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Information frictions, internet and the relationship between distance and trade

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MEMORANDUM

No 01/2018
February 2018

**Information Frictions, Internet and the Relationship between Distance
and Trade***

The seal of the University of Oslo is a large, faint watermark in the background. It features a circular design with the text "UNIVERSITAS OSLOENSIS" at the top and "MDCCCXLI" at the bottom. In the center is a figure of a woman in classical attire, holding a lyre.

**Anders Akerman, Edwin Leuven
& Magne Mogstad**

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Information Frictions, Internet and the Relationship between Distance and Trade*

Anders Akerman[†] Edwin Leuven[‡] Magne Mogstad[§]

Abstract: Recent work suggests the patterns of international trade may be distorted because of information frictions. Little is known, however, about how advancements in information communication technology (ICT) affect trade patterns. The goal of our paper is to analyze how and why the adoption of such technology affects bilateral trade flows. Our context is the adoption of broadband internet in Norwegian firms over the period 2000-2008. We use panel data with information on Norwegian firms with regards to their production, technology, and trade. A public program with limited funding rolled out broadband access points, and provides plausibly exogenous variation in the availability and adoption of broadband internet in firms. We find that adoption of broadband internet makes trade patterns more sensitive to distance and economic size. Going from no broadband availability to full coverage increases the magnitude of the elasticity of trade with respect to distance by 0.12, and the elasticity of trade with respect to destination size by 0.06. For distance, this means that an increase in internet availability of 10 percentage points increases trade for a country at the 25th distance percentile by 1.1% more than for a country at the 75th distance percentile. The same difference for the GDP of a destination is 2.1%. We interpret the empirical results through a gravity theory of trade patterns, augmented with information frictions. We provide comparative statics predictions with respect to a reduction in information frictions, and show that these predictions are consistent with our empirical findings. Taken together, our results point to the importance of incorporating information frictions in the frequently used gravity equation, and they may help explain the so-called “distance puzzle” in international trade.

Keywords: Internet; Trade; Information Frictions; Gravity model; Distance

JEL codes: F12; F15; F61; O33

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1 Introduction

How do trade costs impede international trade? This question is typically analyzed in models with perfect information, examining the importance of variable trade costs (e.g. transport costs, tariffs) and fixed trade costs (e.g., setup costs, bureaucracy). An increasing body of work, however, points to the importance of imperfect information. International trade may be distorted because of information frictions, and advancements in information communication technology (ICT) could therefore promote trade and change trade patterns. Recently, policymakers and researchers emphasize that adoption of internet in firms may affect international trade by reducing information asymmetries, lowering matching frictions between producers and consumers, or enabling better overview and planning of global supply chains (e.g. Freund and Weinhold, 2004; Choi, 2010; UNESCO (2012)). It is also claimed that the internet should reduce the importance of distance and therefore benefit remote and developing countries (e.g. Friedman (2005)). However, there is little scientific evidence to substantiate these claims.

The goal of our paper is to analyze how and why ICT affects bilateral trade flows. Our context is the adoption of broadband internet in Norwegian firms over the period 2001-2008. Norway is a small open economy with segmented local labor markets. A public program with limited funding rolled out broadband access points, and provides plausibly exogenous variation in the availability and adoption of broadband internet in firms. Our analysis employs a panel dataset with detailed information on Norwegian firms with regards to their production, technology, and trade. We use this data to empirically examine how internet adoption in firms affects bilateral trade patterns, before developing a model that helps interpret the empirical findings.

In Section 2, we describe the data. Our analysis employs several data sources that we can link through unique identifiers. Annual accounts provide data on input factors and output, custom records and intra-EU declarations give information on exports and imports, and survey data provides information on the availability and adoption of broadband internet. In Section 3, we describe the source to exogenous variation in broadband availability and adoption. Following Bhuller et al. (2013), our research design takes advantage of a public program aimed at ensuring broadband access at a reasonable price to all households throughout the country.¹ Because of limited funding, access to broadband was progressively rolled out, so that the necessary infrastructure (access points) was established in different municipalities at different times. We document that the staged installation of

¹ While our analysis uses a similar identifications strategy as Bhuller et al. (2013), we apply it to a distinct question and set of outcomes. Bhuller et al. (2013) use the roll-out of broadband internet to study how internet use affects sex crimes. Akerman et al. (2015) use the same strategy to study how adoption of broadband in firms affect workers' wages and labor productivity.

broadband infrastructure generate spatial and temporal variation in broadband availability and, consequently, adoption (even conditional on year and municipality fixed effects).

In Section 4, we describe the empirical model and estimation approach. We specify a gravity equation for the trade flows between firms in different municipalities of Norway and other foreign countries. The basic gravity equation is frequently used to analyze the determinants of bilateral trade based on the economic size of markets and the distance between two areas.² To capture how internet adoption affects the bilateral trade patterns, we augment the standard gravity equation with an indicator for broadband adoption in firms and interaction terms between broadband adoption and the determinants of trade flows. The main challenge is to address the potential endogeneity of broadband adoption. We therefore use the temporal and spatial variation in the availability of broadband internet to construct instruments for broadband adoption and the interaction terms. Given that we control for municipality-country fixed effects and calendar time fixed effects, the identification is similar in spirit to a difference-in-differences design. The key threat to identification is therefore that the timing of the broadband roll-out might be related to different underlying trends in the trade patterns across municipality-country pairs. We demonstrate that the timing does not appear to be systematically related to key observable correlates of trade, and we further challenge our identification strategy in a number of ways, finding little cause for worry.

The empirical results are presented in Section 5. We find that adoption of broadband internet makes trade patterns more sensitive to distance and economic size. Going from no broadband availability to full coverage increases the magnitude of the elasticity of trade with respect to distance by 0.12, and the elasticity of trade with respect to destination size by 0.06. For distance, this means that an increase in internet availability of 10 percentage points increases trade for a country at the 25th distance percentile by 1.1% more than for a country at the 75th distance percentile. The same difference for the size (GDP) of a destination is 2.1%. We show that our estimates do not change appreciably if we exclude the major cities; if we include a large set of time-varying controls for the potential supply and demand factors; and if we allow for different time trends across areas.

In Section 6, we interpret the empirical results through a gravity theory of trade patterns, augmented with information frictions. Our model builds on the Armington model of Anderson (1979) and Anderson and van Wincoop (2003). We model information frictions as a restriction on the access to markets with which a region can trade, similar to how Arkolakis (2010) views the role of marketing to reach foreign consumers. We provide comparative statics predictions with respect to a reduction in information frictions,

²See Head and Mayer (2014) for a review of the large literature using gravity equations to analyze the pattern of international trade.

and show that they are consistent with our empirical findings. The model predicts that adoption of a technology that lowers information frictions increases the magnitude of the elasticity of trade with respect to distance. By comparison, lowering information frictions is predicted to increase the elasticity of trade with respect to destination market size. A corollary of these predictions is that the change in elasticities should be more pronounced for products for which information costs are more salient. Since information is arguably more important for trade in differentiated goods than in homogenous goods (see e.g. Rauch (1999)), we therefore estimate the augmented gravity equations separately for trade flows in these two types of goods. Consistent with broadband internet changing trade patterns through lowering information frictions, we find stronger effects of broadband adoption on the trade pattern of differentiated goods as compared to homogenous goods.

Although the comparative statics predictions are consistent with our empirical findings, several mechanisms outside our model could also explain why adoption of broadband internet increases the sensitivity of trade to distance. For example, the direct effect of internet on bilateral trade flows may be stronger for destination countries with similar language (see e.g. Blum and Goldfarb, 2006). Countries with similar language are closer in distance. We examine this mechanism by including controls for language similarity and its interaction with broadband internet in the empirical model. However, adding these controls does not materially change the estimated coefficient on the interaction term between broadband adoption and distance. Another possibility is that the direct effect of internet on bilateral trade flows may be stronger if the destination countries themselves have high internet penetration (see e.g. the theory of two-sided markets of Rochet and Tirole, 2006). Empirically, countries closer to Norway tend to have higher internet penetration. To examine this mechanism, we add internet penetration in the destination country and its interaction with broadband internet to the empirical model. The estimated coefficient on the interaction term between broadband adoption and distance barely moves.

Our paper contributes to an ongoing debate over how advancements in ICT affect trade and change trade patterns. In his bestseller, Friedman (2005) argued the ‘death of distance’ because modern technology makes the world “flat” and location largely irrelevant. However, there is limited scientific evidence to substantiate these claims. Indeed, Disdier and Head (2008) perform a meta-analysis of 1,000 gravity equations, finding that the magnitude of the estimated coefficient on distance has *increased* since the 1970s.³ Leamer (2007) therefore argues that advancements in ICT since the 1970s have failed to reduce information frictions between countries. Our study suggests this conclusion may be unwarranted.

³Some studies question this finding, arguing that it is due to mis-specification of the gravity equation (see e.g. Yotov (2012)).

As our theoretical model makes clear, technology that lowers information frictions does not necessarily make distance less important as a determinant of bilateral trade flows. On the contrary, our model predicts that adoption of such technology should *increase* the magnitude of the elasticity of trade with respect to distance. To see why, recall that distance in the gravity model is a proxy for the bilateral trade costs between i and j (e.g. due to transport costs). Suppose that the bilateral trade costs between regions i and j increase. The direct effect of this increase in trade costs is that i 's good becomes more expensive in region j , lowering the overall demand for i 's good. However, the excess supply of i 's good causes i to reduce its price. This indirect effect mitigates the negative direct effect on the demand for region i 's good. As shown in Section 6, the indirect effect increases in relative magnitude the more important region j is for region i 's total exports. We assume that information frictions limits i 's access to markets other than j . Hence, a technology that reduces these frictions should make j less important for i 's total exports, thus attenuating the indirect effect of increasing the bilateral trade costs between i and j , and, as a consequence, unambiguously increases the magnitude of the elasticity of trade with respect to distance.

Our empirical estimates suggest technological change reducing information frictions indeed increases the magnitude of the elasticity of trade with respect to distance. These results are broadly consistent with the work of Freund and Weinhold (2004), correlating the growth rates of export with changes in internet penetration across countries. A complementary set of studies examine the role of geographical distance in online markets. The evidence is mixed. Hortaçsu et al. (2009) and Lendle et al. (2016) find smaller effects of distance on eBay as compared to total trade. By comparison Blum and Goldfarb (2006) shows that gravity also holds in the case of goods that have no direct trading costs such as digital goods consumed over the Internet.. Indeed, the magnitude of the estimated distance elasticity for digital goods is much larger than the magnitude of distance elasticities for other goods. Comparing our findings to the results from these studies may be difficult as the products, trade costs, sellers and buyers may be very different in online markets, and thus their comparison with total trade patterns may be problematic.

Our study contributes to a growing literature on the importance of imperfect information for the pattern of international trade.⁴ Rauch (1999) emphasize the importance of information frictions for trade in differentiated products. He presents evidence that supports the view that proximity and search barriers are more important for differentiated products. The reason, he argues, is that these goods require more information and search is strongly conditioned by proximity and pre-existing ties. Rauch and Trindade (2002) offer

⁴This literature is related to work on the importance of intermediation and networks in determining trade patterns. See Antràs and Costinot (2011) and the references therein.

a model where improved information allows home firms to rule out more potential foreign trade partners in advance of attempting to form a match. Chaney (forthcoming) argues that information frictions may help the importance of distance for trade patterns today. As long as the individuals that make up firms engage in direct communication with their clients and suppliers, and provided that information permeates through these direct interactions, the model in Chaney (forthcoming) predicts that aggregate trade is close to proportional to country size and inversely proportional to distance. Allen (2014) incorporates information frictions to a trade model by assuming that heterogeneous producers engage in a costly sequential search process to determine where to sell their produce. His estimates suggest that introducing information frictions helps match the observed trading patterns in the data. Dickstein and Morales (2016) compare the predictions of a standard model in the international trade under two specifications: perfect foresight where firms perfectly predict their profits when exporting, and a minimal information case, under which we assume firms use a specific observed set of variables to predict their export profits. Finding important differences in the predictions from the two models, they estimate an empirical model of export participation that places fewer restrictions on firms' expectations.

2 Data

Our analysis uses several data sources, which we can link through unique identifiers for each firm and municipality.

Firm and trade data. Our firm data come from administrative registers, which are updated annually by Statistics Norway and verified by the Norwegian Tax Authority. The data comprise all non-financial joint-stock firms over the period 2000-2008.⁵ We have information from the firm's balance sheets on output (such as revenues) and inputs (such as capital, labor, intermediates) as well as 4-digit industry codes and geographical identifiers at the municipality level. We merge the firm data set with a trade registry assembled from custom records and intra-EU declarations. We have information on the free on board value of all firm-level exports and imports in the period 2000–2008 at the Harmonized System 8-digit nomenclature product category. We merge the product codes with the so-called Rauch classification (see Rauch, 1999) that classifies products as homogenous or differentiated based on whether these products are traded on organized exchanges, have reference prices or neither.

⁵Joint-stock firms cover the vast majority of revenues and workers in the private sector. In 2001, for example, they cover 81% of revenues and 71% of workers.

