Roadways, Input Sourcing, and Patterns of Specialization*

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September 2018

Abstract

We propose a model where the internal transport network facilitates the sourcing of intermediate goods from different locations. A denser internal transport network promotes thus the growth of industries that rely on a large variety of inputs. The model shows that heterogeneities in internal transport infrastructures can become a key factor in shaping comparative advantage and specialization. Moreover, when sufficiently pronounced, such heterogeneities may even overshadow more traditional sources of specialization based on factor productivities. Evidence based on industry-level trade data grants support to the main prediction of the model: countries with denser road networks export relatively more in industries that exhibit broader input bases. We show that this correlation is robust to several possible confounding effects proposed by the literature, such as the impact of institutions on specialization in complex goods. Furthermore, we show that a similar correlation arises as well when the density of the local transport network is measured by the density of their internal waterways, and also when road density is instrumented with measures of terrain roughness.

Keywords: International Trade, Comparative Advantage, Internal Transportation Costs.

JEL Classifications: F11, O18, R12

*I would like to thank Facundo Albornoz, Ainhoa Aparicio-Fenoll, Holger Breinlich, Giovanni Mastrobuoni, Vincenzo Merella and Ignacio Monzon, as well as seminar participants at the Collegio Carlo Alberto, University of Nottingham, University of Stirling, and University of Surrey for comments and suggestions.

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1 Introduction

The spatial distribution of economic activities means that transportation costs represent a major factor influencing countries' output, trade flows and specialization. Apart from few exceptions, the vast majority of the past trade literature has centered their attention on the cost of shipping goods internationally.[1] However, the evidence at hand suggests that internal transport costs are far from being a secondary component that can be disregarded when confronted with transboundary costs.[2] Furthermore, the impact of internal transport costs on specialization gets magnified by the fact that local infrastructures differ quite substantially between countries, especially when comparing economies at different stages of development.

Being able to efficiently transport commodities across space is crucial to keep total costs low. Yet, owing to specificities of their physical characteristics and of their production processes, some commodities turn out to be inherently more transport-intensive than others. This means that the efficiency of the local transportation infrastructure may unevenly affect the development of different industries. This paper studies a specific channel by which the internal transport network may shape countries' comparative advantages and specialization. One key role of the internal transportation network is that it facilitates the sourcing of intermediate inputs from different locations. As a result, industries that require a large variety of intermediate inputs tend to make more intense use of the network.[3]

To illustrate this idea, we introduce a simple model with two intermediate inputs and a continuum of final good producers. A denser road network allows cheaper transportation of the intermediate inputs to the location site of final good producers. A crucial feature of the model is that industries producing final goods differ in terms of the breadth of their intermediate input requirements. In particular, some industries have production functions that are very intensive in only one intermediate input, while others require a more balanced mix of the two intermediate inputs. Since transportation of inputs is costly, those industries that require a relatively balanced combination of the intermediate inputs turn out to benefit relatively more (in terms of cost reduction) from a denser road network.

[1] For a few papers that have incorporated internal transport costs into trade models, see Allen and Arkolakis (2014), Coşar and Fajgelbaum (2016), Ramondo, Rodriguez-Clare and Saborio-Rodriguez (2016), Redding (2016), Matsuyama (2017).

[2] See, e.g., Limao and Venables (2001), Anderson and Van Wincoop (2004), Hillberry and Hummels (2008), Mesquita Moreira *et al* (2013), Agnosteva *et al* (2014), Atkin and Donaldson (2015), Donaldson (2018).

[3] This idea was first suggested by Clague (1991a, 1991b) who argued that countries with poor infrastructure will specialize in 'self-contained' sectors (i.e., sectors that do not intensively rely on inputs from other sectors).

This simple mechanism yields a very clear prediction in terms of specialization within a framework with open economies. Countries that enjoy a denser local transport network tend to display a comparative advantage in the goods whose production process requires a relatively balanced mix of the intermediate inputs. This is because these are the industries that make heavier use of the local transport network to source their inputs. Conversely, countries with underdeveloped transport networks tend to specialize in industries with narrow input bases, as this allows them to economize on input sourcing.

After presenting the model we provide evidence consistent with its main prediction. To do so, we proceed as follows. Firstly, we index industries by their degree of input breadth using the information contained in the US input-output matrix. Secondly, we measure the density of local transport networks of countries by the length of their roadways per square kilometer. Finally, we correlate countries specialization by industries (measured by their total exports at the industry level) with an interaction term between industries' input breadth and countries' roadways density. We find that countries with denser road networks export relatively more in industries that exhibit broader input bases.

The correlation between road density and specialization in industries with broader input bases may obviously be driven by other mechanisms to the one suggested by our model. We show however that this correlation is robust to the inclusion of a large set of possible confounding covariates. In particular, one important channel related to ours works through institutions, as industries that rely on a wide set of inputs tend to be more dependent on contract enforcement [Levchenko (2007) and Nunn (2007)]. We show that the correlation predicted by our model is still present once we also control for the effect of institutions. In that respect, our findings complement the previous studies that have interpreted the degree of input variety as a sign of product complexity, showing that industries with wide input bases seem also to be strongly reliant on the internal transport network.

One additional concern is whether the found correlation can be interpreted at all as evidence of *causation* from road density to specialization in transport-intensive industries. Roadways are the result of investment choices. Hence, road infrastructure may positively respond to transport needs resulting from patterns of specialization, reversing thus the direction of causation. Interestingly, we show that an analogous correlation to that one found with road density arises when using *waterways* density as an alternative measure of the depth of the local transport network. Moreover, this correlation is especially strong and significant in the case lower-income countries, which are exactly the types of economies that tend to suffer from sparser road networks.

Arguably, while waterways cannot be molded and expanded as flexibly as road networks, and hence they are less sensitive to issues of reverse causation, their evidence does not directly address this concern. In order to address more directly the possibility that reverse causality is behind our empirical results, drawing on Ramcharan (2009), we also instrument the density of a country's road network with topographical measures of terrain roughness.[4] The instrumental variable approach confirms the previous findings, granting further support to the hypothesis that the density of the internal road network is an important determinant of comparative advantage in industries with wide input bases.

There is a growing literature studying the impact of the local transport infrastructure on international and intra-regional trade and specialization. For example, Volpe Martincus and Blyde (2013) study the access to foreign markets and international trade across regions in Chile, Coşar and Demir (2016) does so for Turkey, and Volpe Martincus, Carballo and Cusolito (2017) for Peru. Donaldson (2018) looked at reductions of price and output distortions across Indian regions after expansions of the local railroad network, and Donaldson and Hornbeck (2016) assess how the expansion of the railroad network in the US enhanced market access of US counties. Fajgelbaum and Redding (2014) and Coşar and Fajgelbaum (2016) investigate the regional location of export-oriented activities given the local infrastructure in the cases of Argentina and China, respectively. Closer to our main focus, Duranton, Morrow and Turner (2014) and Coşar and Demir (2016) have tried to capture whether there is some effect of road infrastructure on specialization in transport-intensive activities. Duranton *et al* (2014) show that US cities with more highways tend to produce goods of higher weight per physical unit, while Coşar and Demir (2016) find a similar effect for Turkey. Our paper focuses on a different channel whereby the local transport infrastructure impacts comparative advantages: the notion that the spatial distribution of activities makes industries that need to source a large variety of intermediate inputs relatively more reliant on the internal transport network.

The internal transportation channel studied in this paper was first suggested by Clague (1991a, 1991b). There it is argued that poorer economies specialize in 'self-contained' sectors, as they lack a sufficiently developed infrastructure needed to sustain the production of industries that require a large variety of inputs. These articles, however, do not articulate this hypothesis within an international trade model, nor do they empirically assess whether trade flows at the industry level are associated with actual measures of the internal transport network in a way consistent with it.[5] We formulate the hypothesis that the local transport infrastructure

[4] Ramcharan (2009) shows that countries with rougher topography tend to exhibit less dense road networks. He argues that this is partly due to the impact of terrain roughness and grade variation on the cost of building and maintenance of transport networks.

[5] These articles provide evidence that the relative efficiency of underdeveloped economies is worse in industries

matters relatively more for industries with wider input bases within a trade model, where transport costs, location choices and comparative advantage are explicitly modeled. This leads to an endogenous determination of trade flows and specialization patterns, which respond to heterogeneities in transport infrastructures. In addition, we present evidence supporting the relevance of this mechanism exploiting cross-country variation in the density of road networks.[6]

Finally, our paper also relates to several strands of literature that have expanded upon the traditional Ricardian/Heckscher-Ohlin trade models based on heterogeneities in factor productivities/endowments. One set of papers have looked at enforcement institutions as a source of comparative advantage in industries producing complex goods requiring large variety of input-specific relationships [Antràs (2005), Acemoglu, Antràs and Helpman (2007), Levchenko (2007), Nunn (2007), Costinot (2009), Ferguson and Formai (2013)]. Another strand of literature has delved into the role of financial markets fostering exports in industries that are heavy users of external finance [Beck (2002), Svaleryd and Vlachos (2005), Becker, Chen and Greenberg (2012), Manova (2013)]. Finally, another institutional source of comparative advantage is presented by Cuñat and Melitz (2012), who show that countries with more flexible labor market regulations tend to export more in industries subject to higher volatility.[7] Our paper highlights the impact of local infrastructures when industries differ in their dependence on internal transportation of inputs.

The rest of the paper is organised as follows. Section 2 introduces the main features of the model in the case of a closed economy. Section 3 extends the model to a two-country setup, and derives the main predictions in terms of comparative advantage and trade flows. Section 4 contrasts the main predictions of the model with the data. Section 5 discusses some endogeneity issues and alternative interpretations of the empirical results. Section 6 discusses the empirical plausibility some of the key assumptions implicit in the model in terms of geographic distribution of industries. Section 7 concludes.

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that rely on a large variety of intermediate inputs. While this could be the result of poorer economies having less developed transport networks, it could also be the result of other factors usually associated with underdeveloped economies, like weaker institutions, lower levels of human capital, etc.

[6]Yeaple and Golub (2007) show that the stock of roads affects total factor productivity and sectoral composition across 10 industries for a panel of 18 countries. While their analysis highlights that roads may be a source of comparative advantage in some industries, it does not link the effect of heterogeneities in transport infrastructures to specialization in industries with different degrees of input diversity.

[7]See Chor (2010) for a paper that aims at quantifying the importance of all these institutional sources of comparative advantage, alongside the more traditional ones stemming from heterogeneities in factor productivities and endowments.

2 General Setup in a Closed Economy Model

This section presents the environment and main features of our model in the specific case of a closed economy. Starting off with a closed economy proves helpful in two aspects. First, it allows an easier description of the main building blocks of the model. Second, it facilitates the exposition of the main intuition for how the density of the transport network may heterogeneously affect the cost of production in different sectors.

2.1 Intermediate and Final Goods Sector

There exists a unit continuum of final goods, indexed by $j \in [0,1]$. All final good markets are perfectly competitive. Final goods are purchased by individuals with preferences given by

$$U = \int_0^1 \ln(y_j)\, dj, \tag{1}$$

where y_j denotes the consumed amount of j. There is a mass of individuals equal to L. Each individual is endowed with one unit of labor which is supplied inelastically for a wage w.

In addition to the set of final goods, there exist two intermediate goods, indexed by $i = 0, 1$. There is free entry to the markets of both intermediate goods. Each intermediate good is produced with labor, according to the following linear production functions:

$$X_i = \frac{L_i}{1+\varepsilon_i}, \qquad i = 0, 1. \tag{2}$$

In (2), X_i denotes the total amount of intermediate good i produced in the economy, L_i is the total amount of labor used in producing i, and $\varepsilon_i \geq 0$ is a technological parameter determining labor productivity in sector i.[8]

Final goods are produced by combining the two intermediate goods within Cobb-Douglas production functions. Total output of final good $j \in [0,1]$ is given by:

$$Y_j = \frac{1}{\alpha_j^{\alpha_j}(1-\alpha_j)^{1-\alpha_j}}\, X_{0,j}^{1-\alpha_j}\, X_{1,j}^{\alpha_j}, \qquad \text{where } \alpha_j \in [0,1], \tag{3}$$

and $X_{0,j}$ and $X_{1,j}$ denote the amount of intermediate good 0 and 1 used in the production of final good j, respectively.

