able to facilitate trade. We find, in fact, after accounting for firm networks provincial border effects fall by about half. This results from both provincial borders acting as a barrier to firm networks and by reducing the effectiveness by which these networks induce trade.

There are, of course, many extensions that might be made to this work. First, networks are measured in the form of counts of units. This might be weighted by employment to build a measure of the importance of operating locations controlled by firms. Through input-output tables the upstream-downstream nature of the linked operating units can be defined, providing a better measure of the degree to which trade reflects these functional relationships. Finally, the ultimate next step would be to move from measures of networks and flows across aggregate regions, which obscures the pure effect of intra-firm trade, to a database where shipments within and across firms are measured. With detailed information on the location of where shipments are picked up and dropped off, combined with information on the location and industry of units on the Business Register, and other sources, it may be possible to build such a database.

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7 Appendix

7.1 Surface Transportation File

Trade data are available from Statistics Canada's Surface Transportation File (STF). It combines data from the Trucking Commodity Origin Destination Survey TCOD and railway waybills for 2002 to 2012 and provides estimates on the value of goods trade between regions in Canada and between Canada and the United States. Note that it excludes goods moved by air, pipeline, and water.

The STF also provides data on network distance—that is, the actual distance travelled for a shipment of goods. This gives the most accurate measure of the distance goods travel within and between regions in Canada. For this paper, network distance is available for the entire sample down to Grouped Economic Region pairs. For the 225km-sided hexagons, there are hexagon pairs with missing network distance data. In these cases, we convert great-circle distance, a measure commonly used in the literature, to network distance using a model. This is done by regressing network distance on a polynomial of great-circle distance and using predicted values for the missing data. For own-hexagon pairs, we approximate the hexagon area by a circle and take the implied radius of the circle as a measure of great-circle distance within a hexagon. A detailed description of the STF and its development is provided in Bemrose et al. (2016).

7.2 Additional results

7.2.1 Multiplicative firm networks

Table 8 presents results of the assocation between multiplicative firm networks and trade flows by GER and 225km-sided hexagons using a first difference panel model. As noted in the main body of the paper, the effect of the multiplicative firm networks measure is largely insignificant. For the GER results (Panel A), there are only significant estimates for the fully specified model using firm networks in the hybrid goods sector. Consistent with our main findings, firm networks positively impact trade flows, though less so for regions that are further away (as is shown by the negative coefficient on the interaction term between firm networks and distance). However, these findings are also inconsistent to our main results, showing that interprovincial firm networks increase their positive impact on trade. All of these findings disappear when using 225km-sided hexagons (Panel B), where results are insignificant for all fully specified models.

7.2.2 Employment-weighted firm networks

We expand our three key network measures (N_{ij}, $\mathbb{N}_i j^A$, and $\mathbb{N}_{ij}^M$) to their employment-weighted versions. More specifically, equation (1) can be redefined as follows:

$$E_{ij} = \sum_m \mathbb{1}\{e_{mj} > 0\} e_{mi}, \tag{12}$$

where e_{mi} is the employment of operating locations of firm m in region i (that also have firms in j). Similarly, we may also rewrite equations (2) and (3) as follows:

$$\mathbb{E}^A_{ij} = \sum_m \mathbb{1}\{e_{mj} > 0\} e_{mi} + \sum_m \mathbb{1}\{e_{mi} > 0\} e_{mj} = E_{ij} + E_{ji}. \tag{13}$$

$$\mathbb{E}^M_{ij} = \sum_m \frac{\mathbb{1}\{e_{mj} > 0\} e_{mi} \times \mathbb{1}\{e_{mi} > 0\} e_{mj}}{e_m} = \sum_m \frac{e_{mi} e_{mj}}{e_m}. \tag{14}$$

The aggregate additive measure $\mathbb{E}^A_{ij}$ thus represents the employment-weighted network links between i and j. Note that the multiplicative measure, $\mathbb{E}^M_{ij}$, is now normalized by the total employment of the firm, e_m. Tables 9 to 11 present re-estimates of our main findings using employment-weighted firm networks for the business sector for 225km-sided hexagons. All of the results hold, with the extent of firm networks negatively influenced by distance and borders, firm networks accounting for about half of the provincial border effect, and with the positive influence of firm networks on trade falling with distance and when crossing borders.

Table 8: The impact of multiplicative firm networks on trade flows (ΔX_{ij}), by geography, first difference panel model