Internet data. For the period 2001–2008, we have (i) data on broadband adoption for a stratified random sample of firms, and (ii) municipality-level information on availability of broadband internet to households (independently of whether they take it up). As explained in detail below, we will use the former to measure broadband adoption in firms, while the latter will be used to measure broadband availability rates, our instrumental variable.⁶ Throughout the paper, broadband internet is defined as internet connections with download speeds that exceed 256 kbit/s.⁷

Our data on broadband adoptions of firms comes from the annual Community Survey on ICT Usage of Firms, performed by Statistics Norway. This survey includes information on the use of broadband internet in firms. In each year, the survey samples from the universe of joint-stock firms. The survey design is a stratified random sampling by industry and the number of employees. We calculate municipality-level broadband adoption rates using the joint stock firms in the internet survey (20,966 firm-year observations) for which we observe whether or not a firm has adopted broadband internet. We use sampling weights to produce representative estimates for the corresponding population of joint-stock firms. Appendix Figure A.1 displays the distribution of firms by industry. This figure shows the industry composition in our survey sample and in the corresponding population of firms. The two main industries are manufacturing and wholesale/retail. This holds true both in terms of number of firms, trade, number of employees, and total wage bills. We can also see that the distributions in our sample (with sampling weights) closely mirror the distributions for the population of firms. The ability of our sampling weights to produce representative estimates is confirmed in Appendix Figures A.2 and A.3: The former displays the distributions of output and inputs across firms, while the latter shows the time trends in these variables.

The data on broadband availability come from the Norwegian Ministry of Government Administration. The ministry monitors the supply of broadband internet to households, and suppliers of broadband to end-users are required to file annual reports about their availability rates to the Norwegian Telecommunications Authority. The availability rates are based on information on the area signal range of the local access points and detailed information on the place of residence of households. In each year and for every municipality, this allows us to measure the fraction of households for which broadband internet is available, independently of whether they take it up. In computing these availability rates at

⁶We do not observe the availability rates of broadband internet to firms, and therefore use the availability rates to households as an instrument for broadband adoption in firms. If the availability of broadband to households were a noisy proxy for the availability to firms, this could generate a weak first stage for our instrument (which we do not have) but it would not be a violation of exclusion or independence conditions.

⁷Before the expansion of broadband internet, all firms with a telephone connection would have dial-up access to internet, but limited to a bitrate of less than 56 kbit/s. Broadband internet facilitated internet use without excessive waiting times.

the municipality level, it is taken into account that multiple suppliers may offer broadband access to households living in the same area, so that double counting is avoided.

Socio-economic data. Most of our socio-economic data come from administrative registers provided by Statistics Norway. Specifically, we use a longitudinal database which covers every resident from 2000 to 2008. It contains individual demographic information (regarding gender, age, marital status and number of children), socio-economic data (educational attainment, income, employment status), and geographic identifiers for municipality of residence. The information on educational attainment is based on annual reports from Norwegian educational establishments, whereas the income data and employment data are collected from tax records and other administrative registers. The household information is from the Central Population Register.

Gravity-related data. We use information on population-weighted bilateral distances between countries from the CEPII as described in Mayer and Zignago (2011). Information on GDP and internet usage in foreign countries come from the World Development Indicator database of the World Bank. Total annual income for Norwegian municipalities is calculated as the total income earned by individuals residing in a given municipality and year. For a subset of countries in our sample we also have information on English proficiency from the education firm EF. Aggregating the firm-level trade data to the municipality-country-year level yields a bilateral trade dataset with annual total exports and imports for each Norwegian municipality and foreign country pair.⁸

Estimation sample and summary statistics. Our estimation sample consists of all bilateral pairs between 420 Norwegian municipalities and 181 foreign countries. We create this data by aggregating to the municipality-country-year level international trade conducted by firms in our firm-level dataset which consists of joint-stock firms with at least five employees. We exclude firms with missing information on capital, intermediate inputs or location. In the interest of external validity, we also exclude firms that are carrying out extraction of natural resources (including oil and gas). After these restrictions, we have 287,617 firm-year observations.

Table 1 displays summary statistics for the resulting dataset. We observe bilateral trade for about a fifth of all possible municipality-country pairs and this number is stable throughout the sample. We also divide total trade into homogenous versus differentiated goods, as suggested by Rauch (1999), and find that the majority of trade is in differentiated

⁸The information on the trade patterns of Norwegian municipalities thus comes from the knowledge on where firms are located and their trade flows. All variables in the analysis are expressed in thousand 1998 constant US dollars using a NOK/USD exchange rate of 7.5.

Table 1. Summary statistics on trade (thousand US dollars), municipality-country pairs.

	2001	2004	2008	Overall
Trade propensity	0.16	0.17	0.17	0.17
Trade volume	3,532	2,357	2,484	2,589
Trade Shares				
- Homogenous goods	0.18	0.16	0.14	0.16
- Differentiated goods	0.66	0.68	0.67	0.67
- Exports	0.44	0.40	0.38	0.40
- Imports	0.56	0.60	0.62	0.60
N (pairs with trade)	11,462	12,096	12,429	97,646
N (pairs with or without trade)	72,137	73,260	73,390	586,392

Note: Detailed descriptions of the variables are given in Appendix Table A.1.

goods. We also find that imports are more important than exports in total trade volumes, possibly reflecting the importance of excluded product categories such oil and gas in Norwegian exports.

3 Expansion of broadband internet

Over the past decade, many OECD countries were planning the expansion of services related to information and communications technology. In Norway, the key policy change came with the National Broadband Policy, introduced by the Norwegian Parliament in the late 1990s. This section provides details about the program and describes the expansion of broadband internet.⁹

The program. The National Broadband Policy had two main goals. The first was to ensure supply of broadband internet to every area of the country at a uniform price. The second was to ensure that the public sector quickly adopted broadband internet. The Norwegian government took several steps to reach these goals. First and foremost, it invested heavily in the necessary infrastructure. This investment was largely channeled through the (state-owned) telecom company Telenor, which was the sole supplier of broadband access to end-users in the early 2000s and continues to be the main supplier today. Moreover, virtually all broadband infrastructure was, and still is, owned and operated by Telenor.

Second, local governments were required to ensure supply of broadband internet by 2005 to local public institutions, such as administrations, schools, and hospitals (St.meld.nr. 49, 2002–2003). To assist municipalities in rural areas, the federal government provided

⁹Our discussion draws on Bhuller et al. (2013) and Akerman et al. (2015).

financial support through a funding program known as *Høykom*. Local governments could receive funds from this program by submitting a project plan that had to be reviewed by a program board with expert evaluations. The stated aim was to ensure broadband availability throughout the country. Once approved, financial support was provided in the initial years of broadband access, thus making it possible for public institutions to cover relatively high initial costs.¹⁰

Supply and demand factors. The transmission of broadband signals through fiber-optic cables required installation of local access points. Since 2000, such access points were progressively rolled out, generating considerable spatial and temporal variation in broadband availability. The staged expansion of access points was in part due to limited public funding, but also because Norway is a large and sparsely populated country. There are often long driving distances between the populated areas, which are mostly far apart or partitioned by mountains or the fjord-broken shoreline.¹¹

The documents describing the National Broadband Policy and the roll-out of broadband access points (see St.meld.nr. 38 (1997-1998); St.meld.nr. 49 (2002-2003)), suggest the main *supply factors* determining the timing of roll-out are topographical features and existing infrastructure (such as roads, tunnels, and railway routes), that slow down or speed up physical broadband expansion.¹² Based on the program accounts, we expect the potential *demand factors* to be related to public service provision, income level, educational attainment, and the degree of urbanization in the municipality.

Evolution of broadband availability Figures 1 and 2 show the variation in our measure of broadband availability to households over time and across municipalities. By 2000, broadband transmission centrals were installed in the cities of Oslo, Stavanger, and Trondheim, as well as in a few neighboring municipalities of Oslo and Trondheim. However, because of limited area signal range, broadband internet was available for less than one-third of the households in each of these municipalities. More generally, the figures illustrate that

¹⁰During the period 1999–2005, the Høykom program received more than 1,000 such applications and co-funded nearly 400 projects, allocating a total of NOK 400 million. From 2002 onwards, the Ministry of Education and Research co-financed another scheme (*Høykom skole*), providing financial support for broadband infrastructure in public schools. There are virtually no private schools in Norway.

¹¹The Norwegian territory covers about 149,400 square miles, an area about the size of California or Germany, with around 13 % and 6 % of those regions' populations (in 2008), respectively. The country is dominated by mountainous or high terrain, as well as a rugged coastline stretching about 1,650 miles, broken by numerous fjords and thousands of islands.

¹²The reason is that the transmission of broadband signals through fiber-optic cables required installation of local access points. In areas with challenging topography and landscapes, it was more difficult and expensive to install the local access points and the fiber-optic cables. Furthermore, the existing infrastructure mattered for the marginal costs of installing cables to extend the availability of broadband within a municipality and to neighboring areas.

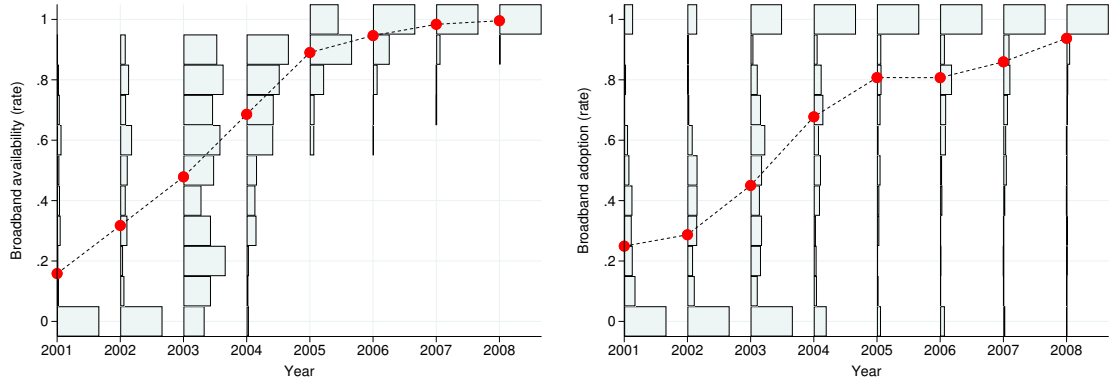


Figure 1. Availability and adoption of broadband internet across municipalities and time.

for a large number of municipalities there was no broadband availability in the first few years, whereas most municipalities had achieved fairly high availability rates in 2005. Moreover, there is considerable variation in availability rates within the municipalities in these years. Indeed, few municipalities experience a complete shift from no availability to full availability in a given year; rather, access points were progressively rolled out within and across municipalities, generating a continuous measure of availability rates that display considerable temporal and spatial variation (even conditional on year and municipality fixed effects).

Broadband adoption in firms Before turning to the estimation of the augmented gravity model in the next section, it is useful to understand the pattern of broadband adoption in firms. Figure 3 illustrates our identification strategy by drawing a scatter plot of the broadband adoption rate of firms against the broadband availability rate in the municipality, after taking out municipality and year fixed effects. The figure is based on the following regression that uses the sample of firms for which we observe whether or not a firm has adopted broadband internet:

$$d_{imt} = \delta z_{mt} + \gamma_m + \eta_t + v_{imt}. \quad (1)$$

where d_{imt} equals one if firm i in municipality m in year t had adopted broadband internet and is zero otherwise. Our instrument z_{mt} is the broadband coverage rate in municipality m in year t (i.e. the share of households for which broadband internet is available, independently of whether they take it up). To exploit the quasi-randomization provided by the broadband internet roll-out documented above we need to condition on municipality fixed effects γ_m and time dummies η_t .

Figure 3 shows a strong linear association between broadband availability and adoption rates. The Y-axis reports residuals from a regression of broadband adoption rates of firms

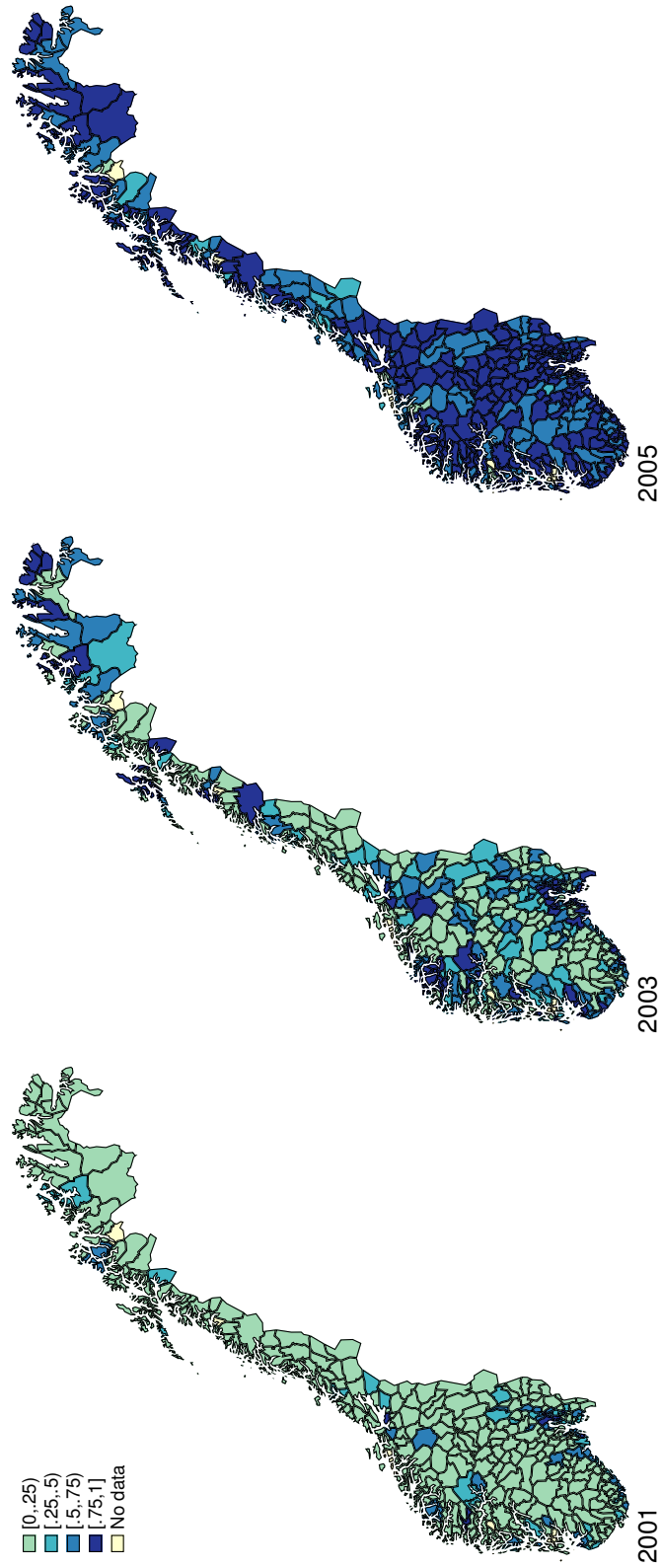


Figure 2. Geographical distribution of broadband availability rates.