The Cobb-Douglas production functions (3) differ across final good sectors in terms of the intensity requirements of each intermediate good. Sectors with a small (resp. large) α_j use

[8]The model can be generalized to comprise N different intermediate goods. Appendix D briefly presents an example with three intermediate goods.

input 0 (resp. input 1) more intensively. On the other hand, sectors whose α_j lies in the vicinity of 0.5 tend to use a relatively balanced mix of both inputs. For the rest of the paper, we will assume that, when considering the whole set of final good producers, the values of α_j are uniformly distributed within the unit interval. Abusing a bit the notation, we can thus henceforth index final goods by their value of α_j.[9]

Perfect competition in final good markets implies that, in equilibrium, each final good j will be sold at a price equal to its marginal cost. Using (3), we can obtain the expression for the marginal cost, which we denote by c_j. Namely,

$$c_j = p_{0,j}^{1-\alpha_j}\, p_{1,j}^{\alpha_j}, \tag{4}$$

where $p_{0,j}$ and $p_{1,j}$ are the prices at which the producer of final good j can purchase each unit of input 0 and 1, respectively.[10]

2.2 Geographic Structure of the Economy

We assume that each intermediate good is produced in a different site, which we refer to as location 0 (for input 0) and location 1 (for input 1). Labor is perfectly mobile across locations at zero cost. Intermediate goods must, however, incur an iceberg transport cost to be moved around. When the distance between the location of j and that of i is $d_{j,i} \geq 0$, the intermediate good producer i must ship $1 + t\, d_{j,i}$ units of input i in order for the final good producer j to receive one unit of i.[11]

There exists a road network of length r linking location 0 and location 1. We assume that the shortest distance between location 0 and 1 is given by a function $\varphi(r)$, with $\varphi'(r) < 0$. That is, we assume that longer road networks facilitate transportation across location 0 and

[9] None of the main results in the model strictly depend on the Cobb-Douglas specification, and we could alternatively use a more general CES production function, where: $Y_j = [(1-\alpha_j)\, X_{0,j}^{\rho} + \alpha_j\, X_{1,j}^{\rho}]^{1/\rho}$, with $\alpha_j \in [0,1]$ and $\rho < 1$. Notice that this excludes the trivial case of a linear production function in $X_{0,j}$ and $X_{1,j}$ (i.e., $\rho = 1$), as this would imply perfect substitutability between the inputs. Appendix D shows how the main results in this section remain true with a general CES function. In the end, the choice of (3) is essentially owing to its algebraic neatness. In addition, in the Cobb-Douglas case, the weights α_j and $1-\alpha_j$ carry a very clear interpretation: they are always equal to the share of each intermediate input over the total cost of intermediates.

[10] Although we are assuming that there is free entry in the intermediate goods sectors, in principle, our model will not always lead to the same price paid by each final good producer j for each of the inputs. The reason for this is that both $p_{0,j}$ and $p_{1,j}$ will also incorporate internal transport costs, and these costs may well differ across final good producers given their location and the locations of intermediate goods.

[11] Appendix D shows that all the main results of this section would remain essentially intact if we assumed that the transport cost on inputs is additive instead of multiplicative.

1 by shortening the distance between the two locations. In Appendix A, we provide a simple geographical structure of the economy as illustration of the function $\varphi(r)$ and the fact that is strictly decreasing in r.

2.3 Location Choice by Final Good Producers

The previous subsection assumed that each intermediate good is produced in a specific and exogenously given location. With regards to final goods producers, we assume that they can freely choose a location on any point along the road network linking location 0 and location 1.

Given that shipping inputs across production sites entails a transport cost, final good producers will choose their own location so as to minimize their marginal costs (c_j). Recall that, given a road network of length r, the distance between location 0 and 1 is equal to $\varphi(r)$. Let now $l_j\varphi(r)$ denote the (minimum) distance between the location chosen by producer j and location 0, where $l_j \in [0,1]$. Notice $l_j = 0$ means that j selects location 0, while $l_j = 1$ means that j chooses location 1. On the other hand, interior values of l_j –that is, $l_j \in (0,1)$– entail that j locates itself at somewhere *along* the road network linking location 0 and 1.

Given the selected $l_j \in [0,1]$, producer j must thus pay

$$p_{0,j} = [1 + l_j\varphi(r)t]\,(1+\varepsilon_0)\,w$$

for each unit of input 0 that he purchases, while he must pay

$$p_{1,j} = [1 + (1-l_j)\,\varphi(r)t]\,(1+\varepsilon_1)\,w$$

for each purchased unit of input 1.

Bearing in mind (4), producer j will thus choose his location by solving:

$$\min_{l_j\in[0,1]} : c_j(l_j) = [(1 + l_j\varphi(r)t)\,(1+\varepsilon_0)\,w]^{1-\alpha_j}\,[(1+(1-l_j)\,\varphi(r)t)\,(1+\varepsilon_1)\,w]^{\alpha_j}\,. \tag{5}$$

The above problem yields corner solutions. Comparing thus $c_j(0)$ vis-a-vis $c_j(1)$, we obtain

$$l_j^* = \begin{cases} 0 & \text{if } \alpha_j \leq 0.5 \\ 1 & \text{if } \alpha_j \geq 0.5 \end{cases} \tag{6}$$

The expression in (6) represents an intuitive agglomeration result: final producers choose to locate their firm in the same place where the input they use more intensively is being produced.[12]

[12] Corner solutions in (5) stem from the fact that transport costs are assumed linear in distance. If transport costs were convex in distance the model could yield interior solutions (at least for those j with values of α_j that lie near one half). In any case, even with sufficiently convex distance costs, the same qualitative patterns of agglomeration between intermediate and final producers would obtain: sectors with relatively small α_j (resp. large α_j) will locate relatively closer to location 0 (resp. location 1).

Finally, plugging (6) back into the expression in the right-hand side of (5) we can obtain the marginal cost of final good j:

$$c_j^* = \begin{cases} (1+\varphi(r)t)^{\alpha_j}\ (1+\varepsilon_0)^{1-\alpha_j}\ (1+\varepsilon_1)^{\alpha_j}\ w & \text{if} \quad \alpha_j \leq 0.5 \\ (1+\varphi(r)t)^{1-\alpha_j}\ (1+\varepsilon_0)^{1-\alpha_j}\ (1+\varepsilon_1)^{\alpha_j}\ w & \text{if} \quad \alpha_j \geq 0.5 \end{cases} \tag{7}$$

The expressions in (7) shows that the marginal cost of final good j is determined by the labor cost of producing the required inputs (via the wage w, and the parameters ε_0 and ε_1), and *also* by the transport cost involved in sourcing those inputs. Importantly, recall that final good producers will optimally choose to set up their firms in the *same* location where the input they use more intensively is being produced. As a result, the transport cost ends up being applied *only* to the input whose Cobb-Douglas weight in (3) is *smaller* than 0.5. In turn, this implies that internal transport costs tend to affect more severely the marginal cost of those final goods whose α_j lies near 0.5. In other words, internal transport costs tend to particularly hurt sectors which use a relatively balanced combination of inputs. On the other hand, this also implies that while improvements in transport infrastructure will lower the cost of production of all final goods (except for the extreme cases where either $\alpha_j = 0$ or $\alpha_j = 1$), such improvements will end up lowering the marginal cost of goods whose α_j is closer to 0.5 by relatively more. The following lemma states this result more formally.

Lemma 1 *Consider the expression for the marginal cost of good j in (7) and two generic values of the road length r_1 and r_2, such that $r_1 < r_2$. Then,*

1. $c_j^*(r_1)/c_j^*(r_2) > 1$ *for all* $\alpha_j \in (0, 1)$, *while* $c_j^*(r_1)/c_j^*(r_2) = 1$ *when* $\alpha_j = 0$ *and* $\alpha_j = 1$.
2. *The ratio* $c_j^*(r_1)/c_j^*(r_2)$ *is strictly increasing in* α_j *for all* $\alpha_j \in \left[0, \frac{1}{2}\right)$ *and strictly decreasing in* α_j *for all* $\alpha_j \in \left(\frac{1}{2}, 1\right]$. *Moreover, the highest value of* $c_j^*(r_1)/c_j^*(r_2)$ *is reached at* $\alpha_j = \frac{1}{2}$.

Lemma 1 shows that larger values of r lead to lower marginal costs of production, but that the fall in the marginal cost is proportionally greater in sectors with values of α_j closer to $\frac{1}{2}$. In the next section, where we extend the model to allow international trade and specialization, this result will turn the density of the road network into a source of comparative advantage: countries with denser road networks will tend to enjoy a comparative advantage in sectors with intermediate levels of α_j.

3 Two-Country Model

We consider now a world economy a lá Dornbusch-Fischer-Samuelson (1977) with two countries: H and F. Both countries are populated by a mass L of individuals. Each individual is endowed with one unit of labor that is supplied inelastically in the local labor market. We let w_H and w_F denote the wage in H and F, respectively. Henceforth, we set $w_F = 1$ (i.e., we set w_F as the *numeraire*), and use $\omega \equiv w_H/w_F$ to denote the relative wage. All individuals share the same preferences –given by (1)– over the unit continuum of final goods.

Each final good could in principle be produced by any of the two countries. The technologies to produce final goods are identical in both H and F, given by the Cobb-Douglas functions (3). All final goods markets are perfectly competitive. In addition, we assume that all final goods are internationally tradeable, subject to an iceberg cost $\tau > 0$ (that is, when $1 + \tau$ units of j are shipped internationally, only 1 unit of j will arrive at the destination country).

Unlike for final goods, we assume that intermediate goods are non-tradeable internationally.[13] We also assume that the technologies to produce the intermediate goods differ between H and F. Letting $X_{i,c}$ denote the total amount of intermediate good i produced in country c, we assume that in H

$$X_{0,H} = L_{0,H} \quad \text{and} \quad X_{1,H} = \frac{L_{1,H}}{1+\varepsilon}, \tag{8}$$

while in F,

$$X_{0,F} = \frac{L_{0,F}}{1+\varepsilon} \quad \text{and} \quad X_{1,F} = L_{1,F}, \tag{9}$$

where $L_{i,c}$ is the total amount of labor used in producing input i in country c, and $\varepsilon > 0$. There is free entry to the intermediate goods markets in both H and in F.

Two features implied by (8) and (9), coupled with the final goods production functions (3), are worth stressing. First, since they imply that H is relatively more productive than F in sector $i = 0$, they tend to yield a comparative advantage by H on the final goods that rely more heavily on input 0 (that is, on those j whose α_j is small). Second, since (8) and (9) exactly mirror one another, they implicitly assume away any aggregate absolute advantage by one country over the other one stemming from the distribution of sectoral labor productivities.[14]

[13] Restricting international trade only to final goods simplifies the exposition of the main results of the model. In principle, we could allow for trade of intermediates as well, as long as (analogously to the case of domestically produced inputs) imported inputs need, to some extent, to be transported internally until reaching the exact location of domestic final good producers.

[14] The model could be generalized to encompass production functions $X_{i,c} = L_{i,c}/(1 + \varepsilon_{i,c})$, where, $i = 1, 2$, $c = H, F$ and $\varepsilon_{i,c} \geq 0$. We deliberately choose a symmetric distribution of labor productivities, as is (8) and (9), since it allows a cleaner depiction of the impact of road networks on the patterns of comparative advantage.