Panel A: GER	Business sector		Hybrid goods		Goods only		Services only	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(ln) Trade value, $(t-1)$	-0.279^a	-0.279^a	-0.277^a	-0.285^a	-0.189^a	-0.189^a	-0.282^a	-0.282^a
	(0.0426)	(0.0428)	(0.0425)	(0.0425)	(0.0298)	(0.0298)	(0.0427)	(0.0429)
$\Delta(\ln)\mathbb{N}_{ij}^{M}$, (t)	-0.117	0.175	-0.0180	2.140^b	0.00390	-0.394	-0.335	-0.115
	(0.287)	(1.870)	(0.155)	(0.966)	(0.0413)	(0.364)	(0.249)	(1.492)
Inter-provincial$\times\Delta(\ln)\mathbb{N}_{ij}^{M}$, (t)		0.407		2.163^a		-0.0527		-0.888
		(1.185)		(0.587)		(0.171)		(0.908)
(ln) Distance $\times\Delta(\ln)\mathbb{N}_{ij}^{M}$, (t)		-0.0891		-0.540^a		0.0574		0.0826
		(0.361)		(0.187)		(0.0533)		(0.292)
Observations	1,740	1,740	1,740	1,740	1,206	1,206	1,740	1,740
R-squared	0.173	0.173	0.173	0.181	0.172	0.173	0.175	0.176
Panel B: Hexagon	**Business sector**		**Hybrid goods**		**Goods only**		**Services only**	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(ln) Trade value, $(t-1)$	-0.350^a	-0.350^a	-0.349^a	-0.349^a	-0.230^a	-0.230^a	-0.351^a	-0.351^a
	(0.0156)	(0.0156)	(0.0159)	(0.0159)	(0.0297)	(0.0297)	(0.0158)	(0.0158)
$\Delta(\ln)\mathbb{N}_{ij}^{M}$, (t)	-0.156^b	-0.837	-0.118^a	-0.256	-0.0500	-0.0840	-0.142^b	-0.183
	(0.0725)	(0.556)	(0.0453)	(0.306)	(0.0416)	(0.406)	(0.0665)	(0.430)
Inter-provincial$\times\Delta(\ln)\mathbb{N}_{ij}^{M}$, (t)		-0.0929		0.0951		0.130		0.104
		(0.224)		(0.110)		(0.182)		(0.178)
(ln) Distance $\times\Delta(\ln)\mathbb{N}_{ij}^{M}$, $(t$		0.103		0.00885		-0.0101		-0.00496
		(0.0895)		(0.0458)		(0.0672)		(0.0693)
Observations	5,389	5,389	5,241	5,241	1,736	1,736	5,337	5,337
R-squared	0.211	0.212	0.208	0.208	0.175	0.176	0.214	0.214

Notes: All models include a constant, fixed effects for origin-destination pairs, and period, and are estimated via OLS. ^{a}, ^{b}, and ^{c} indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Robust standard errors are in parentheses. The sample covers the mean of variables across three equal periods, 2004-2006, 2007-2009, and 2010-2012.

Table 9: Employment-weighted business sector firm network (E_{ij}) Poisson regression results for 225km-sided hexagons

	Model 1	Model 2
(ln) Distance	-0.154^a	-0.0582
	(0.00757)	(0.0951)
(ln)Distance^2		-0.00667
		(0.00653)
Inter-province	-0.165^a	-0.169^a
	(0.0198)	(0.0203)
Inter-region	-0.215^a	-0.257^a
	(0.0474)	(0.0571)
Constant	7.205^a	6.914^a
	(0.118)	(0.314)
Observations	7,306	7,306

Notes: All models utilize a Poisson-PML estimator and include fixed effects for origins and destinations. ^{a}, ^{b}, ^{c} indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Robust standard errors are in parentheses. The cross-section represents an average over 2004 to 2012

Table 10: The impact of employment-weighted business sector firm networks on trade flows (X_{ij}), cross-sectional regression results for 225km-sided hexagons

	Model 1	Model 2	Model 3
(ln) Distance	-0.828^a	-0.797^a	-0.513^a
	(0.0635)	(0.0659)	(0.0694)
Inter-province	-0.466^a	-0.305^a	-0.142^b
	(0.0875)	(0.0966)	(0.0687)
Inter-region	0.120	0.0777	3.960^a
	(0.128)	(0.128)	(0.463)
(ln) $\mathbb{E}_{ij}^A$		0.442^a	
		(0.0750)	
(ln) $\mathbb{E}_{ij}^M$			0.339^a
			(0.0404)
Constant	17.13^a	13.44^a	13.12^a
	(0.763)	(1.053)	(0.864)
Observations	7,306	7,189	7,189

Notes: All models utilize a Poisson-PML estimator and include fixed effects for origins and destinations. ^{a}, ^{b}, ^{c} indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Robust standard errors are in parentheses. The cross-section represents an average over 2004 to 2012

Table 11: The impact of employment-weighted business sector firm networks on trade flows (ΔX_{ij}) for 225km-sided hexagons, first difference panel model

	Additive measure ($\mathbb{E}_{ij}^{A}$)		Multiplicative measure ($\mathbb{E}_{ij}^{M}$)	
	Model 1	Model 2	Model 1	Model 2
(ln) Trade value, $(t-1)$	-0.349^{a}	-0.380^{a}	-0.349^{a}	-0.349^{a}
	(0.0156)	(0.0168)	(0.0155)	(0.0156)
$\Delta(\ln)\mathbb{E}_{ij}$, (t)	0.254	5.119^{a}	-0.106^{c}	-0.0516
	(0.171)	(1.103)	(0.0589)	(0.232)
Inter-provincial$\times\Delta(\ln)\mathbb{E}_{ij}$, (t)		-0.924^{a}		-0.0474
		(0.301)		(0.172)
(ln) Distance $\times\Delta(\ln)\mathbb{E}_{ij}$, (t)		-0.612^{a}		-0.00289
		(0.162)		(0.0447)
Constant	2.128^{a}	2.643^{a}	2.238^{a}	2.243^{a}
	(0.747)	(0.753)	(0.746)	(0.746)
Observations	5,389	5,389	5,389	5,389
R-squared	0.211	0.228	0.222	0.211

Notes: All models include a constant, fixed effects for origin-destination pairs, and period, and are estimated via OLS. ^{a}, ^{b}, and ^{c} indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Robust standard errors are in parentheses. The sample covers the mean of variables across three equal periods, 2004-2006, 2007-2009, and 2010-2012.