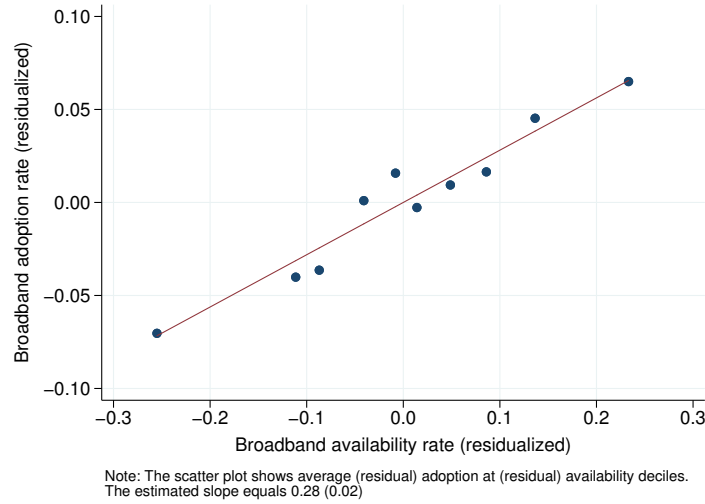


Figure 3. First stage regression.

on municipality and year fixed effects. The X-axis reports residuals from a regression of broadband availability rates of households on municipality and year fixed effects. We estimate the coefficient on the availability rate δ to be about 0.28 with a standard error of 0.02. This estimate implies that a 10 percentage point increase in broadband availability induces (an additional) 2.8% of the firms to adopt broadband internet.

To understand what type of firms that quickly adopt broadband when it becomes available (i.e., the compliers to the instrument), we partition the sample of firms with observed technology into six mutually exclusive groups by industry (the three largest industries) and share of workers with college degree (above and below median within each industry). We then allow the coefficient δ to vary across these groups. Column (1) of Table 2 displays the size of the sample in each industry–skill group. The estimates of δ for the different types of firms are shown in the second column of Table 2. The proportion of the compliers of a given type is then calculated as the ratio of $\hat{\delta}$ for that subgroup to the $\hat{\delta}$ in the overall sample, multiplied by the proportion of the sample in the industry–skill group reported in column (3). Column (4) shows the distribution of the compliers by industry and skill intensity. We see that firms with a large share of high skilled workers are overrepresented among the compliers in every industry as compared to the sample of firms at large.

Columns (5)–(9) of Table 2 report the characteristics of each industry–skill group. Columns (5) and (6) show that in every industry the complier firms tend to be relatively productive and large (as measured by labor productivity and employment), column (7) shows that computer use is higher in complier firms, and columns (8) and (9) show that they are more likely to trade internationally at both the extensive and intensive margins. These findings illustrate that when broadband internet becomes available, it is not randomly

Table 2. Characterizing complier firms (by sector and skill endowment of workers).

	N (1)	$\hat{\delta}$ (2)	Composition		Log labor productivity (5)	Number of workers (6)	Share of workers using PC (7)	Trade	
			Sample (3)	Compliers (4)				Propensity (8)	Volume (9)
Construction									
< median	1,571	0.37 (0.06)	0.07	0.11	4.7	19.0	0.25	0.29	29
> median	1,571	0.47 (0.05)	0.07	0.14	4.8	41.0	0.37	0.31	280
Manufacturing									
< median	2,330	0.19 (0.04)	0.11	0.08	4.7	43.6	0.34	0.78	2,517
> median	2,331	0.26 (0.04)	0.11	0.12	5.0	78.5	0.60	0.82	11,805
Service									
< median	2,187	0.15 (0.07)	0.10	0.06	4.4	51.3	0.46	0.28	139
> median	2,187	0.22 (0.07)	0.10	0.09	4.7	31.3	0.93	0.44	522
Wholesale/retail									
< median	3,414	0.20 (0.04)	0.16	0.13	5.1	18.5	0.44	0.52	515
> median	3,415	0.25 (0.04)	0.16	0.17	5.4	30.3	0.68	0.70	3,859
Overall	20,954	0.25 (0.04)	1.00	1.00	4.9	35.0	0.50	0.52	2,098

Note: We partition the survey sample of joint-stock firms into ten mutually exclusive groups by industry (four largest industries and others) and skill intensity (above and below median within each industry). Column (1) displays the proportion of the sample in each industry-skill intensity group. Column (2) reports estimates of $\hat{\delta}$ from equation (1) for each group. The proportion of the compliers of a given type is then calculated as the ratio of $\hat{\delta}$ for that subgroup to the $\hat{\delta}$ in the overall sample, multiplied by the proportion of the sample in the industry-skill group. Column (4) shows the distribution of the compliers by industry and skill intensity. Columns (5)–(9) report baseline characteristics of each industry-skill group. Sampling weights are used to ensure representative results for the population of joint-stock firms.

adopted; instead, it is more quickly adopted in firms in which complementary factors are abundant, including computers and skilled workers. This is consistent with the predictions of a model of endogenous technology adoption where firms' choices reflect principles of comparative advantage (see e.g. Beaudry and Green, 2003, 2005; Beaudry et al., 2010).

These findings complement previous research by Acemoglu and Finkelstein (2008) and Lewis (2011). The study by Acemoglu and Finkelstein (2008) looks at how changes in relative factor prices faced by U.S. hospitals affect their demand for capital and labor and their technology adoption decisions. They find that technology adoption in the health care sector is sensitive to relative factor prices, and that the skill mix of workers respond quickly to changes in technology. Lewis (2011) considers positive shocks to low skill labor supply across U.S. labor markets (stemming from immigrant flows), and finds that firms react quickly by changing their investments in new technology.

4 Empirical model and identification

In this section we specify a standard gravity equation augmented with interaction terms between broadband adoption and covariates, and outline our estimation approach. The main challenge in the estimation is to address the potential endogeneity of broadband adoption. Randomizing broadband adoption is not feasible: We cannot in practice force firms to adopt a new technology. One can, however, think of a field experiment which randomizes broadband availability at the municipality level. The randomization would break the correlation between availability rates and unobserved determinants of trade. The intention of our identification strategy is to mimic this hypothetical experiment. Our source of exogenous variation comes from the staged installation of broadband infrastructure, which generated spatial and temporal variation in broadband availability and, consequently, adoption as documented above.

4.1 Broadband adoption and trade

Most contemporaneous estimates of the gravity model depart from models that deliver the following structure

$$X_{ij} = b_0 \left(\frac{Y_i}{\Omega_i} \right)^{b_I} \left(\frac{Y_j}{\Phi_j} \right)^{b_J} \tau_{ij}^{b_\tau} \quad (2)$$

where X_{ij} is trade between region i and region j , Y_i is GPD in origin i , Y_j is GDP in destination j , Ω_i and Φ_j are the bilateral resistance terms, and finally τ_{ij} is a measure of bilateral trade costs such as distance. To investigate how internet affected trade we extend this core setup by letting the elasticity b_τ as well as b_I , b_J and b_0 depend on broadband

internet use in i , d_i , i.e.

$$b_k = \alpha_k + \beta_k d_i, \quad k \in \{0, I, J, \tau\}$$

Then, we log-linearize and parametrize (2) and let it depend on time t , giving the following augmented gravity equation

$$\begin{aligned} \log X_{ijt} = & (\alpha_0 + \beta_0 d_{it}) + (\alpha_I + \beta_I d_{it}) \log Y_{it} + (\alpha_J + \beta_J d_{it}) \log Y_{jt} \\ & + (\alpha_\tau + \beta_\tau d_{it}) \log \tau_{Norway,j} + \gamma_{ij} + \tau_t + \varepsilon_{ijt} \end{aligned}$$

which can be written more compactly as

$$\log X_{ijt} = w'_{ijt}(\alpha + \beta d_{it}) + \gamma_{ij} + \tau_t + \varepsilon_{ijt} \quad (3)$$

with

$$w'_{ijt} = (1 \quad \log Y_{it} \quad \log Y_{jt} \quad \log \tau_{Norway,j})$$

and where subscript i refers to municipality, subscript j to destination/source country, and subscript t to year. The outcome X_{ijt} is total trade between i and j , d_{it} is the broadband adoption rate (the fraction of firms that have adopted broadband internet). The vector w_{ijt} contains Y_{it} the economic size of origin i (as measured by municipality i 's total income), Y_{jt} the economic size of destination j (as measured by country j 's GDP), and $\tau_{Norway,j}$ the distance between Norway and j . Because w_{ijt} also includes a constant term, we allow broadband use to directly affect trade between i and j through a change in the intercept. We furthermore normalize the variables in w_{ijt} to mean zero so that we can interpret the coefficient on the main effect of broadband use as the average effect in the sample.

The coefficients $\alpha = (\alpha_0 \alpha_I \alpha_J \alpha_\tau)'$ are the intercept and the coefficients on the standard gravity terms, while the coefficients $\beta = (\beta_0 \beta_I \beta_J \beta_\tau)'$ correspond to the interaction effects with broadband use. We are primarily interested in the coefficient β_τ which captures how broadband internet affects the elasticity of trade with respect to distance. Below, in Section 6.1, we show how to motivate equation (3) and interpret the resulting parameter estimates through the lens of the classical Armington-type gravity model of Anderson and van Wincoop (2003) with information frictions.¹³

In equation ((3)), unobservable determinants of trade that are fixed at the municipality-country-pair level will be controlled for through the pair indicators (γ_{ij}), just like common time shocks are absorbed by the year indicators (τ_t). In our empirical analysis, we will use two specifications of (3). Since our interest is centered on identifying the coefficients β ,

¹³Just like the standard gravity model, this can also be achieved in alternative theoretical settings such as those suggested by Krugman (1980) and Eaton and Kortum (2002) as we show in Appendix C.

we will mainly use a specification with fixed effects γ_{ij} for each municipality-country pair included in equation (3). With this specification, however, we cannot identify the direct effect of distance on trade. To compare our estimate of α_τ to the results in existing studies, we will therefore also report estimates of (3) without these fixed effects.

The main challenge when estimating (3) is addressing potential omitted variable bias arising from the endogeneity of broadband internet use. We therefore instrument the fraction of firms that have adopted broadband internet in municipality i in year t (d_{it}), with the broadband coverage rate in municipality i at the end of year t (z_{it}). This gives the following first-stage equations.

$$d_{it} = w'_{ijt}(\delta_0 + \phi_0 z_{it}) + \zeta_{0,ij} + \theta_{0,t} + v_{0,ijt} \quad (4)$$

$$d_{it} \log \tau_{Norway,j} = w'_{ijt}(\delta_\tau + \phi_\tau z_{it}) + \zeta_{\tau,ij} + \theta_{\tau,t} + v_{\tau,ijt} \quad (5)$$

$$d_{it} \log Y_{it} = w'_{ijt}(\delta_s + \phi_s z_{it}) + \zeta_{s,ij} + \theta_{s,t} + v_{s,ijt} \quad (6)$$

$$d_{it} \log Y_{jt} = w'_{ijt}(\delta_d + \phi_d z_{it}) + \zeta_{d,ij} + \theta_{d,t} + v_{d,ijt} \quad (7)$$

4.2 Regression model of intention-to-treat effects

IV estimation of equation (3) requires that increased availability of broadband internet affects trade only through broadband adoption in firms, and not directly in any other way. This exclusion restriction could be questioned. For example, one may be worried that increased availability of broadband internet among households changes their demand for goods. Since Norway is a small open economy, one would expect this effect to be relatively small, at least for firms in the tradable sector where demand is given by the world market. However, we cannot rule out that the exclusion restriction is violated. Thus, we also present estimates of the reduced form effects of (increasing) broadband coverage rates z_{it} on trade – so-called intention-to-treat effects – which do not rely on this exclusion restriction but only require exogeneity of the instrument z_{it} .

To estimate these intention-to-treat effects of the increased availability of broadband internet, we specify the following panel data regression:

$$\log X_{ijt} = w'_{ijt}(\varphi + \eta z_{it}) + \gamma_{ij} + \tau_t + u_{ijt}, \quad (8)$$

Equation (8) is the standard gravity equation augmented with interaction terms between broadband availability and the covariates w_{ijt} . The coefficients $\varphi = (\varphi_0 \varphi_I \varphi_J \varphi_\tau)'$ estimate the relationship between (log) trade and locations with different distance and economic sizes before the roll-out of broadband internet ($z_{it} = 0$), while the coefficients of primary interest $\eta = (\eta_0 \eta_I \eta_J \eta_\tau)'$ measure the interaction effects between these covariates and broadband availability. As above, because of the normalization of the variables in w_{ijt} we

can interpret the coefficient on the main effect of broadband availability as the average effect in the sample.

4.3 Inference and estimation

While we can estimate equation (8) on the full estimation sample of municipality-country pairs, we rely on information on broadband adoption from surveys to estimate equations (4)-(7). This means that we estimate the first stages in a subsample of the full estimation sample of municipality-country pairs that we use in the reduced form. It is well known that in such cases we need to adjust the estimated standard errors (Angrist and Krueger, 1995; Inoue and Solon, 2010). To do this, however, we cannot use existing results. This is because our first stages are estimated in a subsample of the full sample used in the reduced form estimation, and not in a separate (split) sample as in existing work.