Analogously to the closed economy setup in Section 2.2, we assume that each input is produced in a specific location. We keep referring as location 0 to the production site of input 0, and as location 1 to that one of input 1. (In this case, there is one such location in each of the countries.) Also like in the closed economy setup, we assume that the distance between location 0 and 1 in country c depends on the length of the road network in c via the distance function $\varphi(r_c)$. We also assume that the iceberg cost t per unit of distance $d_{j,i}$ travelled by input i to reach producer j is identical in H and F.[15]

We denote now by r_H and r_F the length of the road network in H and F, respectively. Henceforth, we assume:

Assumption 1 $r_F < r_H$.

In our model, Assumption 1 will convey a source of comparative advantage to H in the types of goods that depend on (internal) transport of inputs more strongly. In addition, $r_H > r_F$ also implies that H can, in general, ship inputs internally at lower cost than F. This fact will in turn grant a source of aggregate absolute advantage by H over F.

3.1 Pricing of Final Goods in *H* and *F*

The fact that all good markets in H and F are perfectly competitive implies again that final goods will be sold at their marginal costs. Notice that this will include both the incurred internal and international transport costs. In its general form, the price of final good $j \in [0,1]$ produced in country $c = H, F$ and sold in country $m = H, F$ will be given by

$$P^m_{j,c} = (1 + \tau \cdot \mathbb{I}_{m \neq c}) \left[(1 + l_{j,c}\, \varphi(r_c) t)\,(1 + \varepsilon_{0,c})\right]^{1-\alpha_j} \left[(1 + (1 - l_{j,c})\, \varphi(r_c) t)\,(1 + \varepsilon_{1,c})\right]^{\alpha_j} w_c, \quad (10)$$

where: *i*) $\mathbb{I}_{m \neq c}$ is an indicator function that is equal to one when $m \neq c$, and zero otherwise; *ii*) $\varepsilon_{0,H} = \varepsilon_{1,F} = 0$ and $\varepsilon_{1,H} = \varepsilon_{0,F} = \varepsilon$; *iii*) $l_{j,c}\, \varphi(r_c)$, where $l_{j,c} \in [0, 1]$, is the (minimum) distance between producer j in country c and location 0.

Final good producers will optimally seek to minimize their marginal costs. Analogously as done in Section 2.3, it can be proved that this is achieved by setting up firm j in location 0

[15] One may find it somewhat artificial the fact that the model assumes that transporting intermediate goods within the country entails a cost, but at the same time it abstracts from any cost regarding transportation of final goods. Yet, in the context of our model, none of the main results would be qualitatively altered by adding an internal transport cost of final goods, provided this cost applies both to locally produced and imported goods, and that the *direct* cost of transportation for final goods bears no systematic relation with the parameter α_j.

when $\alpha_j \leq 0.5$, and setting it up in location 1 when $\alpha_j \geq 0.5$. That is, condition (6) still holds true within the two-country model, with $l_{j,c} = l_j^*$ for $c = H, F$.

By using this result, together with (10), the price of good j when produced in country H and sold in $m = H, F$, denoted by $P_{j,H}^m$, can be written as

$$P_{j,H}^m = \begin{cases} (1 + \tau \cdot \mathbb{I}_{m \neq H})\ (1 + \varphi(r_H)t)^{\alpha_j}\ (1 + \varepsilon)^{\alpha_j}\ \omega & \text{if} \quad \alpha_j \leq 0.5 \\ (1 + \tau \cdot \mathbb{I}_{m \neq H})\ (1 + \varphi(r_H)t)^{1-\alpha_j}\ (1 + \varepsilon)^{\alpha_j}\ \omega & \text{if} \quad \alpha_j \geq 0.5 \end{cases}. \tag{11}$$

Analogously, $P_{j,F}^m$, with $m = H, F$, can be written as

$$P_{j,F}^m = \begin{cases} (1 + \tau \cdot \mathbb{I}_{m \neq F})\ (1 + \varphi(r_F)t)^{\alpha_j}\ (1 + \varepsilon)^{1-\alpha_j} & \text{if} \quad \alpha_j \leq 0.5 \\ (1 + \tau \cdot \mathbb{I}_{m \neq F})\ (1 + \varphi(r_F)t)^{1-\alpha_j}\ (1 + \varepsilon)^{1-\alpha_j} & \text{if} \quad \alpha_j \geq 0.5 \end{cases}. \tag{12}$$

To ease notation, it proves convenient to define

$$\delta \equiv \frac{1 + \varphi(r_F)t}{1 + \varphi(r_H)t}. \tag{13}$$

Notice that $\delta > 1$, since $r_F < r_H$. In the context of our model, δ can be interpreted as a measure of the advantage of H over F in terms of length of road network.

3.2 Traded (and Non-Traded) Goods

In equilibrium, consumers will buy each final good j from the producer who can offer j at the lowest price. In some cases this will mean that consumers will source good j locally, while in others they will choose to import it. Naturally, given that shipping final goods internationally entails an iceberg cost $\tau > 0$, if in equilibrium country c is an exporter of good j, then it must also be the case that individuals from c must be buying good j from local producers.

By comparing (11) vis-a-vis (12), we can observe that international trade of final goods takes place when the following conditions hold true (henceforth, without any loss of generality, we assume that when confronted with identical prices, consumers always buy from local producers).

- H will export final good j to F if and only if:

$$\begin{aligned} &\omega < (1 + \tau)^{-1}\, \delta^{\alpha_j}\, (1 + \varepsilon)^{1-2\alpha_j} && \text{when } \alpha_j \leq 0.5, \\ &\omega < (1 + \tau)^{-1}\, \delta^{1-\alpha_j}\, (1 + \varepsilon)^{1-2\alpha_j} && \text{when } \alpha_j \geq 0.5 \end{aligned} \tag{14}$$

- H will import final good j from F if and only if:

$$\begin{aligned} &\omega > (1 + \tau)\, \delta^{\alpha_j}\, (1 + \varepsilon)^{1-2\alpha_j} && \text{when } \alpha_j \leq 0.5, \\ &\omega > (1 + \tau)\, \delta^{1-\alpha_j}\, (1 + \varepsilon)^{1-2\alpha_j} && \text{when } \alpha_j \geq 0.5 \end{aligned} \tag{15}$$

The presence of $\tau > 0$ in (14) and (15) implies that some final goods may end up *not* being traded internationally. In particular, if for some subset of final goods whose $0 \leq \alpha_j \leq 0.5$, the model yields $(1+\tau)^{-1} \leq \omega\delta^{-\alpha_j}(1+\varepsilon)^{2\alpha_j-1} \leq (1+\tau)$, then consumers from both H and F will end up sourcing these goods locally. Similarly, if for some subset of final goods whose $0.5 \leq \alpha_j \leq 1$, the model yields $(1+\tau)^{-1} \leq \omega\delta^{\alpha_j-1}(1+\varepsilon)^{2\alpha_j-1} \leq (1+\tau)$, these goods will also be sourced in both H and F from local producers.

3.3 Equilibrium and Patterns of Specialization

In equilibrium, the total (world) spending on final goods produced in each country must equal the total labor income of each country. In our two-country setup, this condition can be restated as a trade balance equilibrium for either H or F. The utility function (1) implies that consumers allocate identical expenditure shares across all final goods in the optimum.[16] Hence, in our model, the equilibrium condition in the world economy boils down to:

$$\int_0^{\frac{1}{2}} \mathbb{I}\left\{\omega < (1+\tau)^{-1}\delta^{\alpha_j}(1+\varepsilon)^{1-2\alpha_j}\right\} d\alpha_j + \int_{\frac{1}{2}}^{1} \mathbb{I}\left\{\omega < (1+\tau)^{-1}\delta^{1-\alpha_j}(1+\varepsilon)^{1-2\alpha_j}\right\} d\alpha_j =$$
$$\left[\int_0^{\frac{1}{2}} \mathbb{I}\left\{\omega > (1+\tau)\delta^{\alpha_j}(1+\varepsilon)^{1-2\alpha_j}\right\} d\alpha_j + \int_{\frac{1}{2}}^{1} \mathbb{I}\left\{\omega > (1+\tau)\delta^{1-\alpha_j}(1+\varepsilon)^{1-2\alpha_j}\right\} d\alpha_j\right]\omega, \tag{16}$$

where $\mathbb{I}\{\cdot\}$ in (16) is an indicator function that is equal to 1 when the condition inside the braces holds true, and 0 otherwise. The left-hand side of (16) thus amounts to the total value of H's exports, whereas its right-hand side equals the total value of H's imports.

Henceforth, we impose an additional parametric restriction to the model:

Assumption 2 $\varepsilon > \tau$.

Assumption 2 ensures that our model will always feature positive trade in equilibrium. Intuitively, $\varepsilon > \tau$ implies that the source of comparative advantages linked to heterogeneities in sectoral labor productivities –i.e., those determined by (8) and (9)– are strong enough so as never to be completely overturned by international trade costs in all final sectors.[17]

[16] All the results in this section can easily be extended to a general Cobb-Douglas utility function with constant (but non-equal) expenditure shares across goods. The specific choice of (1) is just for algebraic simplicity.

[17] Assumption 2 is a *sufficient* condition (but is not a *necessary* condition) to ensure that positive trade between H and F always takes place in equilibrium. Intuitively, Assumption 1 creates another source of comparative advantage in our model, in addition to heterogeneities in sectoral labor productivities. As a result, even when $\varepsilon \leq \tau$, our model may still deliver positive trade, provided δ is sufficiently large.

From the trade balance equilibrium condition (16) we can obtain our first result concerning the equilibrium relative wage, ω^*.

Proposition 1 *In equilibrium, the wage in H is strictly greater than in F. That is, $\omega^* > 1$. Furthermore, ω^* is strictly increasing in δ, and $\omega^* < \min\left\{(1+\tau)\,\delta^{\frac{1}{2}}, (1+\varepsilon)\,(1+\tau)^{-1}\right\}$ if $(1+\varepsilon)^2 > \delta$, whilst $\omega^* < (1+\tau)^{-1}\,\delta^{\frac{1}{2}}$ if $(1+\varepsilon)^2 \leq \delta$.*

The result $\omega^* > 1$ is a straightforward implication of the fact that Assumption 1 conveys an aggregate advantage by H over F. As a result, in equilibrium, ω must rise above one, in order to allow F to be able to export to H as much as H exports to F. Notice that since labor is the only non-reproducible input in our model, wages are also equal to income per head in each country. Thus, Proposition 1 is ultimately stating that H is richer than F.

For future reference it proves convenient to define four different thresholds for α_j, namely:

$$\underline{\alpha}_H \equiv \frac{\ln(1+\varepsilon) - \ln(1+\tau) - \ln(\omega^*)}{2\ln(1+\varepsilon) - \ln(\delta)} \tag{17}$$

$$\overline{\alpha}_H \equiv \frac{\ln(1+\varepsilon) - \ln(1+\tau) + \ln(\delta) - \ln(\omega^*)}{2\ln(1+\varepsilon) + \ln(\delta)} \tag{18}$$

$$\underline{\alpha}_F \equiv \frac{\ln(1+\varepsilon) + \ln(1+\tau) - \ln(\omega^*)}{2\ln(1+\varepsilon) - \ln(\delta)} \tag{19}$$

$$\overline{\alpha}_F \equiv \frac{\ln(1+\varepsilon) + \ln(1+\tau) + \ln(\delta) - \ln(\omega^*)}{2\ln(1+\varepsilon) + \ln(\delta)}. \tag{20}$$

The above thresholds are obtained from the expressions in (11) and (12) in the following way: $\underline{\alpha}_H$ solves $P^F_{j,F}(\underline{\alpha}_H) = P^F_{j,H}(\underline{\alpha}_H)$ and $\underline{\alpha}_F$ solves $P^H_{j,H}(\underline{\alpha}_F) = P^H_{j,F}(\underline{\alpha}_F)$ when $\alpha_j \leq 0.5$, whereas $\overline{\alpha}_H$ solves $P^F_{j,F}(\overline{\alpha}_H) = P^F_{j,H}(\overline{\alpha}_H)$ and $\overline{\alpha}_F$ solves $P^H_{j,H}(\overline{\alpha}_F) = P^H_{j,F}(\overline{\alpha}_F)$ when $\alpha_j \geq 0.5$. Hence, the thresholds $\underline{\alpha}_H$ and $\overline{\alpha}_H$ (resp. $\underline{\alpha}_F$ and $\overline{\alpha}_F$) pin down the final goods such that, given the value of ω^*, their market price when sold in F (resp. when sold in H) would be identical regardless of where it was originally produced. Notice that $\tau > 0$ implies $\overline{\alpha}_H < \overline{\alpha}_F$, while Assumption 2 together with the equilibrium result $\omega^* > 1$ means that $\overline{\alpha}_F < 1$. Furthermore, $\underline{\alpha}_H < \underline{\alpha}_F$ when $(1+\varepsilon)^2 > \delta$, while $\underline{\alpha}_H > \underline{\alpha}_F$ holds when $(1+\varepsilon)^2 < \delta$. In addition, the results in Proposition 1 concerning the bounds for ω^* imply that $\underline{\alpha}_H > 0$ always holds.[18]

By using the thresholds (17)-(20), we can fully split the space of final goods according to their price in the destination country, given the country of origin of the good.