If we generically write the second stage as

$$y = X\beta + e$$

with first-stages

$$X = Z\Pi + U$$

and corresponding reduced form

$$y = Z\gamma + v$$

where $\gamma = \Pi\beta$ and $v = U\beta + e$, then we show in Appendix B that

$$d\beta/d\text{vec}\Pi = -(\beta' \otimes (\Pi'Z'Z\Pi)^{-1}\Pi'Z'Z)$$

and

$$d\beta/d\gamma = (\Pi'Z'Z\Pi)^{-1}\Pi'Z'Z.$$

Let $\eta = (\text{vec}\Pi' \gamma')'$, then these results can then be used to construct the covariance matrix of β using the Delta method as follows

$$V(\beta) = (\partial\beta/\partial\eta)' V(\eta) (\partial\beta/\partial\eta)$$

where

$$\text{Var}(\eta) = (I_{K+1} \otimes E[Z'Z]^{-1}) E[Z'\xi\xi'Z] (I_{K+1} \otimes E[Z'Z]^{-1})$$

and $\xi = (\text{vec}U' v')'$. In a first step we directly get the covariance matrices of $\hat{\Pi}_k$ and $\hat{\gamma}$ from our OLS estimation. These are then used to compute residuals $\hat{\xi}$. An estimate of $E[Z'\xi\xi'Z]$ is obtained using $\hat{\xi}$ and standard covariance matrix estimation using the method

of moments, allowing for clustering at the municipality level.

4.4 Assessing the identification strategy

Broadband coverage, the instrumental variable z_{it} in our 2SLS estimation above, varies across municipalities and time. Given that we are controlling for municipality and time fixed effects, the core of our design is similar in spirit to a difference-in-difference setup. The key threat to identification of how broadband affects the relationship between trade and distance is therefore that the timing of the broadband roll-out might be related to different underlying trends in this relationship across municipality-country pairs. Before turning to a more detailed regression-based analysis that addresses this concern, we examine here the determinants of the timing of the broadband roll-out.

Timing of the broadband roll-out. Our identification strategy controls for municipality-country pair and year fixed effects. This is motivated by two features of the program that expanded broadband availability. First, most of the confounding supply and demand factors tend to vary little over time and are therefore accounted for by the municipality-country fixed effects. Second, the timing of the roll-out (i.e. the variation in broadband availability conditional on the fixed effects) is unlikely to co-vary with key correlates of trade.

To investigate whether the data are consistent with these program features, we first regress z_{it} on municipality and time fixed effects as well as time-varying supply and demand factors. We find that 79 % of the variation in broadband availability can be attributed to time-invariant municipality characteristics and common time effects, while less than 3 % of the variation in broadband availability can be attributed to a large set of time-varying variables.¹⁴

To further examine the relationship between the timing of broadband roll-out and baseline (2000) municipality characteristics $m_{i,t0}$ we estimate the following equation

$$\Delta z_{it} = \eta_t + \theta_t m_{i,t0} + \varepsilon_{ijt} \quad (9)$$

where $\Delta z_{it} = z_{it} - z_{i,t-1}$ is the change in the broadband availability rate, and η_t is a vector of year fixed effects. To match the IV and reduced form model, we use weights so that the sample is representative with respect to municipality-country pairs. We estimate regressions where we let $m_{i,t0}$ contain municipality-level information from year 2000 on demography,

¹⁴The time-varying variables include demographic factors (income level, education, share of population residing in a densely populated locality, size of population), inputs and output (municipality averages of revenues, intermediates, capital stock, number of workers and wage bill), industry structure (employment share in manufacturing, employment share in wholesale and employment share in transport) and the fraction of firms in the municipality that import and export, as well as the mean value of imports and exports in the municipality.

average levels of international trade, inputs and output, industry structure, and pre-reform growth rates in trade. Demographic variables include size of population, share of population residing in a densely populated locality (an urbanization indicator), income level and education. For firm inputs and output, we have included municipality averages of revenues, intermediates, capital stock, number of workers and wage bill. As measures of industry structure, we use number of firms, employment share in manufacturing, employment share in wholesale, and baseline (1999-2000) trade growth. Finally we also look at the fraction of firms in the municipality that import and export, as well as the mean value of imports and exports in the municipality.

Appendix Figure A.4 plots the estimated coefficients θ_t (and the associated 95% confidence intervals) from the multi-variate regression model in equation (9). We have standardized both the dependent variable and $m_{i,t0}$ so that we can interpret θ_t as correlation coefficients. The main pattern that stands out is that broadband was rolled out in more urban areas at the start of the roll-out. There are some other correlations with roll-out and municipality characteristics, especially in the earlier years. Figure A.4 also plots estimates of θ_t from regressions where $m_{i,t0}$ only contain one municipality-level variable in addition to a control for urbanization. These estimates confirm that urban areas is the key predictor of internet arrived earlier. From 2003 and onwards, there appears to be little if any systematic relationship between the timing of the broadband expansion and the other municipality characteristics.

Taken together, the evidence presented in Appendix Figure A.4 suggests that, apart from the degree of urbanity, the roll-out of broadband availability does not appear to be systematically related to key observable correlates of trade. Nevertheless, a concern is that there could be differential underlying trends in the outcomes of interest depending on urbanization or some characteristic. To examine whether our estimates are biased because of differential trends, we perform three robustness checks. First, we make sure that our estimates are robust to excluding the three or five biggest cities. Second, we explicitly allow for differential trends by initial conditions as measured in year 2000. This is done by interacting urbanization and other municipality-level information with municipality-specific time trends. Third, we show robustness to allowing for differential time trends across areas by including linear municipality specific trends. To check that the estimated effects are not driven by time-varying observable factors, we additionally report results with and without a large set of time-varying controls for the potential supply and demand factors (discussed in Section 3).

5 Internet and the relationship between distance and trade

5.1 Main results

Table 3 reports our estimates of a basic gravity equation, and the augmented gravity equation in (3), as well as the (intention-to-treat) effects of broadband coverage on trade from (8). The sample consists of all municipality-country-year combinations where one trading partner is a Norwegian municipality and the other a country (not Norway) and where log value of trade is positive.

OLS estimates. The first three columns show the estimation results using OLS. Column (1) shows the estimates from a standard gravity equation that does not include any interactions with internet. To estimate the coefficient on log distance, we do not include the pair specific fixed effects γ_{ij} and only use municipality and time fixed effects. We see that the magnitude of the elasticity of trade with respect to distance is 1.25, and the elasticities with respect to economic size are 0.50 for the origin (municipality), and 0.74 for the destination (foreign country). While the origin elasticity is quite imprecisely estimated, we find that the gravity-related elasticities in our dataset lie well within the range commonly found in the literature (see for example Table 3.4 of Head and Mayer, 2014).

In column (2), we report the OLS estimates of equation (3) which include the interaction variables for internet adoption and the gravity variables. As in column (1), in order to estimate an effect on distance, we include municipality and time fixed effects but not pair specific fixed effects. As explained above, all main gravity variables are expressed as deviations from population means. This means that we can interpret the main elasticities as the elasticities without internet, and the coefficient on the interactions between internet and the intercept as the partial effect of internet at the sample average. The main gravity coefficients do not change significantly. As to the internet related terms, we find a positive but imprecisely estimated main effect of internet adoption on trade. However, we find a negative and statistically significant effect of the interaction variable with distance, which means that the elasticity of trade with respect to distance increases in magnitude with internet. Moreover, the elasticity with respect to destination market size, Y_{jt} , increases significantly. We do not find evidence that the elasticity with respect to origin market size depends on internet adoption.

In column (3), we present our baseline specification where we include also the pair-specific fixed effects as specified in equation (3) which capture all time-constant heterogeneity across all bilateral pairs. In this specification the coefficients are estimated using variation within pairs and across time. The signs and magnitudes of the interaction

Table 3. Gravity estimation results – Trade volume (log)

	OLS			ITT	SSIV
	(1)	(2)	(3)	(4)	(5)
$\log \tau_{NOR,jt}$	-1.253 (0.023)	-1.208 (0.032)			
$\log Y_{it}$	0.499 (0.275)	0.702 (0.303)	0.880 (0.378)	0.709 (0.348)	0.675 (0.326)
$\log Y_{jt}$	0.736 (0.022)	0.721 (0.021)	1.552 (0.167)	1.668 (0.165)	1.734 (0.152)
d_{it}		0.046 (0.047)	0.063 (0.051)		0.252 (0.489)
$d_{it} \times \log \tau_{NOR,jt}$		-0.092 (0.030)	-0.093 (0.028)		-0.171 (0.045)
$d_{it} \times \log Y_{it}$		-0.006 (0.048)	-0.031 (0.053)		0.088 (0.081)
$d_{it} \times \log Y_{jt}$		0.075 (0.019)	0.037 (0.014)		0.094 (0.022)
z_{it}				0.050 (0.105)	
$z_{it} \times \log (\tau_{NOR,jt})$				-0.119 (0.035)	
$z_{it} \times \log Y_{it}$				0.050 (0.050)	
$z_{it} \times \log Y_{jt}$				0.064 (0.017)	
Mean dep. var.	10.96	11.07	11.07	10.96	10.96
N	97,646	89,522	89,522	97,646	97,646
Pair FE			✓	✓	✓

Note: Columns (1) and (2) include fixed effects for year and municipality. Columns (3) to (5) include fixed effects for year and municipality-country-specific pairs. The sample period is 2001-2008. The sample consists of all municipality-country-year combinations where one trading partner is a Norwegian municipality and the other a country (not Norway) and where log value of trade is positive. All reported standard errors are clustered at the municipality level.

coefficients with internet take-up do not change significantly when adding these controls.

Reduced form effects. The OLS estimates in column (3) suggest that adoption of broadband internet makes trade patterns more sensitive to distance and the size of the destination market. However, an important concern with the OLS results is that potential endogeneity of internet take-up biases these estimates. In the remainder we will therefore use the roll-out of broadband internet coverage as an instrument for internet take-up.

Before turning to our 2SLS estimates we will first discuss the reduced form effects of broadband internet roll-out. These intention-to-treat results, which do not rely on exclusion restrictions, are shown in column (4). These estimates show that going from no coverage to full coverage increases the magnitude of the elasticity of trade with respect to distance by 0.12, and the elasticity of trade with respect to destination size by 0.06. For distance, this means that an increase in internet availability of 10 percentage points increases trade for a country at the 25th distance percentile by 1.1% more than for a country at the 75th distance percentile. The same difference for the size (GDP) of a destination is 2.1%. There is no evidence that broadband coverage impacts the elasticity of trade with respect to origin size. While the OLS results are potentially biased, they are qualitatively in line with these intention-to-treat estimates which we can give a causal interpretation.

2SLS estimates. The intention-to-treat effects establish that expanding internet coverage indeed affects the composition of trade by increasing the magnitudes of distance and size elasticities. Invoking the exclusion restriction, it is also possible to estimate how broadband internet use (and not only coverage) affects the elasticity of trade with respect to distance. This means that we need to scale the broadband coverage effects up by the effect of coverage on take-up. We achieve this by estimating the first stages (4)-(7) using the survey information on firms' broadband adoption. Table 4 reports the results. The first thing to note is that the Sanderson-Windmeijer F-statistics (Sanderson and Windmeijer, 2016) range from 12.5 for the first stage of the average broadband take-up rates in municipality i , d_{it} , to more than 1,200 in the first stage that interacts d_{it} with (log of) distance. In the first column we see that on average expanding coverage by 10 percentage points increased take-up rates by about 2.2 percentage points. This effect is somewhat smaller in larger municipalities, and there is no heterogeneity in take-up with respect to the size and distance to trade partners. Columns (2)-(4) report the first stages of the interaction between take-up and the gravity variables. Here we see that the only instruments that matter are the overall coverage rate z_{it} , and the interaction between the coverage rate and the interacting gravity variable.

Column (5) in Table 3 reports the sub-sample IV estimation results of the augmented gravity equation in (3). We see that broadband internet take-up increases the magnitude of the elasticity of trade with respect to distance by 0.17, and the elasticity of trade with respect to destination size by 0.09. While qualitatively the same, these effects are larger than the OLS estimates. This suggests that municipalities with higher unobserved propensities to trade with remote and large destinations were more likely to adapt internet. The evidence in Table 3 shows that internet shifted trade towards closer destinations and towards larger trade partners. The point estimates suggest that broadband internet adoption increased the

Table 4. First stage regressions with pair-specific ($i \times j$) fixed effects.

	d_{it}	$d_{it} \times \log(\tau_{NOR,jt})$	$d_{it} \times \log Y_{it}$	$d_{it} \times \log Y_{jt}$
	(1)	(2)	(3)	(4)
$\log Y_{it}$	0.064 (0.155)	0.064 (0.052)	0.552 (0.205)	-0.214 (0.145)
$\log Y_{jt}$	-0.017 (0.017)	0.196 (0.024)	0.116 (0.024)	-0.410 (0.071)
z_{it}	0.216 (0.052)	-0.037 (0.018)	-0.230 (0.097)	0.105 (0.057)
$z_{it} \times \log(\tau_{NOR,jt})$	-0.003 (0.008)	0.707 (0.022)	-0.006 (0.011)	0.031 (0.014)
$z_{it} \times \log Y_{it}$	-0.038 (0.025)	0.004 (0.010)	0.713 (0.036)	-0.022 (0.023)
$z_{it} \times \log Y_{jt}$	0.000 (0.004)	0.006 (0.004)	0.001 (0.006)	0.696 (0.024)
F-statistic	12.5	1,257.3	44.8	1,066.7
N	89,522	89,522	89,522	89,522

Note: All regressions include fixed effects for year and municipality-country pairs. The sample period is 2001-2008. The sample consists of all municipality-country-year combinations where one trading partner is a Norwegian municipality and the other a country (not Norway) and where log value of trade is positive. The table reports the Sanderson-Windmeijer F-statistic. All reported standard errors are clustered at the municipality level.

magnitude of the elasticity of distance by 14%, and the elasticity of destination size by 5%.

5.2 Specification checks

The reduced form and 2SLS estimates suggest that adoption of broadband internet shifted trade towards closer destinations and towards larger trade partners. We now perform several specification checks to investigate the robustness of these results.

The first set of robustness checks examines whether the timing of the broadband internet roll-out correlates with other time-varying covariates and/or trends. The results from regressions that may vary the set of controls are reported in Table 5. The first column repeats the baseline estimates from the reduced form model. Columns (2) and (3) include a wide range of controls for the time-varying demographic and industry characteristics that we used in Section 4.4 to examine the determinants of the timing of the broadband roll-out. As can be seen from the table, including these covariates barely moves the estimates of interest. In column (4), we include linear trends interacted with baseline (year 2000) demographic and industry covariates, while in column (5) we allow for municipality-specific linear trends. The coefficients barely move in any of these alternative specifications. We therefore conclude there is no evidence that our estimates are biased

Table 5. Gravity estimation results, covariate robustness – Trade volume (log)

	(1)	(2)	(3)	(4)	(5)
A. ITT					
$z_{it} \times \log(\tau_{NOR,jt})$	-0.119 (0.035)	-0.119 (0.035)	-0.120 (0.034)	-0.117 (0.033)	-0.107 (0.033)
$z_{it} \times \log Y_{jt}$	0.064 (0.017)	0.064 (0.017)	0.065 (0.016)	0.061 (0.017)	0.048 (0.017)
B. SSIV					
$d_{it} \times \log(\tau_{NOR,jt})$	-0.171 (0.045)	-0.171 (0.045)	-0.172 (0.044)	-0.174 (0.043)	-0.156 (0.042)
$d_{it} \times \log Y_{jt}$	0.094 (0.022)	0.093 (0.022)	0.094 (0.021)	0.091 (0.021)	0.072 (0.021)
Pair FE	✓	✓	✓	✓	✓
Time-varying covariates:					
– Demographic		✓	✓	✓	✓
– Industry			✓	✓	✓
Trends interacted with:					
– Baseline covariates				✓	
– Municipality FE					✓

Note: All regressions include fixed effects for year and municipality-country-specific pairs. The sample period is 2001-2008. The sample consists of all municipality-country-year combinations where one trading partner is a Norwegian municipality and the other a country (not Norway) and where log value of trade is positive. Column (2) adds demographic controls to the baseline model, including municipality-level information on average household income, mean years of schooling, share of population residing in a densely populated locality and size of population. Column (3) also includes industry controls, consisting of municipality averages of revenues, intermediates, capital stock, number of workers and wage bills as well as employment share in manufacturing, employment share in wholesale, employment share in transport/communication, and mean levels of export and import propensity and log export and import volumes. Column (4) interacts linear trends with baseline (year 2000) values of these covariates. Column (5) includes municipality-specific linear time trends. All reported standard errors are clustered at the municipality level.

because the broadband internet roll-out correlated with municipality specific trends in trade, or differential trends in the propensity to trade between for example more and less urban areas, or other demographic and/or industry dimensions.

The second set of robustness checks are presented in Table 6. In these checks, we examine the sensitivity of our findings to the composition of our sample. For ease of reference, column (1) reports the estimates from our baseline specification. We start by investigating whether dynamics on the extensive margin (i.e. which municipality-country pairs engage in trade) matters for our conclusions. In column (2), we restrict the sample to the sub-sample of municipality-country pairs where trade also occurred in 2000 (the year before our sample period starts). The effects are qualitatively similar for this subsample and, if anything, the internet causes a somewhat larger change in the magnitudes of the elasticities with respect to trade and size of destination market.

The baseline results assign the same weight to each municipality-country pair. In columns (3) and (4), we report estimation results where we weight all observations by

Table 6. Gravity estimation results, sample robustness – Trade volume (log)

	Baseline	Cond. on 2000	Weights		# Largest cities excl.	
	(1)	(2)	Population (3)	GDP (4)	3 (5)	5 (6)
A. ITT						
$z_{it} \times \log(\tau_{NOR,jt})$	-0.119 (0.035)	-0.171 (0.038)	-0.177 (0.062)	-0.188 (0.067)	-0.123 (0.035)	-0.127 (0.035)
$z_{it} \times \log Y_{jt}$	0.064 (0.017)	0.102 (0.018)	0.041 (0.028)	0.042 (0.029)	0.068 (0.017)	0.071 (0.017)
B. SSIV						
$d_{it} \times \log(\tau_{NOR,jt})$	-0.171 (0.045)	-0.248 (0.052)	-0.222 (0.066)	-0.233 (0.071)	-0.178 (0.045)	-0.185 (0.046)
$d_{it} \times \log Y_{jt}$	0.094 (0.022)	0.150 (0.025)	0.051 (0.028)	0.052 (0.028)	0.100 (0.022)	0.105 (0.022)
Mean dep.var.	10.96	11.79	10.96	10.96	10.89	10.87
N	97,646	70,312	97,646	97,646	94,565	92,657
Pair FE	✓	✓	✓	✓	✓	✓

Note: All regressions include fixed effects for year and municipality-country-specific pairs. The sample period is 2001-2008. The sample consists of all municipality-country-year combinations where one trading partner is a Norwegian municipality and the other a country (not Norway) and where log value of trade is positive. Column (2) restricts the sample to municipality-country pairs which report positive trade in 2000. Columns (3) and (4) weight observations by population and GDP, respectively, in the Norwegian municipality. In columns (5) and (6) we omit the 3 and 5 largest Norwegian cities, respectively. All reported standard errors are clustered at the municipality level.

the number of inhabitants and the GDP of the Norwegian municipality, respectively. The results above confirm that adoption of broadband internet shifted trade towards closer destinations and towards larger trade partners.

Above we documented that the timing of the broadband internet roll-out correlated with degree of urbanity. In columns (5) and (6), we examine the robustness of the results to removing the three and five largest cities in Norway, respectively. As can be seen in Table 6, removing the urban centers from the sample suggests that the correlation of the internet roll-out with urbanity does not change the conclusion adoption of broadband internet shifted trade towards closer destinations and towards larger trade partners.

6 Mechanisms

We have established that broadband internet affects bilateral trade flows by making trade patterns more sensitive to distance and economic size of destination markets. To better understand the channels through which broadband internet affects trade patterns, we proceed to explore potential mechanisms in this section. We first interpret the empirical

results through the lens of a gravity theory of trade patterns, augmented with information frictions. Next, we consider alternative mechanisms outside the model which could also explain why adoption of broadband internet increases the sensitivity of trade to distance.

6.1 Gravity with information frictions

We proceed to ask whether augmenting a classical gravity model with information frictions can help interpret our results. We want to analyze comparative statics with respect to the size of a country's information set. For ease of exposition, we use the Armington-type model by Anderson and van Wincoop (2003) but show in Appendix C that our results also apply to gravity models with alternative microeconomic foundations, such as for example those described by Krugman (1980) and Eaton and Kortum (2002). Our main conclusion on how the elasticity of trade to specific variables changes with a country's information set holds also for competitive settings not typically used to derive the gravity model, such as Cournot competition or with quasilinear demand as shown by for example Freund and Weinhold (2004) and Melitz and Ottaviano (2008), respectively. We return to this at the end of this section.

Consumers in region $j = \{1, \dots, N\}$ take prices as given and maximize a CES objective, U_j , across a continuous set of varieties:

$$U_j = \left(\sum_i c_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (10)$$

where c_{ij} is the level of consumption of region i 's goods by region j 's consumers and $\sigma > 1$ is the elasticity of substitution across goods in the utility function. The budget constraint of region j is

$$\sum_i p_{ij} c_{ij} = y_j \quad (11)$$

where y_j is the nominal income of region j consumers and p_{ij} is the price of region i goods when sold in region j . We make the standard assumption that exporters incur trade costs of a factor $t_{ij} \geq 1$ when exporting from i to j but pass these on to the importer such that prices in foreign markets are set as a markup over the domestic price p_i so that $p_{ij} = t_{ij} p_i$.

The nominal value of demand in region i of region j 's output is then $x_{ij} = p_{ij} c_{ij}$. The total income of region i becomes

$$y_i = \sum_j \omega_{ij}^X(\mathcal{I}_i, \mathcal{I}_j) x_{ij}. \quad (12)$$

We make a departure from the standard literature by introducing information frictions. Let \mathcal{I}_i denote the information set of region i so that $\omega_{ij}^X(\mathcal{I}_i, \mathcal{I}_j) \in [0, 1]$ shows the access of region i 's exporters to the market of region j . The term $\omega_{ji}^M(\mathcal{I}_i, \mathcal{I}_j) \in [0, 1]$ on the other hand captures what access region i 's importers have to region j 's product. For ease of exposition, we will not include the information set arguments, \mathcal{I}_i and \mathcal{I}_j , in the remaining analysis.

Utility maximization by region j consumers subject to the budget constraint in (11) yields the following demand for region i 's goods if i has full access to j :

$$x_{ij} = \left(\frac{p_i t_{ij}}{P_j} \right)^{1-\sigma} y_j \quad (13)$$

where the price index in region j is defined as $P_j^{1-\sigma} \equiv \sum_l \omega_{lj}^M (p_l t_{lj})^{1-\sigma}$.

We can now use (13) to rewrite the market clearing condition (12) of region i as $y_i = p_i^{1-\sigma} \sum_j \omega_{ij}^X \left(\frac{t_{ij}}{P_j} \right)^{1-\sigma} y_j$ which can be used to solve for p_i . Using this solution in the demand equation in (13) yields the following gravity equation if i has full access to j :

$$x_{ij} = y_i y_j \frac{t_{ij}^{1-\sigma}}{\Omega_i P_j^{1-\sigma}} \quad (14)$$

where $\Omega_i \equiv \sum_j \omega_{ij}^X (t_{ij}/P_j)^{1-\sigma} y_j$.

Following Donaldson and Hornbeck (2016), we view Ω_i as a measure of “firm market access” since it measures the total world market for firms in region i , i.e. the sum of income in all potential markets in the information set discounted by the distance to these markets and the price level (the degree of competition) in these markets. $P_j^{1-\sigma}$, on the other hand, measures “consumer market access” since it consists of the weighted average price of all potential source regions of region i 's imports discounted by the distance to these markets.¹⁵ We also note that both firm and consumer market access increase when information frictions decrease, i.e. when ω_{ij}^X and ω_{ji}^M increase.

Rewriting (14) in logarithmic form yields

$$\log x_{ij} = (1 - \sigma) \log t_{ij} + \log y_i + \log y_j - \log \Omega_i - (1 - \sigma) \log P_j \quad (15)$$

¹⁵ Anderson and van Wincoop (2003) show that perfect information, i.e. $\omega_{ij}^X = \omega_{ji}^M = 1$ for all i and j , and symmetry in trade cost, $t_{ij} = t_{ji}$ leads to symmetry in the two “multilateral resistance terms” in the denominator, i.e. $\Omega_i = P_i^{1-\sigma}$. We are, however, unable to reach this degree of simplification due to the information frictions that cause information sets to differ across countries.

and the elasticity of exports from region i to region j is

$$\begin{aligned}\varepsilon_{x_{ij},t_{ij}} &\equiv \frac{\partial \log x_{ij}}{\partial \log t_{ij}} = 1 - \sigma - \frac{\partial \log \Omega_i}{\partial \log t_{ij}} \\ &= -(\sigma - 1)(1 - s_{ij}^X)\end{aligned}\quad (16)$$

where

$$s_{ij}^X \equiv \frac{\omega_{ij}^X (t_{ij}/P_j)^{1-\sigma} y_j}{\Omega_i(\mathcal{I}_i)} = \frac{\omega_{ij}^X x_{ij}}{\sum_j \omega_{ij}^X x_{ij}}$$

where the variable s_{ij}^X denotes j 's share of i 's total sales. We assume that Norwegian municipalities are sufficiently small not to affect foreign price levels (i.e. the share of a Norwegian municipality in a foreign country's import basket is close to zero, $s_{ij}^M \approx 0$), so that the derivative of $\partial \log P_j / \partial \log t_{ij}$ drops out in (16).

We denote the elasticity of imports of i 's good from j with respect to distance as $\varepsilon_{m_{ij},t_{ij}}$ where $m_{ij} \equiv x_{ji}$. As above we can derive the following expression:

$$\varepsilon_{m_{ij},t_{ij}} \equiv \frac{\partial \log x_{ji}}{\partial \log t_{ji}} = -(\sigma - 1)(1 - s_{ji}^M) \quad (17)$$

where

$$s_{ji}^M \equiv \frac{\omega_{ji}^M (p_j t_{ji})^{1-\sigma}}{P_i^{1-\sigma}} = \frac{\omega_{ji}^M x_{ji}}{\sum_j \omega_{ji}^M x_{ji}}$$

and the derivative of $\partial \log \Omega_j / \partial \log t_{ji}$ drops out by assuming that Norwegian municipalities are small enough not to affect the market access of foreign firms ($s_{ji}^X \approx 0$).

The relationship between trade and the destination market size follows a similar pattern. The export and import elasticities for this variable (ε_{x_{ij},y_j} and ε_{m_{ij},y_j}) are:

$$\begin{aligned}\varepsilon_{x_{ij},y_j} &\equiv \frac{\partial \log x_{ij}}{\partial \log y_j} = 1 - s_{ij}^X \\ \varepsilon_{m_{ij},y_j} &\equiv \frac{\partial \log x_{ji}}{\partial \log y_j} = 1 - s_{ji}^M.\end{aligned}$$

6.1.1 Comparative statics with regard to information frictions We first derive the total effect of a reduction in information frictions on trade. Summing the exports from i over all destinations k , we can also calculate the total exports and imports, x_i^X and x_i^M respectively, from municipality i :

$$\begin{aligned}x_i^X &= \sum_{j \neq i} \omega_{ij}^X x_{ij} = y_i (1 - s_{ii}^X). \\ x_i^M &= \sum_{j \neq i} \omega_{ji}^M x_{ji} = y_i (1 - s_{ii}^M).\end{aligned}$$

It is evident that both x_i^X and x_i^M increase when the information set of i increases, since both s_{ii}^X and s_{ii}^M decrease when the information set increases. More importantly for our empirical analysis, we now ask how a change in the information set changes the importance of distance and destination market size for bilateral trade flows.