[18] The comparisons of $\underline{\alpha}_H$ vis-a-vis $\overline{\alpha}_H$ and $\underline{\alpha}_F$ vis-a-vis $\overline{\alpha}_F$ are somewhat more convoluted, as they involve several possible combinations of parametric configurations and feasible solutions for ω^* given those configurations. For example, whenever $(1+\varepsilon)^2 < \delta$ holds true, for any feasible values of ω^*, we have $0 < \underline{\alpha}_H < 0.5 < \overline{\alpha}_H < 1$ and $\underline{\alpha}_F < 0.5 < \overline{\alpha}_F < 1$. Instead, when $(1+\varepsilon)^2 > \delta$, we have $\underline{\alpha}_H < \overline{\alpha}_H$ iff $\omega^* > (1+\tau)^{-1}\delta^{\frac{1}{2}}$, and $\underline{\alpha}_F < \overline{\alpha}_F$ iff $\omega^* > [(1+\tau)\delta]^{\frac{1}{2}}$ holds in that range; both conditions fail to hold true for τ sufficiently close to zero.

Lemma 2 *From (11) and (12), and the equilibrium relative wage ω^*, by using (17)-(20), we can derive the following set of conditions for $P^F_{j,F}$ relative to $P^F_{j,H}$ and for $P^H_{j,H}$ relative to $P^H_{j,F}$:*

1. *Suppose $\delta < (1+\varepsilon)^2$, then:*
   - $P^F_{j,H} < P^F_{j,F}$ *for* $0 \leq \alpha_j < \alpha^*_H$, *while* $P^F_{j,H} > P^F_{j,F}$ *for* $\alpha^*_H < \alpha_j \leq 1$, *where* $\alpha^*_H = \underline{\alpha}_H$ *if* $\omega^* \geq (1+\tau)^{-1}\delta^{\frac{1}{2}}$ *holds true, while* $\alpha^*_H = \overline{\alpha}_H$ *if instead* $\omega^* < (1+\tau)^{-1}\delta^{\frac{1}{2}}$.
   - $P^H_{j,H} < P^H_{j,F}$ *for* $0 \leq \alpha_j < \overline{\alpha}_F$, *while* $P^H_{j,H} > P^H_{j,F}$ *for* $\overline{\alpha}_F < \alpha_j \leq 1$.
2. *Suppose $\delta > (1+\varepsilon)^2$, then:*
   - $P^F_{j,H} < P^F_{j,F}$ *for* $\underline{\alpha}_H < \alpha_j < \overline{\alpha}_H$, *while* $P^F_{j,H} > P^F_{j,F}$ *for* $0 \leq \alpha_j < \underline{\alpha}_H$ *and for* $\overline{\alpha}_H < \alpha_j \leq 1$.
   - $P^H_{j,H} < P^H_{j,F}$ *for* $\max\{0, \underline{\alpha}_F\} < \alpha_j < \overline{\alpha}_F$, *while* $P^H_{j,H} > P^H_{j,F}$ *for* $\overline{\alpha}_F < \alpha_j \leq 1$ *and* $0 \leq \alpha_j < \max\{0, \underline{\alpha}_F\}$, *where* $\underline{\alpha}_F > 0$ *if and only if* $\omega^* > (1+\tau)(1+\varepsilon)$ *holds true.*

In equilibrium, consumers in both H and F will always buy good j from the producer who can sell it in each market at the lower price. Hence, relying on Lemma 2, we can next derive the equilibrium patterns of trade and specialization in the two-country world economy.

Proposition 2 *The patterns of specialization and trade differ qualitatively depending on whether $\delta > (1+\varepsilon)^2$ or $\delta < (1+\varepsilon)^2$.*

i) Ricardian-based specialization: *When $\delta < (1+\varepsilon)^2$, trade patterns and specialization are governed by heterogeneities in labor productivities. Country H becomes an exporter of final goods whose $\alpha_j \in [0, \alpha^*_H)$, where $\alpha^*_H = \underline{\alpha}_H$ (resp. $\alpha^*_H = \overline{\alpha}_H$) if $\omega^* \geq (1+\tau)^{-1}\delta^{\frac{1}{2}}$ (resp. $\omega^* < (1+\tau)^{-1}\delta^{\frac{1}{2}}$) holds true. Country F becomes an exporter of the final goods whose $\alpha_j \in (\overline{\alpha}_F, 1]$. Final goods whose $\alpha_j \in [\alpha^*_H, \overline{\alpha}_F]$ are sourced locally by both H and F.*

ii) Transport cost-based specialization: *When $\delta > (1+\varepsilon)^2$, trade patterns and specialization are governed by road network length differences between H and F. Country H becomes an exporter of final goods whose $\alpha_j \in (\underline{\alpha}_H, \overline{\alpha}_H)$. Country F becomes an exporter of final good whose $\alpha_j \in [0, \underline{\alpha}_F) \cup (\overline{\alpha}_F, 1]$ if $\omega^* > (1+\varepsilon)(1+\tau)$ holds true, while it becomes an exporter of final goods whose $\alpha_j \in (\overline{\alpha}_F, 1]$ if instead $\omega^* \leq (1+\varepsilon)(1+\tau)$ holds true. When $\omega^* > (1+\varepsilon)(1+\tau)$ final goods whose $\alpha_j \in [\underline{\alpha}_F, \underline{\alpha}_H] \cup [\overline{\alpha}_H, \overline{\alpha}_F]$ are sourced locally by both H and F, while when $\omega^* < (1+\varepsilon)(1+\tau)$ this happens for those goods whose $\alpha_j \in [0, \underline{\alpha}_H] \cup [\overline{\alpha}_H, \overline{\alpha}_F]$.*

The patterns of trade and specialization described by Proposition 2 are graphically depicted in Figure 1.[19] The upper panel plots *case i)* of Proposition 2 –i.e., $\delta < (1+\varepsilon)^2$–, while and the lower panel shows *case ii)* –i.e., $\delta > (1+\varepsilon)^2$.[20] The horizontal axis of Figure 1 orders final goods according to their specific $\alpha_j \in [0,1]$; the vertical one measures the relative wage ω.

Consider first the upper panel of Figure 1. Given a certain level of ω, all the goods that lie on the left of the solid line would be exported by H, while all the goods lying on the right of the dashed line would be exported by F. The gap in between the two curves represents the set of goods that would *not* be traded internationally. As it can be observed, the set of goods exported by H gets smaller as ω increases. Conversely, the set of goods exported by F expands with ω. At the extremes, when $\omega \leq 1/(1+\tau)(1+\varepsilon)$ all final goods would be produced in H, whereas for $\omega \geq (1+\tau)(1+\varepsilon)$ they would all be produced in F (naturally, such extreme values of ω could not possibly hold in equilibrium).

At the equilibrium wage, ω^*, final goods with $\alpha_j > \overline{\alpha}_F$ are exported by F, and those with $\alpha_j < \underline{\alpha}_H$ are exported by H.[21] Hence, H becomes an exporter of the final goods that use input 0 more intensively (i.e., low-α_j goods), while F an exporter of those which use input 1 more intensively (i.e., high-α_j goods). Intuitively, the condition $\delta < (1+\varepsilon)^2$ means that differences in road network lengths between H and F are *small* relatively to their heterogeneities in sectoral labor productivities. As a result, the labor productivity differentials in the intermediate sectors –dictated by (8) and (9)– become the leading source of comparative advantage, regulating trade flows in the model.

Consider now the lower panel of Figure 1. For values of $\alpha_j > 0.5$, this graph exhibits the same qualitative features as the one in the upper panel. In fact, the interpretation of the curves within the range $0.5 < \alpha_j < 1$ is analogous in both graphs: given a ω, the final goods that lie on the left of the solid line would be exported by H and those lying on the right of the dashed line would be exported by F. The main visual differences between the graphs arise

[19]The solid line in Figure 1 is obtained by plotting $\underline{\alpha}_H$ and $\overline{\alpha}_H$, as given by (17) and (18) but replacing the specific equilibrium wage ω^* by a generic $\omega \geq 0$. Similarly, the dashed line is obtained by plotting $\underline{\alpha}_F$ and $\overline{\alpha}_F$, as given by (19) and (20) for a generic $\omega \geq 0$. Note that only the parts of the solid and dashed lines below $\alpha_j = 0.5$ follow the expressions in (17) and (19), while only the parts above $\alpha_j = 0.5$ follow (18) and (20).

[20]For brevity, the upper panel of Figure 1 shows the sub-case where $\omega^* > (1+\tau)^{-1}\delta^{\frac{1}{2}}$ –implying that H exports goods with $\alpha_j \in [0, \underline{\alpha}_H)$–, while its lower panel shows the sub-case where $\omega^* > (1+\varepsilon)(1+\tau)$ –entailing that F exports goods with $\alpha_j \in [0, \underline{\alpha}_F)$ and with $\alpha_j \in (\overline{\alpha}_F, 1]$–. In Appendix A, Figure 1 (bis) plots the other two sub-cases encompassed by Proposition 2.

[21]Notice that given the utility function (1), it must be that in equilibrium $(1-\overline{\alpha}_F) \times \omega^* = \underline{\alpha}_H$, where $(1-\overline{\alpha}_F) \times \omega^*$ equals total imports by H and $\underline{\alpha}_H$ equals total exports by H.

when $0 < \alpha_j < 0.5$. Within this range, the final goods located on the *right* of the solid line would be exported by H, whereas those located on the *left* of the dashed line would be exported by F.[22] In turn, this case leads to a pattern of specialization that differs quite drastically from that one shown in the upper panel of Figure 1. When, $\delta > (1+\varepsilon)^2$, we can observe that F ends up exporting the final goods located at the two (opposite) ends of the unit set –namely, $\alpha_j \in [0, \underline{\alpha}_F)$ and $\alpha_j \in (\overline{\alpha}_F, 1]$–, while H becomes an exporter of those in the intermediate range of α_j –namely, $\alpha_j \in (\underline{\alpha}_H, \overline{\alpha}_F)$–

The pattern of specialization depicted in the lower panel of Figure 1 represents the main insight of the model. The intuition for the result rests on the fact that when $\delta > (1+\varepsilon)^2$ the gap in the road network length is *large* relative to the heterogeneities in sectoral labor productivities, and thus becomes the leading determinant of comparative advantages. Final goods with intermediate values of α_j require the use of both inputs in similar intensity. Given the geographically diffused distribution of input locations, this means that a large share of their inputs will *necessarily* have to be transported along the road network. Instead, firms producing final goods with high and low values of α_j can source a relatively large share of their inputs from the *same* location where they are located, thus with less need to rely for it on the internal transport network so heavily. In other words, sectors in the intermediate range of α_j require stronger use of the internal transport network than those whose α_j lies on the upper and lower spectrum of the unit interval. Accordingly, when H has a much denser road network than F, the former ends up specializing in the final goods with intermediate values of α_j, and the latter in those with more extreme values of α_j.