We model information frictions as a restriction on the access to markets with which a region can trade, similar to how Arkolakis (2010) views the role of marketing to reach foreign consumers. Specifically, we assume that an increase in a country's information corresponds to an increase in ω_{ij}^X or ω_{ji}^M for at least one foreign region j , i.e. the access of firms or consumers in i to foreign markets. Consider first the magnitude of the elasticity of exports to distance in (16). There are two channels through which distance affects export volumes. First, there is a “direct effect” through t_{ij} in the numerator of (14) which is the effect that most estimates of the gravity model capture. The direct effect, however, is mitigated by a second “indirect effect” coming from the firm market access Ω_i in the denominator of (14). The indirect effect, however, decreases in relative magnitude as information frictions are reduced (the importance of a single export destination j , s_{ij}^X , is reduced when i can export to more destinations). We summarize this and the analogous effect on the elasticity with respect to destination size, y_j , in the following proposition.

Proposition 1. *The elasticities of exports with respect to distance and destination market size increase in magnitude when the exporter's export information set expands.*

Proof. If $\mathcal{J}_i \subseteq \tilde{\mathcal{J}}_i$, then

$$\begin{aligned} \varepsilon_{x_{ij}, t_{ij}}(\tilde{\mathcal{J}}_i) - \varepsilon_{x_{ij}, t_{ij}}(\mathcal{J}_i) &= -(\sigma - 1)(s_{ij}^X(\mathcal{J}_i) - s_{ij}^X(\tilde{\mathcal{J}}_i)) \\ &= -(\sigma - 1)s_{ij}^X(\mathcal{J}_i) \frac{\Omega_i(\tilde{\mathcal{J}}_i) - \Omega_i(\mathcal{J}_i)}{\Omega_i(\tilde{\mathcal{J}}_i)} \\ &= -(\sigma - 1)s_{ij}^X(\mathcal{J}_i) \sum_{l \in \tilde{\mathcal{J}} / \mathcal{J}} s_{il}^X(\tilde{\mathcal{J}}_i) \leq 0 \\ \varepsilon_{x_{ij}, y_j}(\tilde{\mathcal{J}}_i) - \varepsilon_{x_{ij}, y_j}(\mathcal{J}_i) &= s_{ij}^X(\mathcal{J}_i) \sum_{l \in \tilde{\mathcal{J}} / \mathcal{J}} s_{il}^X(\tilde{\mathcal{J}}_i) \geq 0. \end{aligned}$$

□

The direct effect of distance captures that region i 's goods become more expensive in region j as the trade cost between i and j increases. This lowers the demand for region i 's goods in j . However, an increase in trade costs between the two countries decreases firm market access for i 's firms (the denominator in the gravity equation in equation (14) decreases). This additional effect mitigates the negative effect in the numerator. An example would be to imagine that Norway only exports to Denmark and Sweden. Increasing export costs from Norway to Sweden makes Norwegian goods more expensive

in Sweden and exports would decrease because of the direct effect. However, the drop in aggregate demand for Norwegian goods forces Norway to lower the price of its good. The reduction in price raises demand in Norway and Denmark but also in Sweden. This is the indirect effect that mitigates the direct effect. The example also shows why the indirect effect is smaller the larger is the exporter's information set. The smaller share of Norway's total exports that Sweden represents the less Norway has to lower the price of its good to eliminate the excess supply caused by the drop in demand in Sweden, since there are more alternative export markets where demand responds when the price is reduced. In the extreme, when information frictions go to zero and the number of possible export destinations increases, the effect of distance to a single destination will have no effect at all on the denominator. In this case, the absolute level of the elasticity of export volumes with respect to distance will approach the direct effect $(\sigma - 1)$.

Analyzing the elasticity of imports to distance as shown in (17) follows a similar logic. There is a direct effect from t_{ji} in (14) and a mitigating indirect effect from the price level P_j in the denominator. As with exports, the indirect effect decreases in magnitude when the import information set of region i increases.

Proposition 2. *The elasticities of imports with respect to distance and source market size increase in magnitude when the importers's import information set expands.*

Proof. If $\mathcal{J}_i \subseteq \tilde{\mathcal{J}}_i$, then

$$\begin{aligned} \varepsilon_{m_{ij}, t_{ij}}(\tilde{\mathcal{J}}_i) - \varepsilon_{m_{ij}, t_{ij}}(\mathcal{J}_i) &= -(\sigma - 1)(s_{ji}^M(\mathcal{J}_i) - s_{ji}^M(\tilde{\mathcal{J}}_i)) \\ &= -(\sigma - 1)s_{ji}^M(\mathcal{J}_i) \frac{P_i(\tilde{\mathcal{J}}_i)^{1-\sigma} - P_i(\mathcal{J}_i)^{1-\sigma}}{P_i(\tilde{\mathcal{J}}_i)^{1-\sigma}} \\ &= -(\sigma - 1)s_{ji}^M(\mathcal{J}_i) \sum_{l \in \tilde{\mathcal{J}}/\mathcal{J}} s_{li}^M(\tilde{\mathcal{J}}_i) \leq 0 \\ \varepsilon_{m_{ij}, y_j}(\tilde{\mathcal{J}}_i) - \varepsilon_{m_{ij}, y_j}(\mathcal{J}_i) &= s_{ji}^M(\mathcal{J}_i) \sum_{l \in \tilde{\mathcal{J}}/\mathcal{J}} s_{li}^M(\tilde{\mathcal{J}}_i) \geq 0. \end{aligned}$$

□

The intuition for importing is isomorphic to the case of exporting. Consider again the example of Norway importing from only Denmark and Sweden. Raising the costs of importing Swedish goods to Norway makes Swedish goods more expensive in Norway and imports fall. This is the direct effect. However, the increase in trade costs between Norway and Sweden also has an indirect effect, it increases the price index in Norway which makes it easier for any country, including Sweden, to export to Norway (the consumer market access of Norway falls). The indirect effect therefore mitigates the direct effect.

Information frictions matter because the impact of a single country's distance to Norway matters less the more importing sources (less information frictions) that Norway has.

In Appendix C we show that the predictions in Propositions 1 and 2 hold also when using alternative microeconomic foundations for the gravity model, such as those suggested by Krugman (1980) and Eaton and Kortum (2002). Our findings hold also for competitive settings not normally used to derive the gravity model. As is shown by Freund and Weinhold (2004), for example, competition and the magnitude of price elasticities in a Cournot model increase in the number of trading partners a country has. Melitz and Ottaviano (2008) show that the same relationship between price elasticities and market size holds also for models based on quasilinear demand. Since distance is an important variable cost entering into prices, Freund and Weinhold (2004) and Melitz and Ottaviano (2008) therefore imply that the magnitude of the elasticity of international trade to distance increases also under these assumptions on the underlying economic structure.

6.1.2 Product information content Our model therefore produces two key predictions, in line with the results: technological change reducing information frictions should increase the magnitudes of the elasticities of trade with respect to distance and destination market size. A corollary is that the changes in these elasticities should be less pronounced for products for which information costs are more salient.

The analysis of Rauch (1999) suggests that information frictions are more important for trade in differentiated goods than for trade in homogenous goods. We would therefore expect heterogeneity in the consequences of broadband internet across these types of goods. To examine this, we match our data with the product classification from Rauch (1999) and estimate our baseline regressions separately for homogenous and differentiated goods. Table 7 shows larger increases in the magnitudes of the elasticities of trade with respect to distance and destination market size for differentiated goods as compared to homogenous goods.

6.2 Alternative mechanisms

Although the comparative statics predictions are consistent with our empirical findings, several mechanisms outside our model could also explain why adoption of broadband internet increases the sensitivity of trade to distance.

One possible explanation is that the direct effect of internet on bilateral trade flows may be stronger for destination countries with similar language (see e.g. Blum and Goldfarb, 2006). No other country has Norwegian as its main language, but English proficiency in other countries may play an important role due to the knowledge of English among Norwegians. If countries close to Norway are on average more proficient in English than

Table 7. Gravity estimation, by product type – Trade volume (log)

	Homogenous (1)	Differentiated (2)
A. ITT		
$z_{it} \times \log(\tau_{NOR,jt})$	-0.053 (0.061)	-0.104 (0.035)
$z_{it} \times \log Y_{jt}$	0.002 (0.029)	0.086 (0.018)
B. SSIV		
$d_{it} \times \log(\tau_{NOR,jt})$	-0.078 (0.075)	-0.152 (0.045)
$d_{it} \times \log Y_{jt}$	0.003 (0.037)	0.125 (0.024)
Mean dep.var.	10.80	10.63
N	43,713	87,426
Pair FE	✓	✓

Note: All regressions include fixed effects for year and municipality-country-specific pairs. The sample period is 2001-2008. The sample consists of all municipality-country-year combinations where one trading partner is a Norwegian municipality and the other a country (not Norway) and where log value of trade is positive. Products have been divided into homogenous and differentiated according to the classification proposed in Rauch (1999). All reported standard errors are clustered at the municipality level.

countries further away, then this might be the reason why the internet generates more trade with countries closer than further away. We use the English Proficiency Index for 71 countries as measured by the language teaching firm Education First (EF) and include this as a control variable in our regressions, as well as this variable interacted with internet. Column (2) in Table 8 reports the results while column (1) repeats our baseline specification. We find that adding these controls barely moves the estimated coefficient on the interaction term between broadband and destination market size, whereas the estimated coefficient on the interaction term between broadband and distance does not change materially.

Another possibility is that the direct effect of internet on bilateral trade flows may be stronger if the destination countries themselves have high internet penetration (see e.g. the theory of two-sided markets of Rochet and Tirole, 2006). Empirically, countries closer to Norway tend to have higher internet penetration. To examine this mechanism, we use estimates from the World Bank on internet penetration and include this variable as well as its interaction with internet into our baseline regression. Column (3) in Table 8 shows that adding these controls does not substantially change the estimated coefficient on the interaction term between broadband and destination market size or the estimated coefficient on the interaction term between broadband and distance.

Table 8. Gravity estimation results, alternative mechanisms – Trade volume (log)

	Baseline	Destination	
		English	Internet
	(1)	(2)	(3)
A. ITT			
$z_{it} \times \log(\tau_{NOR,jt})$	-0.119 (0.035)	-0.143 (0.055)	-0.131 (0.039)
$z_{it} \times \log Y_{jt}$	0.064 (0.017)	0.070 (0.021)	0.073 (0.017)
B. SSIV			
$d_{it} \times \log(\tau_{NOR,jt})$	-0.171 (0.045)	-0.205 (0.070)	-0.193 (0.051)
$d_{it} \times \log Y_{jt}$	0.094 (0.022)	0.105 (0.028)	0.105 (0.021)
Mean dep.var.	10.96	11.18	10.97
N	97,646	73,274	97,207
Pair FE	✓	✓	✓

Note: All regressions include fixed effects for year and municipality-country-specific pairs. The sample period is 2001-2008. The sample consists of all municipality-country-year combinations where one trading partner is a Norwegian municipality and the other a country (not Norway) and where log value of trade is positive. Column (2) includes also English proficiency and its interaction with internet. Column (3) adds destination level internet usage and its interaction with internet. All reported standard errors are clustered at the municipality level.

7 Conclusion

Recent work suggests the patterns of international trade may be distorted because of information frictions. Little is known, however, about how advancements in information communication technology affect trade patterns. The goal of our paper was to analyze how and why the adoption of such technology affects bilateral trade flows.

The context of our study is the adoption of broadband internet in Norwegian firms over the period 2000-2008. We used panel data with information on Norwegian firms with regards to their production, technology, and trade. A public program with limited funding rolled out broadband access points, and provided plausibly exogenous variation in the availability and adoption of broadband internet in firms. We found that adoption of broadband internet makes trade patterns more sensitive to distance and economic size. Going from no broadband availability to full coverage increases the magnitude of the elasticity of trade with respect to distance by 0.12, and the elasticity of trade with respect to destination size by 0.06. For distance, this means that an increase in internet availability of 10 percentage points increases trade for a country at the 25th distance percentile by

1.1% more than for a country at the 75th distance percentile. The same difference for the GDP of a destination is 2.1%.

We interpreted the empirical results through a gravity theory of trade patterns, augmented with information frictions. We provided comparative statics predictions with respect to a reduction in information frictions, and showed that these predictions are consistent with our empirical findings. We also considered alternative mechanisms outside the model which, in principle, could also explain why adoption of broadband internet increases the sensitivity of trade to distance. However, the data are at odds with these alternative mechanisms.

Taken together, our results point to the importance of incorporating information frictions in the frequently used gravity equation of trade. Moreover, our study offers a possible explanation for the so-called “distance puzzle” which is that the magnitude of the distance coefficient in gravity equations has change little or increased over time, despite the significant advancements in globalization and ICT. We provided both theory and evidence suggesting that adoption of a technology that lowers information frictions actually increases the magnitude of the elasticity of trade with respect to distance.

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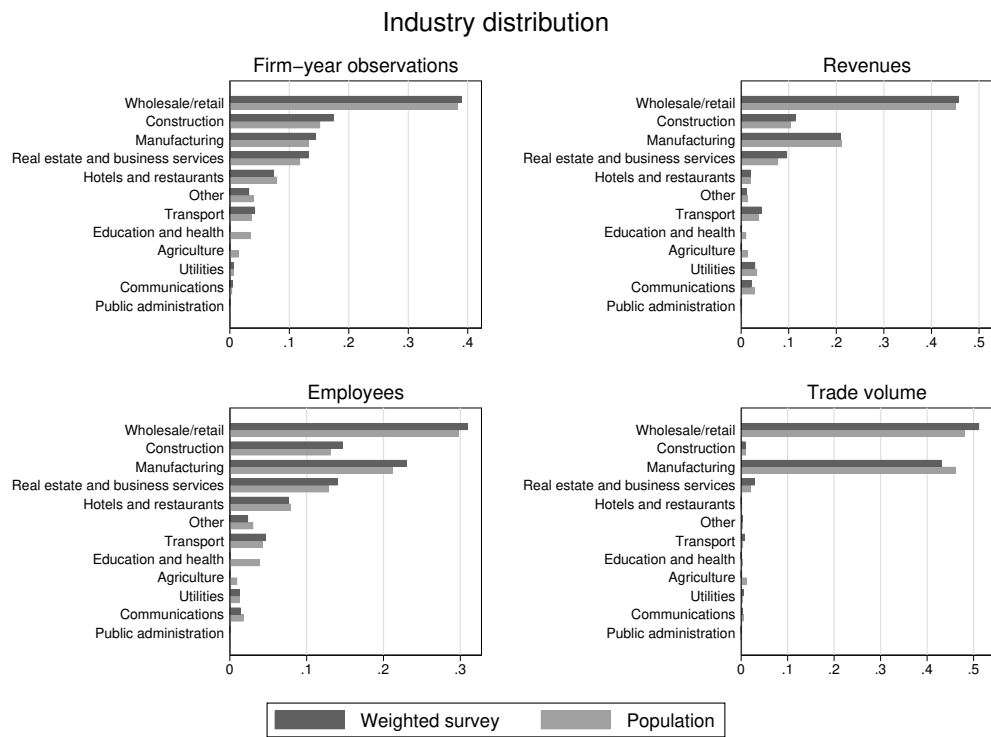
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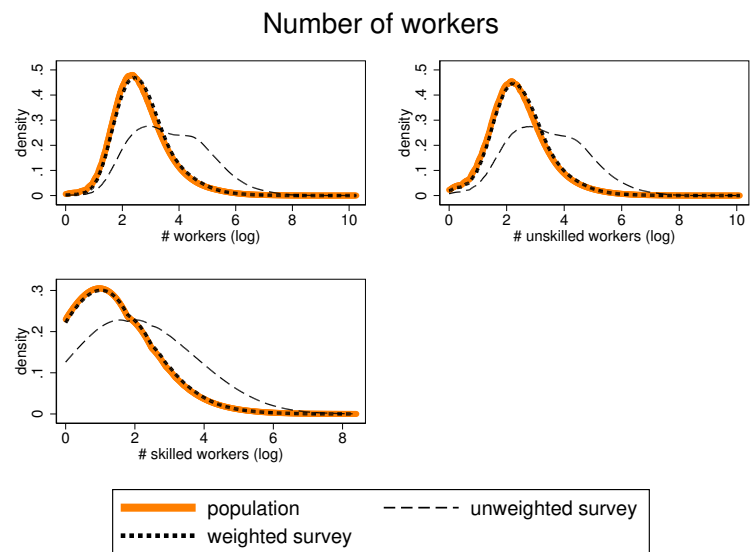
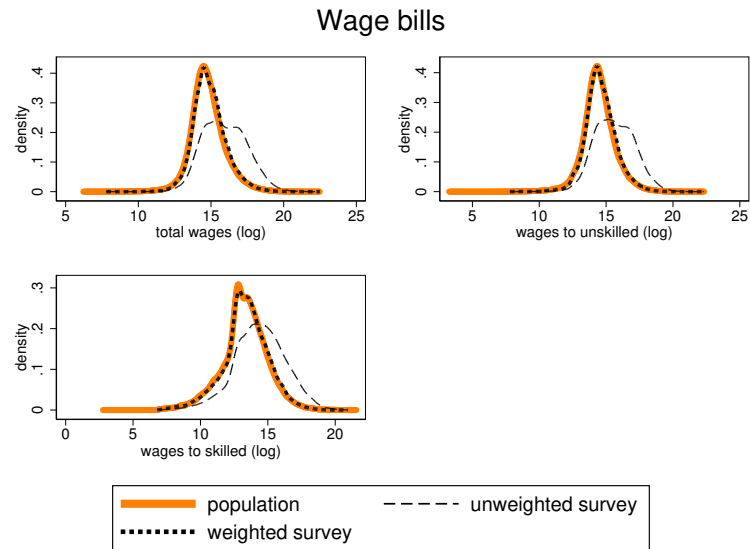
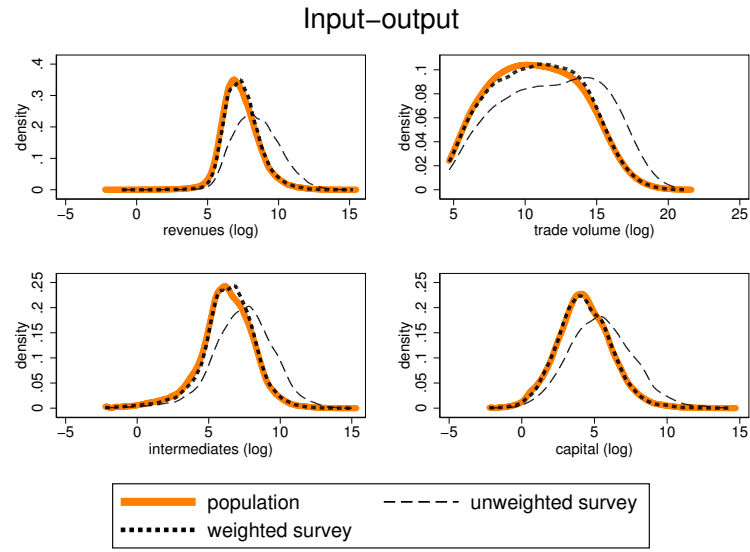
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Appendix A: Data and expansion



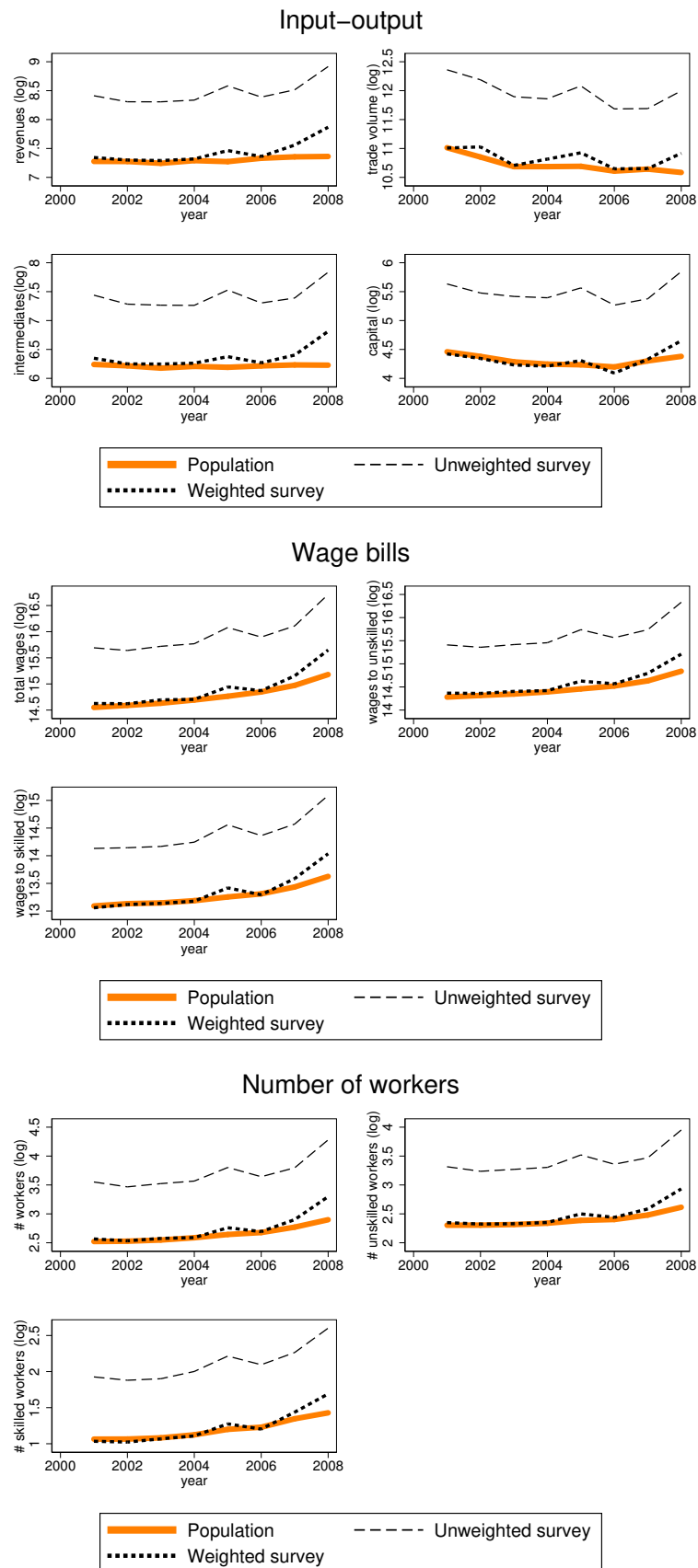
Note: The figure compares the weighted survey sample of joint-stock firms to the population of joint-stock firms.

Figure A.1. Distribution of firms by industry



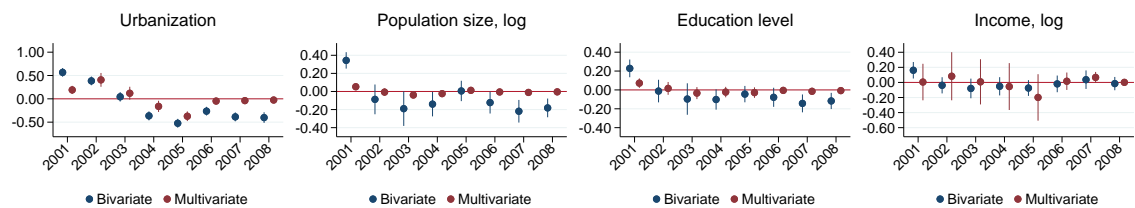
Note: The figures compare the weighted survey sample of joint-stock firms to the population of joint-stock firms. Detailed descriptions of the variables are given in Appendix Table A.1.

Figure A.2. Cross-sectional distribution of key firm variables

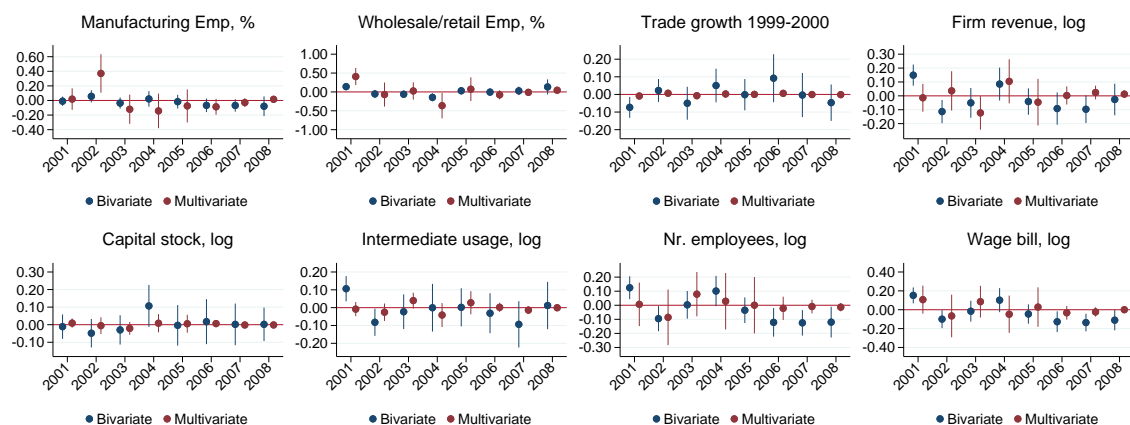


Note: The figures compare the weighted survey sample of joint-stock firms to the population of joint-stock firms. Detailed descriptions of the variables are given in Appendix Table A.1.