[22] Analogously to the upper panel of Figure 1, as ω increases, the set of goods exported by H shrinks and that one exported by F expands. The gap in between the curves represents the set of goods that are not traded internationally. Finally, for $\omega < 1/(1+\tau)(1+\varepsilon)$ all final goods would end up being produced by H, while for $\omega > (1+\tau)\delta^{0.5}$ they would all end up being produced by F.

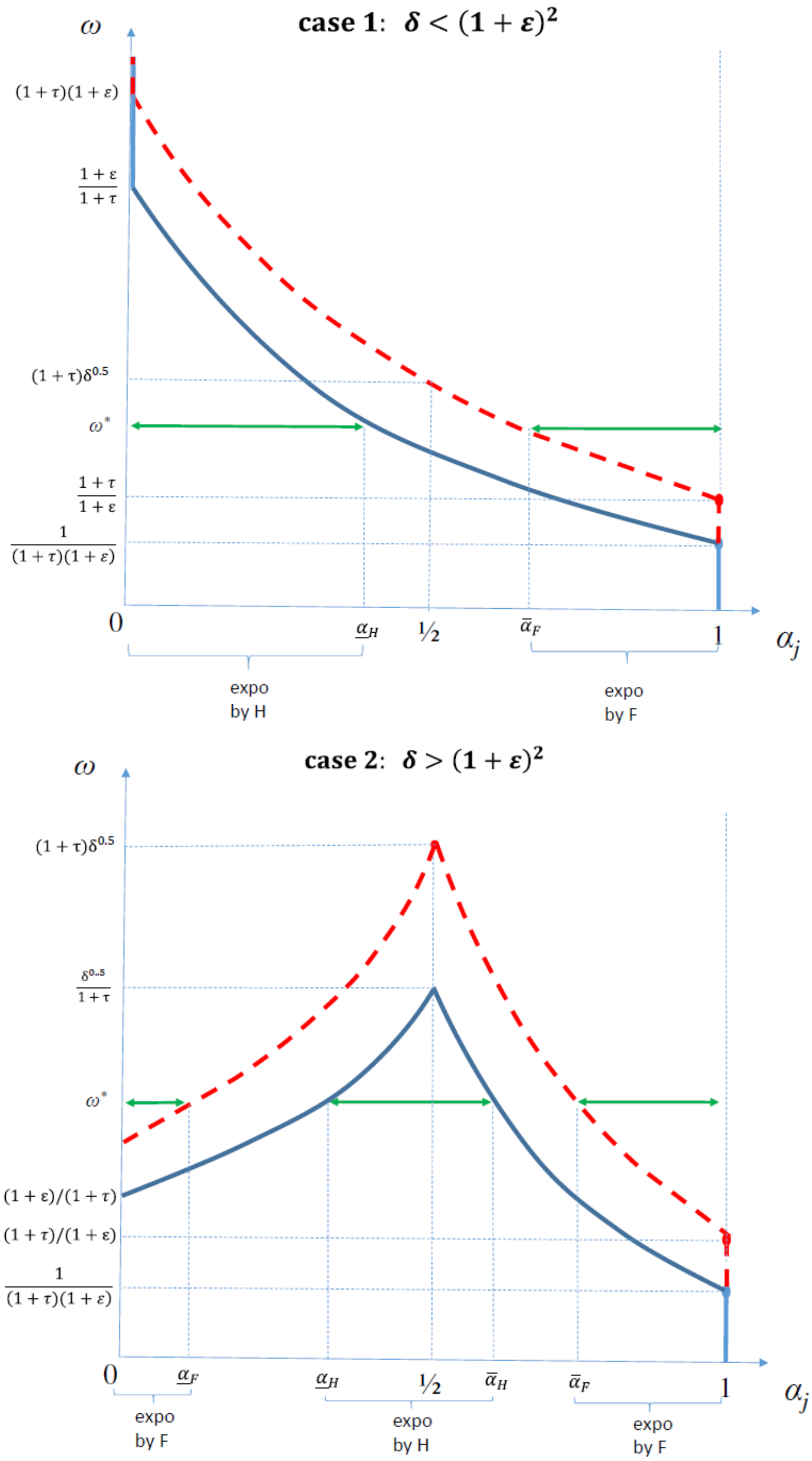

Figure 1: Patterns of Trade and Specialization

4 Empirical Predictions: From the Theory to the Data

In this section, we first describe how we attempt to bring to the data the main variables of interest present in the model. Next, we explain how we approach the data on trade flows to seek for evidence consistent with the main novel predictions of the model. Table A.1 in Appendix B provides some summary statistics for the main variables described below.

4.1 Main Variables of Interest

Input Narrowness

The first task is coming up with a measure of the breadth of the set of intermediate inputs used by each industry. The model is quite stylized to allow a direct match between its technological environment and real world data on inputs and outputs by sectors. In particular, in the real world production functions tend to use more than only two intermediate goods. Furthermore, the distinction between intermediate and final goods is not so clear-cut as assumed by the model, as many goods satisfy both roles. Despite these shortcomings, we can still use the model as a guide to construct measures of narrowness of the intermediate inputs base for industries.

In the model, sector j allocates a fraction $1-\alpha_j$ of their total spending in intermediate goods on input 0 and the remainder α_j on input 1. This means that sectors with very low or very high values of α_j source most of their inputs from only one intermediate sector, and thus exhibit a *narrow* intermediate input base. Conversely, sectors with values of α_j around one half rely quite heavily on both inputs, and thus display a *wide* intermediate input base.

We formally define the *narrowness* of the input base of sector j by the Gini coefficient of their expenditure shares across both inputs ($Gini_j$). The greater the value of $Gini_j$ is, the narrower input base of sector j.[23] By using the fact that expenditure shares on input 0 and 1 are given, respectively, by $1-\alpha_j$ and α_j, we can observe that:

$$Gini_j = \begin{cases} \frac{1}{2}-\alpha_j & \text{if } 0 \leq \alpha_j \leq \frac{1}{2} \\ \alpha_j - \frac{1}{2} & \text{if } \frac{1}{2} \leq \alpha_j \leq 1. \end{cases} \tag{21}$$

[23] Imbs and Wacziarg (2003) have previously used the Gini coefficient to measure the degree of concentration of labor and value added across different sectors. We apply the same methodology, but we use it to measure the degree of narrowness/concentration of the intermediate input base of different industries. There are other measures that could alternatively be used to capture the same concept; e.g., coefficient of variation, log-variance, Herfindahl index. We also use those alternative measures in Section 4.3 as robustness checks. Clague (1991a, 1991b) have previously used the Herfindahl index for the input concentration to measure what he called the degree of 'self-containment' of industries; this concept is essentially the same as our notion of 'input narrowness'.

Hence, $Gini_j = 0$ when $\alpha_j = 0.5$, while it grows symmetrically as α_j moves away from its central value of 0.5 towards either extremes on 0 and 1.

To construct a measure of input narrowness analogous to that one in (21), but based on the available real world data, we resort to the input-output (IO) matrix of the US in 2007 from the Bureau of Economic Analysis (BEA).[24] The IO matrix comprises 389 sectors/industries. Although the IO matrix exhibits the same number of sectors producing intermediate goods as those producing final output, we restrict the set of final goods to those also present in the international trade data (see description below). Thus, we index by $k = 1, 2, ..., K$ each of the sectors present in the IO matrix and also in the trade data, and by $n = 1, 2, ..., N$ each of the sectors selling intermediate inputs.

We let $X_{k,n} \geq 0$ denote the total value of intermediate good n purchased by sector k. Defining $S_{k,n} \equiv X_{k,n} / \sum_{n=1}^{N} X_{k,n} \geq 0$ as the share of n over the total value of intermediates purchased by k, we can compute the Gini coefficients analogously to those in (21). Namely,

$$Gini_k = \frac{2 \times \sum_{n=1}^{N} n \times S_{k,n}}{N \times \sum_{n=1}^{N} S_{k,n}} - \frac{N+1}{N}, \tag{22}$$

where the argument $\sum_{n=1}^{N} n \times S_{k,l}$ in the numerator of $Gini_k$ is ordering intermediates in non-decreasing order (i.e., $S_{k,n} \leq S_{k,n+1}$).

In the empirical analysis in Section 4.3, we use $Gini_k$ to measure the degree of narrowness of the input base of sector k. Large values of $Gini_k$ are the result of sector k sourcing most of their intermediate inputs from relatively few sectors. Conversely, small values of $Gini_k$ tend to occur when the distribution of $S_{k,n}$ is quite evenly spread across a large number of intermediates.[25] Notice finally the link between $Gini_k$ in (22) and $Gini_j$ in (21): the former boils down to the latter when $N = 2$, and $S_{k,n} = \alpha_{k,n}$ with $\alpha_{k,1} + \alpha_{k,2} = 1$.

Export Specialization

In order to measure the degree of export specialization by sectors we use the data on trade flows from COMTRADE compiled by Gaulier and Zignago (2010). We use only trade flows in year 2014. The data are categorized following the Harmonized System (HS) 6-digit classification, with 5,192 products. We map the trade flows data based on the HS 6-digit classification to the BEA industry codes using the concordance table between the 2002 IO matrix commodity codes

[24] This data is publicly available from https://www.bea.gov/industry/io_annual.htm.

[25] In the extreme (unequal) case in which $S_{k,n'} = 1$ for some n' and $S_{k,n} = 0$ for all $n \neq n'$, (22) yields $Gini_k = 2 - [(N+1)/N]$, which approaches 1 as $N \to \infty$. On the other hand, in the case when $S_{k,n} = S_k > 0$ for all $n = 1, ..., N$, we would have $Gini_k = 0$.

and the HS 10-digit classification from the BEA website (after grouping the HS 10-digit codes into HS 6-digit products). In the cases in which an HS-6 product maps into more than one BEA code, we assign their trade flows proportionally to each of the BEA sectors in which it maps.[26] Lastly, the IO industry codes of the 2002 classification are matched to those of the 2007 classification, which are the ones actually used in the computation of the Gini coefficients.[27]

Road Network

The last key variable in our model is the length of the road network of country c (r_c). We take the road network length by countries from the data on roadways from the CIA World Factbook. Roadways are defined as 'total length of the road network, including paved and unpaved portions'. The year of the data point for each country varies, ranging from year 2000 to 2016, with the median year of the sample being 2010. (See details of this variable in Table A.8 in Appendix C.) When defining our empirical counterpart of the variable r_c, we divide the length of the road network by the total area of the country: $r_c \equiv roadways_c/area_c$. In some of the robustness checks, we use also two additional measures of transport density: waterways density (defined as $waterways_c/area_c$) and railway density (defined as $railways_c/area_c$). The data on length of waterways and railways are also taken from the CIA World Factbook.

4.2 Road Density and Patterns of Specialization: Testing the predictions of the model

The two-country model presented in Section 3 predicts that when heterogeneities in road networks are sufficiently large, the patterns of specialization and trade flows follow those depicted by the lower panel of Figure 1. More formally, when the condition $\delta > (1+\varepsilon)^2$ holds true, the country with the longer road network (i.e., country H) will export goods with intermediate

[26] There are 526 HS-6 products that map into two BEA Input-Output industry codes, 96 products that map into three IO codes, 33 products that map into four IO codes, and 11 products that map into five or more IO codes. (We excluded the 11 products that map into five or more IO codes.) None of the regression results in Section 4.3 are significantly altered when all the HS-6 products that map into more than one BEA Input-Output industry code are dropped from the sample.