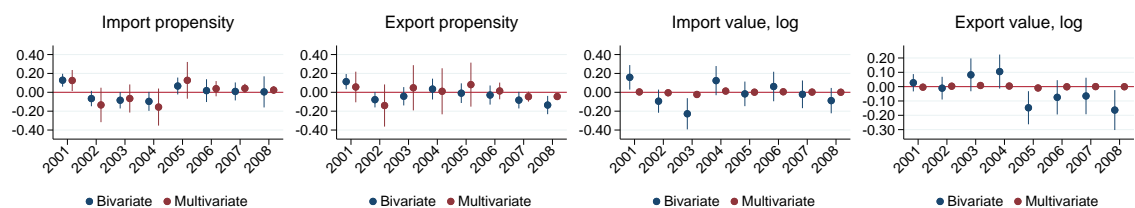
Figure A.3. Time trends in key firm variables



(a) Demography



(b) Industry structure



(c) Trade

Figure A.4. Expansion graphs

Table A.1. Variable definitions

Variable	Description
<i>Firm accounts</i>	Source: The Account Statistics.
Revenues	Total sales by a firm in year t .
Industry	4-digit code classifying a firm's main activity in year t according to the Nomenclature of Economic Activities (NACE2002) system.
Municipality	4-digit code for the municipality in which a firm is located in year t .
Export volume	Total value of exported goods of a firm in year t .
Import volume	Total value of imported goods of a firm in year t .
Trade volume	Total value of exported and imported goods of a firm in year t .
<i>Internet variables</i>	Source: The community survey on ICT in firms
Broadband	Dummy variable for whether a firm has adopted broadband internet (speed at or above 256 kilobits per second) in year t .
Share of workers using a PC	Share of workers that use a PC in a firm in year t .
<i>Individual characteristics</i>	Source: National Education Database and Central Population Register.
Education level	Years of schooling.
<i>Language</i>	Source: EF English Proficiency index, sixth edition (2016).
EF English Proficiency Index	A score of English proficiency in a country as reported by the language firm EF.
<i>Geography</i>	Source: CEPII (Centre d'Etudes Prospectives et d'Informations Internationales).
Distance	The distance between population weighted central points of Norway and another country as described in Mayer and Zignago (2011).
<i>Other country characteristics</i>	Source: World Development Indicators (World Bank).
GDP	The gross domestic product of a country
Internet usage	The share of people who have used the internet in the last 12 months.
<i>Product characteristics</i>	Source: Rauch (1999).
Homogenous	If a good is traded on an organized exchange or if it is reference priced
Differentiated	If a good is neither of the above.
<i>Internet availability</i>	Source: Norwegian Ministry of Government Administration.
Availability rate	Fraction of households in year t in a given municipality for which broadband internet is available, independently of whether they take it up.
<i>Demographics</i>	Source: Central Population Register.
Urbanization	Population share living in densely populated area in a given municipality in year t .
Income	Average annual disposable income across individuals aged 16–59 years in a given municipality in year t .
Education	Average years of schooling across individuals aged 16–59 in a given municipality in year t .
Unemployment	Unemployment rate among individuals aged 16–59 in a given municipality in year t .
<i>Industry and firm</i>	Source: The Account Statistics and Register of Employers and Employees.
Share of skilled workers	Share of employed workers with a college degree in a given municipality in year t .
Share of total wages to skilled workers	Share of the total wage bill paid to workers with a college degree in a given municipality in year t .
Share of employment by industry	Share of workers in the manufacturing/wholesale/service industry in a given municipality in year t .
Average input levels	Average level of capital stock/value added/number of workers/wages paid/revenues across firms in a given municipality in year t .

Appendix B: Sub-sample instrumental variable estimation

If we generically write the second stage as

$$y = X\beta + e$$

first-stage

$$X = Z\Pi + U$$

with corresponding reduced form

$$y = Z\gamma + v$$

Then we have

$$Z\gamma = Z\Pi\beta \Rightarrow \beta = (\Pi'Z'Z\Pi)^{-1}\Pi'Z'Z\gamma$$

which gives

$$\begin{aligned} d\beta &= d((\Pi'Z'Z\Pi)^{-1}) \cdot \Pi'Z'Z\gamma + (\Pi'Z'Z\Pi)^{-1} d(\Pi'Z'Z\gamma) \\ &= -(\Pi'Z'Z\Pi)^{-1} d(\Pi'Z'Z\Pi) \underbrace{(\Pi'Z'Z\Pi)^{-1}\Pi'Z'Z\gamma}_{\beta} + (\Pi'Z'Z\Pi)^{-1} d\Pi'Z'Z\gamma \\ &= -(\Pi'Z'Z\Pi)^{-1} d(\Pi'Z'Z\Pi)\beta + (\Pi'Z'Z\Pi)^{-1} d\Pi'Z'Z \cdot \gamma \end{aligned}$$

Now since

$$\begin{aligned} d(\Pi'Z'Z\Pi) &= d\Pi'Z'Z \cdot \Pi + \Pi'Z'Z d\Pi \\ \text{vec}(d(\Pi'Z'Z\Pi)) &= (\Pi'Z'Z \otimes I) d\text{vec}\Pi' + (I \otimes \Pi'Z'Z) d\text{vec}\Pi \end{aligned}$$

we obtain

$$\begin{aligned} d\beta &= \text{vec}(d\beta) = \text{vec}(-(\Pi'Z'Z\Pi)^{-1} d(\Pi'Z'Z\Pi)\beta + (\Pi'Z'Z\Pi)^{-1} d\Pi'Z'Z\gamma) \\ &= \text{vec}(-(\Pi'Z'Z\Pi)^{-1} d(\Pi'Z'Z\Pi)\beta) + \text{vec}((\Pi'Z'Z\Pi)^{-1} d\Pi'Z'Z\gamma) \\ &= -(\beta' \otimes (\Pi'Z'Z\Pi)^{-1}) \text{vec}(d(\Pi'Z'Z\Pi)) + (\gamma' \otimes (\Pi'Z'Z\Pi)^{-1}) \text{vec}(d\Pi') \\ &= -(\beta' \otimes (\Pi'Z'Z\Pi)^{-1}) ((\Pi'Z'Z \otimes I) d\text{vec}\Pi' + (I \otimes \Pi'Z'Z) \cdot d\text{vec}\Pi) \\ &\quad + (\gamma' \otimes (\Pi'Z'Z\Pi)^{-1}) d\text{vec}\Pi' \\ &= -\underbrace{(\beta'\Pi')_{\gamma'}}_{\gamma'} \otimes (\Pi'Z'Z\Pi)^{-1} d\text{vec}\Pi' - (\beta' \otimes (\Pi'Z'Z\Pi)^{-1} \Pi'Z'Z) d\text{vec}\Pi \\ &\quad + (\gamma' \otimes (\Pi'Z'Z\Pi)^{-1}) d\text{vec}\Pi' \\ &= -(\beta' \otimes (\Pi'Z'Z\Pi)^{-1} \Pi'Z'Z) d\text{vec}\Pi \end{aligned}$$

which gives

$$d\beta/d\text{vec}\Pi = -(\beta' \otimes (\Pi'Z'Z\Pi)^{-1}\Pi'Z'Z)$$

We furthermore have

$$d\beta/d\gamma = (\Pi'Z'Z\Pi)^{-1}\Pi'Z'Z$$

We use these results to construct the covariance matrix of $\hat{\beta}$ using the Delta method. In a first step we directly get the covariance matrices of $\hat{\Pi}_k$ and $\hat{\gamma}$ from our OLS estimation. Let

$$\hat{\eta} = \begin{pmatrix} \text{vec}\hat{\Pi} \\ \hat{\gamma} \end{pmatrix} = \eta + (I_{K+1} \otimes (Z'Z)^{-1})Z'\xi$$

where

$$\xi = \begin{pmatrix} \text{vec}U \\ v \end{pmatrix}$$

then

$$\text{Var}(\hat{\eta}) = (I_{K+1} \otimes E[Z'Z]^{-1})E[Z'\xi\xi'Z](I_{K+1} \otimes E[Z'Z]^{-1})$$

and $E[Z'\xi\xi'Z]$ is obtained using the estimated residuals $\hat{\xi}$ and standard covariance matrix estimation using the method of moments. The final covariance matrix of $\hat{\beta}$ using the Delta method can then be computed as follows

$$V(\beta) = (\partial\beta/\partial\eta)'V(\hat{\eta})(\partial\beta/\partial\eta).$$

Appendix C: Alternative theoretical settings

In this appendix we show that Propositions 1 and 2 hold also under the assumptions of Krugman (1980) and Eaton and Kortum (2002).

Krugman (1980)

Consumer preferences are characterized by equation (10). There are no endowments, however, and production is modeled explicitly and characterized by the following technology:

$$l_k = \alpha + \beta q_k$$

where l_k is the labor used to produce q_k units of output in firm k and β is a scalar. We know that firms facing CES demand with an elasticity of substitution of σ will set a markup of $\frac{\sigma}{\sigma-1}$ over its marginal cost. This means that the price of firm k will be $p_k = \frac{\sigma}{\sigma-1}\beta w$ where w is the wage rate that firm k faces. Firm k 's profits will therefore be

$$\pi_k = p_k q_k - w(\alpha + \beta q_k)$$

meaning that in equilibrium where profits are zero we also have that the optimal size of a firm k is $x_k = (\sigma - 1)\alpha\beta^{-1}$. The number of varieties in a country with L workers is therefore $n = L\beta / (\alpha(\sigma - 1))$. Symmetry in technology across firms means that output is the same across firms such that $q = q_k$ for all k . We will instead let x_{ij} denote sales in country j of a representative firm in country i .

We know that preferences as in equation (10) yields the following demand in a country j for a product from country i

$$x_{ij} = \left(\frac{p_i t_{ij}}{P_j} \right)^{1-\sigma} y_j$$

where $P_j(\mathcal{J}_j)^{1-\sigma} \equiv \sum_l \omega_{lj}^M n_l (p_l t_{lj})^{1-\sigma} = \beta / (\alpha(\sigma - 1)) \sum_l \omega_{lj}^M L_l (p_l t_{lj})^{1-\sigma}$.

Equation (12) then yields

$$\begin{aligned} y_i &= \sum_j \omega_{ij}^X x_{ij} \\ &= \sum_j \omega_{ij}^X \left(\frac{p_i t_{ij}}{P_j} \right)^{1-\sigma} y_j \end{aligned}$$

which yields a solution for $p_i^{1-\sigma}$ which we then plug back into the demand equation which

yields

$$x_{ij} = y_i y_j \frac{t_{ij}^{1-\sigma}}{\Omega_i P_j^{1-\sigma}} \quad (18)$$

where again $\Omega_i \equiv \sum_j \omega_{ij}^X (t_{ij}/P_j)^{1-\sigma} y_j$.

Equation (18) shows that replacing the endowment assumption with that of production following an increasing returns technology, as in Krugman (1980), does not alter any of the conclusions. Propositions 1 and 2 hold. The key difference in the intuitive interpretation of the model is that instead of the price of the endowed good changing as a consequence of an increase in the trade cost, it is now the wage in a country that changes. This is because the wage is the only factor that determines the nominal price in Krugman (1980). When a trade cost between i and j raises the cost and lowers the demand of i 's goods in j , the excess supply of country i 's goods lower the nominal wage in i and therefore also the nominal price of its goods which reestablishes the global equilibrium in the demand for country i 's goods. The drop in country i 's wages is therefore also what leads to the indirect effect through the denominator that leads to variability in the elasticities of trade to distance and destination size.

Eaton and Kortum (2002)

Consumer preferences are characterized by equation (10). Again, there are no endowments and production of good k in country i is now conducted with a constant marginal cost of $c_i/z_i(k)$ where c_i is a country-wide parameter and $z_i(\cdot)$ is a country-specific distribution of productivity across goods k . There are iceberg trade costs of $t \geq 1$ between any countries i and j . Perfect competition ensures that prices are equal to unit costs:

$$p_{ij}(k) = \frac{c_i t_{ij}}{z_i(k)}.$$

All countries can produce good k but consumers search for the lowest price source such that $p_j(k) = \min \{p_{ij}(k) \text{ for all } i \text{ where } \omega_{ij}^X = 1\}$. Here we will only allow ω_{ij}^X to take the values 0 or 1 for all i and j . The technology governing the distribution of the productivity $z_i(k)$ follows a Fréchet distribution $F_i(z) = e^{-T_i z^{-\theta}}$ where $T_i > 0$ and $\theta > 1$. It follows from this that the distribution of prices offered by country i to country j is

$$G_{ij}(p) = 1 - e^{-T_i (c_i t_{ij})^{-\theta} p^\theta}. \quad (19)$$

The distribution of prices for what country j actually buys is therefore $G_j(p) =$

$1 - \prod_{i:\omega_{ij}^X=1} [1 - G_{ij}(p)]$ and using equation (19) gives

$$G_j(p) = 1 - e^{-\Phi_j p^\theta}$$

where $\Phi_j = \sum_{i:\omega_{ij}^X=1} T_i (c_i t_{ij})^{-\theta}$.

The probability that country i provides a good at the lowest price in country j is

$$\begin{aligned} \pi_{ij} &= \Pr [P_{ij}(k) \leq \min \{P_{sj}(k); s \neq j, \omega_{sj}^X = 1\}] \\ &= \int_0^\infty \prod_{s:s \neq j, \omega_{sj}^X=1} [1 - G_{sj}(p)] dG_{ij}(p) \\ &= \frac{T_i (c_i t_{ij})^{-\theta}}{\Phi_j}. \end{aligned}$$

The fraction of country j 's expenditure that is spent on goods from country i must then also be

$$\frac{x_{ij}}{y_j} = \frac{T_i (c_i t_{ij})^{-\theta}}{\sum_{s:\omega_{sj}^X=1} T_s (c_s t_{sj})^{-\theta}}. \quad (20)$$

Noting that the exporter's total sales, $y_i = \sum_{j:\omega_{ij}^X=1} x_{ij} = T_i c_i^{-\theta} \sum_{j:\omega_{ij}^X=1} \frac{t_{ij}^{-\theta}}{\Phi_j} x_{ij}$ and solving for $T_i c_i^{-\theta}$ and substituting this into equation (20) gives a gravity equation:

$$x_{ij} = \frac{t_{ij}^{-\theta}}{\Omega_i P_j^{-\theta}} y_i y_j$$

where $\Omega_i \equiv \sum_{l:\omega_{il}^X=1} \left(\frac{t_{il}}{P_l} \right)^{-\theta} y_l$ and $P_j \equiv \gamma \Phi_j^{-1/\theta}$ (where $\gamma \equiv [\Gamma(\frac{\theta+1-\sigma}{\theta})]^{1/(1-\sigma)}$ and Γ is the Gamma function).

Although the underlying supply structure is very different, we still arrive at gravity equation similar to the ones in the Anderson and van Wincoop (2003) and Krugman (1980) settings. This means that also here there is a direct effect from the numerator and an indirect effect from the denominator when trade costs increase. The indirect effect is smaller when the information set is larger because this makes any market constitute a smaller share of Ω_i . Propositions 1 and 2 therefore hold.