[27] Unfortunately, we are not aware of any correspondence table between BEA 2007 codes and the HS codes, hence we indirectly link them via the BEA 2002 codes. In the end, after mapping the HS 6-digit products into the BEA 2002 codes, and mapping the BEA 2007 codes to the 2002 codes, we are left with data on trade flows and input narrowness for 294 industries as coded by the BEA 2002 classification. Of the original 389 codes, only 307 are matched to HS 10-digit codes. We have export data for 303 industries among those 307. Nine other industries are lost when matching the BEA 2007 codes to those in BEA 2002.

values of α_j, while the country with the shorter road network (i.e., country F) will export goods with values of α_j located on the extremes of the unit continuum. Conceptually, this prediction can be interpreted as stating that countries with denser road networks will tend to exhibit a comparative advantage in the types of goods that require a wider (or more diverse) set of intermediate inputs.

From an empirical viewpoint, if road network length differences across countries shaped somehow their patterns of specialization as our model predicts, we should then observe the following: economies with a greater r_c will tend to export relatively more of the goods produced in industries with a smaller value of $Gini_k$ vis-a-vis economies with smaller r_c. We test this prediction using the following regression:

$$\ln(Expo_{c,k}) = \beta \cdot (r_c \times Gini_k) + \boldsymbol{\chi} \cdot \boldsymbol{\Delta}_{k,c} + \varsigma_c + \kappa_k + \upsilon_{c,k}, \tag{23}$$

In the regression equation (23) the dependent variable is given by the natural logarithm of the total value of exports in industry k by country c to all other countries in the world in year 2014. The term $(r_c \times Gini_k)$ interacts the measure of input narrowness defined in (22) with the measure of road density (i.e., length of roadways per square kilometer). $\boldsymbol{\Delta}_{k,c}$ denotes a vector of additional covariates that may possibly influence specialization across countries in industries differing in terms of the degree of input narrowness. ς_c and κ_k denote country fixed effects and industry fixed effects, respectively, and $\upsilon_{c,k}$ represents an error term.

The main coefficient of interest in (23) is β. If, as the model predicts, countries with a denser road network (i.e., countries with a greater r_c) indeed tend to exhibit a comparative advantage in goods from industries that require a wider set intermediate inputs (i.e., industries with a smaller $Gini_k$), then the data should deliver a negative estimate of β.

4.3 Empirical Results

Table I displays the first set of estimation results corresponding to (23). Column (1) includes only our main variable of interest (i.e., $r_c \times Gini_k$), together with the exporter and industry dummies. The correlation is negative and highly significant, suggesting that countries with denser road networks tend to export relatively more of the final goods whose production process requires a wider intermediate input base (i.e., those exhibiting a lower $Gini_k$).

Columns (2) -(4) in Table I show the results of this simple correlation when input narrowness is measured by three alternative measures: the Herfindahl index, the coefficient of variation, and the log-variance of industry k's intermediates expenditure shares ($S_{k,n}$). The estimate of β is negative and highly significant under all these alternative measures as well. Finally, column

TABLE I

Export Specialization across Industries with Different Levels of Input Narrowness

	(1)	(2)	(3)	(4)	(5)
Road Density x Input Narrowness	-4.084***	-0.710***	-0.034***	-0.122***	-3.960***
	(0.305)	(0.141)	(0.004)	(0.012)	(0.814)
Road Density					4.060***
					(0.837)
Observations	42,578	42,578	42,578	42,578	42,578
R-squared	0.765	0.764	0.764	0.764	0.263
Country FE	Yes	Yes	Yes	Yes	No
Sector FE	Yes	Yes	Yes	Yes	Yes
Dependent Variable	$\log(Expo_{c,k})$	$\log(Expo_{c,k})$	$\log(Expo_{c,k})$	$\log(Expo_{c,k})$	$\log(Expo_{c,k}/Expo_{c})$
Number of Countries	166	166	166	166	166
Narrowness Measure	Gini	Herf	Coef Var	Log Var	Gini

Robust standard errors reported in parentheses in colums (1) - (4), and clustered at the country level in column (5). The dependent variable in columns (1) - (4) is the log of total exports in industry k by country c in year 2014. The dependent variable in column (5) is the log of the share of exports in industry k by country c over total exports by country c in year 2014. The number of industries is 294 in all regressions. *** p<0.01, ** p<0.05, * p<0.1

(5) displays the result of a regression that includes the length of the road network as a regressor, together with the interaction term $r_c \times Gini_k$.[28] Since $Gini_k$ is always smaller than unity, the results show that countries with longer road networks tend to export more across the board, but the increase in exports is more pronounced in industries whose $Gini_k$ is smaller.

In Table II we sequentially incorporate some additional interaction terms that may also influence the patterns of specialization across industries with different levels of input narrowness. Column (1) adds an interaction term between $Gini_k$ and an index of *Rule of Law*, taken from World Governance Indicators. The rationale behind including this term lies on the argument in Levchenko (2007) and Nunn (2007), who show that countries with better contract enforcement institutions display a comparative advantage in industries that are heavily dependent on relationship-specific investments. Within our context, industries that need to source a broader set of intermediates may benefit relatively more from a sound legal environment, as they need to establish relationships with a greater number of input providers. Given that countries with better institutions tend to be also richer and invest more in basic infrastructure, omitting this term could lead to an overestimation (in absolute value) of the correlation coefficient of interest in (23). The regression in column (1) of Table II yields indeed a negative and significant coefficient associated with the interaction term between rule of law and $Gini_k$, consistent with

[28]Since in column (5) we have to drop the country fixed effects ς_c from the regression, there we use as dependent variable the log of the export share in industry k by country c –i.e., $\ln(Expo_{c,k}/Expo_c)$– rather than simply $\ln(Expo_{c,k})$, so as to take care of the size of exports by each country. The estimates in column (5) remain essentially the same if alternatively using $\ln(Expo_{c,k}/GDP_c)$ as dependent variable.

the previous literature on institutions and specialization. In addition, while the magnitude of $\widehat{\beta}$ falls relative to column (1) of Table I, it still remains negative and significant.

Another possible source of omitted variable bias is related to the effect of financial markets. There is a large body of literature that sustains that financial markets are instrumental to opening new sectors and increasing the variety of industries in the economy (e.g., Greenwood and Jovanovic, 1990; Saint-Paul, 1992; Acemoglu and Zilibotti, 1997). We could then expect that countries with more developed financial markets would also be better able to specialize in industries that require a wider input base. To deal with this concern, in column (2) we interact the Gini coefficients with an indicator of financial development: the log ratio of private credit to GDP. (This indicator is taken from the World Bank Indicators database, and averaged during years 2005-2014.) As we can readily observe, the effect of financial development interacted with $Gini_k$ is significant and it carries a sign consistent with the past literature on growth and diversification. Yet, the estimate of β still remains negative and significant.

Column (3) adds an interaction term between $Gini_k$ and log GDP per capita. This term would control for the possibility that richer economies may be better able to produce goods with lower $Gini_k$, as in general richer economies tend to exhibit a more diversified productive structure than poorer ones. As we can see, the results concerning β remain essentially unaltered.

In column (4) we introduce two additional regressors to control for specialization driven by factor endowments: *i*) an interaction term between capital intensity of industry k and the (log) stock of physical capital per worker in country c; *ii*) an interaction term between the skill intensity of industry k and the (log) stock of human capital in country c. The measures of capital and skill intensity at the industry level are constructed from the NBER-CES Manufacturing Industry database, for year 2011.[29] Some industries are lost from the sample when we introduce the industry factor intensity measures, since the NBER dataset contains information only for manufacturing industries. For comparability, in column (5) we display the results of the regression in column (3), but using the restricted sample. The coefficients associated to the factor intensities carry the expected sign, while the estimates of β remain negative and significant. Furthermore, the estimated coefficients are of similar magnitude in both columns.

Finally, the last two columns of Table II address the possibility of a differential effect of the road network on the pattern of specialization depending on the population density of the

[29] Capital intensity is computed as the total stock of physical capital per worker by industry. Skill intensity is measured by the average wage by industry. (See Becker, Gray and Marvakov (2013) for details on the NBER-CES Manufacturing Industry database.) Both the measure of physical capital per worker and the index of human capital are drawn from the Penn Tables database. (The human capital index is based on the average years of schooling from Barro & Lee (2013) and an assumed rate of return of education based on Mincer estimates.)

TABLE II

Export Specialization across Industries with Different Levels of Input Narrowness: Additional Covariates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Road Density x Input Narrowness	-2.240***	-2.382***	-2.356***	-1.852***	-1.845***	-2.956***	-2.439***
	(0.334)	(0.363)	(0.364)	(0.379)	(0.385)	(0.437)	(0.453)
Rule of Law x Input Narrowness	-5.414***	-2.639***	-2.435***	-3.132***	-3.045***	-2.304***	-2.999***
	(0.441)	(0.648)	(0.702)	(0.762)	(0.766)	(0.703)	(0.765)
log (Priv Credit/GDP) x Input Narrowness		-3.743***	-3.547***	-1.704*	-1.681*	-3.224***	-1.500*
		(0.760)	(0.822)	(0.913)	(0.915)	(0.828)	(0.918)
log GDP per capita x Input Narrowness			-0.417	0.905	1.306**	-0.522	0.822
			(0.602)	(0.656)	(0.654)	(0.604)	(0.658)
Capital Intensity x log $(K/L)_c$				0.010**			0.010**
				(0.004)			(0.004)
Skill Intensity x log H_c				0.008***			0.008***
				(0.001)			(0.001)
(Pop) Density x Input Narrowness						-0.333***	-0.197**
						(0.107)	(0.101)
Road Dens x (Pop) Dens x Input Nwness						0.089***	0.064**
						(0.028)	(0.027)
Observations	41,947	40,692	40,692	31,892	31,892	40,692	31,892
R-squared	0.764	0.764	0.764	0.794	0.793	0.764	0.794
Number of Countries	163	157	157	134	134	134	157
Number of Industries	294	294	294	259	259	294	259

Robust standard errors in parentheses. All regressions include country and industry fixed effects. The dependent variable is the log of exports in industry k by country c in 2014. Rule of law is taken from the World Governance Indicators (WB) for year 2014. Private credit over GDP is taken from the World Bank Indicators, averaged for years 2005-2014. GDP per capita, stock of physical capital, and the human capital index are taken from the Penn Tables, all for 2014. Measures of physical capital and skill intensity by industry are taken from the NBER-CES Manufacturing Industry Database, and corresponds to year 2011. *** p<0.01, ** p<0.05, * p<0.1

economy. One could expect that more densely populated countries may display also a greater concentration of activities in fewer locations. Hence, all else equal, more densely populated countries may need to resort less strongly on a vast road network than sparsely populated countries do. Columns (7) and (8) assess this possibility by introducing an interaction term between population density and $Gini_k$, and a *triple* interaction term which also includes r_c. If road network length is especially important for specialization in economies that are *less* densely populated, then the triple interaction term should carry a positive estimate. As can be observed, this is indeed the case. Moreover, the estimate of β after introducing the triple interaction term is still negative and highly significant.

Table III displays some of the regressions previously presented in Table II, but now splitting the sample of countries in two subsamples, according to whether their income is above or below the median. The odd-numbered columns show the results for the subsample of 'high-income countries', while the even-numbered columns do that for the 'low-income countries'. The results show that the effect of road density on pattern of specialization holds true both for richer and poorer countries. In addition to that, the effect seems to be consistently greater in magnitude for the subsample of economies whose income is below the median.[30]

Additional Robustness checks

Some further robustness checks are provided in Appendix B in Tables A.2, A.3, and A.4.

Tables A.2 and A.3 change the measure of transport density used in the previous regressions. In Table A.2, we show the results of a set of regressions substituting r_c in (23) by railway density, computed as the total railway network length of country c per square kilometer. In Table A.3, we expand our measure transport network length to include (in addition to roadways) also the total length of internal railways and waterways. All the results in Table A.2 and A.3 follow a similar pattern as those previously shown in Table I and II.

Table A.4 shows that all the previous results are also robust to: *i*) excluding very small countries (both in terms of area and population), *ii*) excluding very large countries (in terms of area), *iii*) controlling for the effect of area and population (in both cases interacted with the measure of input narrowness), *iv*) including the interaction between total GDP and input narrowness, and *v*) excluding from the sample those countries whose road networks were measured before year 2010 (which is the median year in the sample).

The rationale for these additional robustness checks is the following. In the case of very

[30] This difference in magnitude could suggest the presence of some sort of decreasing marginal effect of road density, since richer economies tend to exhibit denser road networks than poorer ones (see Figure 2 later on).

TABLE III

High-Income and Low-Income Subsamples

	(1)	(2)	(3)	(4)	(5)	(6)
Road Density x Input Narrowness	-2.118***	-4.935***	-1.636***	-4.495***	-1.635***	-4.477***
	(0.354)	(1.482)	(0.373)	(1.712)	(0.375)	(1.713)
Rule of Law x Input Narrowness	-0.673	-4.075**	-1.393	-2.865	-1.170	-2.810
	(1.005)	(1.739)	(1.094)	(2.025)	(1.091)	(2.029)
log (Priv Cred/GDP) x Input Narrowness	-4.882***	-2.001	-4.640***	0.758	-4.712***	0.739
	(1.086)	(1.319)	(1.193)	(1.428)	(1.190)	(1.428)
log GDP per capita x Input Narrowness	-0.418	1.723	2.002	2.087*	2.357	2.459**
	(1.541)	(1.069)	(1.638)	(1.112)	(1.650)	(1.111)
Capital Intensity x log $(K/L)_c$			0.010	0.014*		
			(0.012)	(0.009)		
Skill Intensity x log H_c			0.014***	-0.015***		
			(0.002)	(0.002)		
Observations	22,087	18,605	17,137	14,755	17,137	14,755
R-squared	0.791	0.632	0.808	0.652	0.807	0.651
Countries Sample (high/low income)	High	Low	High	Low	High	Low
Number of Countries	79	78	68	66	68	66
Number of Industries	294	294	259	259	259	259

Robust standard errors reported in parentheses. All regressions include country and industry fixed effects. The dependent variable is log ($Expo_{c,k}$) in the year 2014. The high-income sample comprises countries with GDP per capita above the sample median, and the low-income sample the countries with GDP per capita below it. The median income of the sample lies between that of Iraq ($12,095 PPP) and South Africa ($12,128 PPP) in 2014. Rule of law is taken from World Governance Indicators for year 2014. Private credit over GDP is taken from the World Bank Indicators, averaged for years 2005-2014. Physical capital and skill intensity by industry are taken from the NBER-CES Manufacturing Industry Database, and corresponds to year 2011. *** p<0.01, ** p<0.05, * p<0.1

small countries, on the one hand, they may find it easier to link together geographic locations while, on the other hand, they may be less able to provide sufficient opportunities for input diversity. Next, regarding very large countries in terms of area, the concern could be that some of those countries may contain very large portions of uninhabitable land, which may end up turning our measure of road density somewhat imprecise in those cases. Controlling for the size of the country (both in terms of area and population) takes into account the possibility that larger countries may face more opportunities for input diversity, regardless of the density of their internal transport network. Similarly, including total GDP can control for the possibility that there exist minimum size requirements to open up some sectors in the economy. Finally, restricting the sample to countries whose road networks were measured after 2010 helps in harmonizing the data year on trade flows and road density, and shows that the found effects are not contaminated by countries whose data on road networks is relatively older.

5 Endogeneity and Alternative Interpretations

The previous section presented a robust association between road density in country c and its degree of specialization in industries that rely on a wide set of inputs. While those results are certainly consistent with the main predictions of the model, they cannot be taken as hard evidence of its underlying mechanism. Two separate issues deserve further discussion and analysis. First, the correlation found in the previous regressions could as well be the result of road infrastructure responding to transport needs stemming from industry specialization (i.e., reverse causation). Second, our interpretation of a lower value of $Gini_k$ as reflecting greater need of industry k for the local transport infrastructure is debatable, as previous authors have looked at that variable as capturing a different feature: the degree of product complexity of industry k. In the next two subsections we aim to address these two points more explicitly.

5.1 Endogeneity and Reverse Causation

Our model has resorted to two critical assumptions that warrant further discussion in case the previous empirical results are intended to be interpreted as evidence of a *causal* effect from road density to specialization. Firstly, it has taken r_c as exogenously given. The length of a country's road network is however the result of investment choices in infrastructure, and hence it will respond to a host of economic variables and incentives. Secondly, the model has assumed away any sort of intrinsic differences in productivities *directly* linked to the production functions of final goods. In fact, all differences in countries' productivities across final sectors arise *indirectly* from the heterogeneities in the intensity of inputs implied by the parameter α_j in (3).

Relaxing the two above-mentioned assumptions can easily lead to a model where β in (23) can be confounding an effect from road density to specialization, together with reverse causality from the latter to the former. For example, suppose that for some reason the final good production functions differ across countries, and that H is relatively more productive than F in the final sectors whose α_j lies near one half.[31] In a context like this one, if countries can invest in expanding their road networks, we could well expect r_H to be larger than r_F simply because the incentives to do so are greater in H than in F. From an empirical viewpoint, this

[31] For example, we may have that final good productions functions are given by (3) for $\alpha_j \in [0, 0.5 - \epsilon]$ and for $\alpha_j \in [0.5 + \epsilon, 1]$, where $0 < \epsilon < 0.5$, and by

$$Y_j = (1 + \phi_c) \frac{1}{\alpha_j^{\alpha_j} (1 - \alpha_j)^{1-\alpha_j}} X_{0,j}^{1-\alpha_j} X_{1,j}^{\alpha_j}, \quad \text{for } \alpha_j \in (0.5 - \epsilon, 0.5 + \epsilon), \quad \text{with } \phi_H > \phi_F.$$

reasoning means that β could end up capturing (at least partially) an effect going from patterns of specialization to road density.

The rest of this subsection provides some further support for the notion that the density of the internal transport network is instrumental to specialization in industries with wider input bases. First, we show that a similar correlation to that one found in Section 4.3 arises when the density of the transport network is measured by the density of internal waterways. Next, we show that the results in Section 4.3 remain true when we instrument the density of a country's road network with topographical measures of terrain roughness.

5.1.1 Patterns of Specialization and Waterways Density

This first part intends to provide some further evidence consistent with the main mechanism of the model, by relying on a measure of countries' transport network that is *less* sensitive to reverse causality concerns than r_c is. We measure now the internal transport network of an economy by the density of their waterways network. We draw the data on waterways from the CIA World Factbook, and define waterways density as waterways length per square km.[32] Arguably, while countries can still expand their waterways by investing in creating canals or improving the navigability of some rivers and bodies of water, the scope for this is far more limited than in the case of roads.

One additional aspect we investigate here is the possibility that waterways impact specialization *heterogeneously* at different stages of development. For various reasons, richer economies tend to have much denser road networks than poorer ones. In particular, poorer economies may find it harder to undertake the necessary investment to build a sufficiently developed road infrastructure. On the other hand, while the presence of waterways may have influenced patterns of development before railroads and roads became more widespread worldwide, waterways are no longer a mode of transportation that seems to be associated with economies' current level of development. In fact, a quick look at simple cross-country correlations in Figure 2 shows that income per head and road density display a clear positive correlation, while the association between income per head and waterways density is rather weak.[33]

[32] The CIA World Factbook measures waterways as the total length of navigable rivers, canals and other inland bodies of water.

[33] One possible interpretation of the correlations in Figure 2 is that, as economies grow richer, roadways tend to gradually overshadow waterways as a mode of internal transportation. From this perspective, we could then expect waterways to represent an important determinant of patterns of specialization in poorer economies, but losing preeminence in richer economies where roadways can more easily make up for an insufficiently dense internal waterway network.

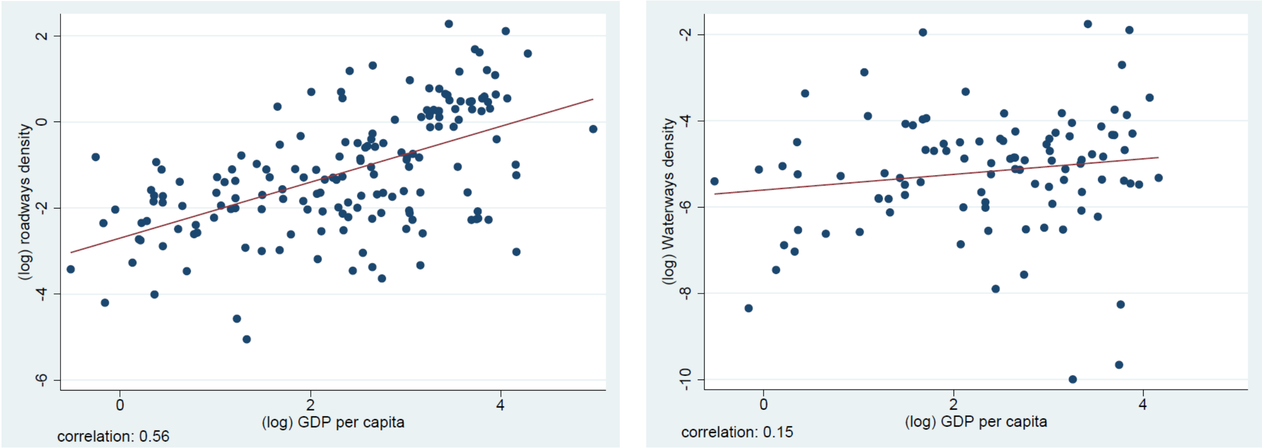

Figure 2: Roadways and waterways density against GDP per head

Table IV displays the results of a regression equation analogous to (23), but where r_c is replaced by a measure of *waterways density.* The table shows the results of two sets of regressions for three different countries sample: entire sample, high-income countries, and low-income countries.

The regressions based on the whole set of countries tend to yield an estimate that is negative. However, this aggregate result masks important heterogeneities in the effect of waterways density on export specialization in the case of richer versus poorer economies. Column (2) shows that waterways density carries no impact at all in the subsample of above-median income economies. By contrast, column (3) exhibits a negative and highly significant coefficient. This suggests that, in the case of poorer economies, those that enjoy a denser network of waterways tend to export relatively more in industries that require a wider intermediate input base. Columns (4)-(6) re-run the regressions in columns (1)-(3) but also including the original interaction term $r_c \times Gini_k$. The results for the impact of waterways density on specialization in (5) and (6) follow a very similar pattern as those in (2) and (3). Moreover, the regressions also show that the coefficient for road density remains negative and significant.[34]

Finally, Table A.5 in Appendix B shows the results a of set of regressions that include a triple interaction term between r_c, $Gini_k$ and log income, rather than splitting the sample of countries according to income. All the results remain qualitatively consistent with those in Table IV.

[34]Note that the results in columns (5) and (6) of Table IV are not directly comparable to those in columns (3) and (4) of Table III due to the loss of some countries in the samples of Table IV.

TABLE IV

Waterways Density as Measure of Transport Network

	(1)	(2)	(3)	(4)	(5)	(6)
Road Density x Input Narrowness	-0.262*	0.016	-1.120***	-0.137	0.194	-1.100***
	(0.148)	(0.140)	(0.347)	(0.170)	(0.172)	(0.347)
Rule of Law x Input Narrowness	-4.205***	-4.727***	-7.389***	-3.576***	-4.257***	-4.533*
	(0.838)	(1.546)	(2.511)	(0.902)	(1.561)	(2.811)
log (Priv Cred/GDP) x Input Narrowness	-1.724*	-2.403*	0.484	-1.857*	-2.505*	0.624
	(1.077)	(1.377)	(1.664)	(1.085)	(1.382)	(1.663)
log GDP per capita x Input Narrowness	0.457	5.220*	0.283	0.620	5.752**	0.830
	(0.867)	(2.944)	(1.256)	(0.874)	(2.962)	(1.268)
Capital Intensity x log $(K/L)_c$	0.007	-0.014	0.021*	0.008	-0.013	0.021*
	(0.006)	(0.014)	(0.012)	(0.006)	(0.014)	(0.012)
Skill Intensity x log H_c	0.007***	0.020***	-0.018***	0.007***	0.020***	-0.018***
	(0.001)	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)
Road Density x Input Narrowness				-1.381**	-1.426**	-7.249***
				(0.711)	(0.703)	(2.386)
Observations	22,357	11,750	10,607	22,357	11,750	10,607
R-squared	0.811	0.798	0.712	0.811	0.798	0.712
Countries Sample	All	High	Low	All	High	Low
Number of Countries	93	46	47	93	46	47
Number of Industries	259	259	259	259	259	259

Robust standard errors in parentheses. All regressions include country and industry fixed effects. The dependent variable is log($Expo_{c,k}$) in year 2014. Waterways is taken from the CIA World Factbook. It comprises total length of navigable rivers, canals and other inland water bodies. Waterway density equals internal waterways per square km. Columns (2) and (5) include only those countries with above median income in the sample. Columns (3) and (6) include only those countries whose income lies below the median income in the sample.
***p<0.01, **p<0.05, *p<0.1

5.1.2 Instrumental Variables: Terrain Roughness and Roadway Density

This second part intends to address more directly the concern of reverse causation from industry specialization to road density. To do so we instrument r_c with measures of terrain roughness in country c. The idea is drawn from Ramcharan (2009), who shows that countries with rougher terrain surface tend to exhibit less dense road networks.[35] In the context of our paper, if the roughness of the terrain affects the density of the internal road network, but it does not exert a systematic impact on specialization across industries with varying degrees of input narrowness via other alternative channels, then it can serve as a valid instrument for r_c.[36]

In Table V we show the results of the two-stage least square (2SLS) regressions using three alternative measures of terrain roughness: *i*) the difference between the maximum and minimum land elevation in country c, taken from the CIA Factbook; *ii*) the standard deviation of elevation of country c measured at 30" degree grids (approx. 1km cells), taken from Ramcharan (2009); *iii*) the percentage of mountainous terrain, taken from Fearon and Laitin (2003). Table A.6 in Appendix B shows that all three measures of terrain roughness are negatively correlated with road density, even after controlling for several other country-level variables.[37]

[35] Ramcharan (2009) studies the spatial concentration of economic activities within countries, and how this is affected by their surface topography. The author argues that countries with rougher topography tend to display stronger spatial concentration of economic activity, and that this is partly of explained by the poorer land transportation associated with rougher terrain.

[36] Notice that a violation of the exclusion restriction in this context requires more than simply terrain roughness having an impact on industry specialization. For the exclusion restriction to be violated, it must be the case that terrain roughness affects specialization across industries in a way that is also correlated with their degree of input narrowness (besides the effect mediated by the impact of terrain roughness on road density). For example, the exclusion restriction may be threatened if economies with rougher terrain tend to also display more heterogeneous climatic conditions and land configurations, and this allows them to enjoy a more diverse productive structure. Conversely, it may be that rougher terrain reduces the share of inhabitable land, curtailing productive heterogeneity, and thereby possibly leading to a violation of the exclusion restriction via a negative impact of roughness on specialization in industries with wide input breadth. While we cannot test the validity of the exclusion restriction, the results in Table A.7 in Appendix B (see also the discussion therein) are in principle encouraging about how concerned we should remain about a the possibility of a direct impact of terrain roughness, besides that one mediated by its effect on road density.

[37] All the measures of terrain roughness used here aim at capturing large-scale terrain irregularities. In a sense, these seem to be the types of irregularities that can most severely hinder internal transport networks. Other papers, e.g. Nunn and Puga (2012), have resorted to the methodology developed by Riley et al. (1999) so as to measure small-scale terrain irregularities. While small-scale terrain roughness measures seem more appropriate for capturing the presence of small geographic formations that may provide natural sources of protection to certain groups of people, they may not represent the main source of obstruction to dense transport networks.

Columns (1) and (2) display the results of the 2SLS regressions based on the difference between the maximum and minimum land elevation in c as instrument for r_c. Arguably, this variable may be seen as a relatively crude measure for terrain roughness. However, it has the upside of being available for the exact same samples as those in Section 4.3. As a result, columns (1) and (2) of Panel A can be directly compared to their respective OLS counterparts in columns (3) and (4) in Table II. Next, columns (4) and (6) display the estimation results of the 2SLS regressions in which the instrument for road density is based on the standard deviation of land elevation. Since for some of the countries in the original sample this information is missing, columns (3) and (5) show their respective OLS estimates for the corresponding sample. Finally, columns (8) and (10) report the 2SLS results when using the percentage of mountainous terrain as instrumental variable. Again, in the sake of comparability, columns (7) and (9) report the OLS estimates for the corresponding country samples.

The main message to draw from Table V is that the 2SLS regressions consistently yield a negative and significant estimate for our coefficient of interest. These results reinforce the support for the hypothesis that the density of the internal transport network is an important determinant of specialization in industries with wide input bases, by exploiting the variation in the internal road network across countries predicted by their degrees of terrain roughness.

One additional point to note from Table V is that the 2SLS estimates for β tend to be consistently greater in absolute magnitude than their OLS counterparts. This would in principle run against the direction of the bias that would stem from the reverse causality concern discussed in the second paragraph of Section 5.1 (i.e., the notion that economies specializing in industries that rely on a wide variety of inputs may tend to invest more in transport infrastructure). One possible reason behind these results is that the instrument may also be alleviating some degree of measurement error in our indicator of road density. In that respect, recall that r_c is computed using the total length of roads by country. This disregards the fact that different roads may differ substantially in terms of quality and width, and it is also summing up together paved and unpaved roads. Furthermore, the total length or the road network is not taking into account the possibility of a very inefficient lay out of the network. All these issues could end up reducing the precision with which r_c captures the notion that a denser road network allows cheaper internal transportation of inputs. Therefore, when instrumenting r_c, we may not only be dealing with problems of endogeneity, but also with the fact that in some cases our measure of road density may be quite imprecisely gauging the efficiency of the internal road network.

TABLE V

Two-Stage Least Squares Regressions using Terrain Roughness as Instrument for Roadway Density

	PANEL A: SECOND-STAGE RESULTS (AND OLS COMPARISONS)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	2SLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
Road Density x Gini	-5.006***	-3.188*	-3.364***	-6.199**	-2.204***	-6.166*	-3.347***	-5.638*	-2.000***	-5.645*
	(1.513)	(1.670)	(0.509)	(2.800)	(0.544)	(3.573)	(0.506)	(3.258)	(0.515)	(3.355)
Rule of Law x Gini	-1.260	-2.469**	-2.285***	-1.306	-2.886***	-1.264	-2.082***	-1.108	-3.147***	-1.543
	(0.943)	(1.100)	(0.720)	(1.187)	(0.786)	(1.635)	(0.737)	(1.564)	(0.790)	(1.661)
Fin Dev x Gini	-3.340***	-1.678*	-4.063***	-3.978***	-2.605***	-2.849***	-3.975***	-4.060***	-1.507	-1.719*
	(0.838)	(0.917)	(0.878)	(0.890)	(0.956)	(0.963)	(0.870)	(0.874)	(0.938)	(0.948)
log GDP pc x Gini	-0.088	1.077*	0.161	0.620	1.170*	1.857**	0.056	0.437	0.926	1.562*
	(0.623)	(0.677)	(0.667)	(0.781)	(0.714)	(0.908)	(0.641)	(0.820)	(0.676)	(0.868)
K Intens x log $(K/L)_c$		0.010**			0.009**	0.009**			0.008*	0.008*
		(0.004)			(0.0045)	(0.0045)			(0.004)	(0.004)
Skill Intens x log H_c		0.008***			0.007***	0.007***			0.008***	0.008***
		(0.001)			(0.001)	(0.001)			(0.001)	(0.001)
Observations	40,692	31,892	35,988	35,988	29,229	29,229	36,544	36,544	30,067	30,067
R-squared	0.763	0.794	0.764	0.764	0.794	0.793	0.757	0.757	0.795	0.795
Number of Countries	157	134	135	135	121	121	138	138	126	126
Number of Industries	294	259	294	294	259	259	294	294	259	259
	PANEL B: FIRST-STAGE RESULTS (Dep. Variable: Road Density x Input Narrowness)									
Terrain Roughness x Gini	-0.013***	-0.013***		-0.452***		-0.392***		-0.007***		-0.007***
	(0.0004)	(0.001)		(0.017)		(0.019)		(0.0002)		(0.0003)
Rule of Law x Gini	0.344***	0.371***		0.290***		0.350***		0.398***		0.413***
	(0.011)	(0.012)		(0.011)		(0.012)		(0.011)		(0.012)
Fin Dev x Gini	0.109***	0.059***		0.066***		-0.029***		-0.004		-0.032***
	(0.011)	(0.013)		(0.011)		(0.011)		(0.009)		(0.010)
log GDP pc x Gini	0.144***	0.164***		0.165***		0.184***		0.152***		0.163***
	(0.007)	(0.010)		(0.009)		(0.010)		(0.008)		(0.009)
K Intens x log $(K/L)_c$		0.005				0.010				0.008
		(0.008)				(0.007)				(0.007)
Skill Intens x log H_c		-0.010				-0.017				-0.010
		(0.015)				(0.013)				(0.014)
F-Stat: P-Value	0.00	0.00		0.00		0.00		0.00		0.00

Robust standard errors in parentheses. All regressions include country and industry fixed effects. The dependent variable in Panel A is the log($Expo_{c,k}$) in year 2014. 'Terrain Roughness' is measured as follows: *i*) in columns (1) and (2) by the diffference between the maximum and the minimum elevation in country *c* (source: CIA World Factbook); *ii*) in columns (4) and (6) by the std. deviation of elevation in country c computed at the 30" degree resolution (source: Ramcharan, 2009); *iii*) in columns (8) and (10) by the percentage of mountainous in terrain in country c (source: Fearon and Laitin, 2003). *** p<0.01, ** p<0.05, * p<0.1

5.2 Alternative Interpretations of the Input Breadth Measures

The analysis in Section 4 was based on the notion that the degree of input breadth of industry k can serve as an indicator for how reliant this industry is on the internal transport network. The need to source a large variety of inputs can certainly make a particular sector heavily dependent on efficient transportation; however, it can also mean that the sector is highly sensitive to sound contract enforcement. Indeed, Blanchard and Kremer (1997) and Levchenko (2007) have previously used input-output data to compute diversification indices for intermediate input purchases across industries, and use them to proxy the degree of complexity of sectors: sectors with more diversified (i.e., less concentrated) input bases are considered to be more complex.[38] In their analysis, more complex sectors require better contract enforcement to work efficiently. From this viewpoint, countries with better functioning institutions should exhibit a comparative advantage in industries with broad intermediate input bases. Levchenko (2007) shows that this is indeed the case for US imports: the US imports a higher share of goods with greater diversity of intermediate inputs from countries with better rule of law.

The regressions in Tables II - IV have conditioned on the interaction between rule of law in country c and the Gini coefficient for intermediate inputs in industry k. The estimate of β remained consistently negative and significant, regardless of the introduction of this additional control. In that regard, our results seem to suggest that *both* institutions and local transport networks are instrumental and complementary to the growth of industries with wide input bases. This section will attempt to further strengthen this argument

Countries with better institutions are in general richer, and also exhibit a denser transportation infrastructure network. If $Gini_k \times r_c$ in (23) were *not* capturing any type of impact related to how transport-intensive industry k is, but *only* the effect of rule of law in country c through its correlation with r_c, then the correlation found in Table I should arise more prominently for industries that are relatively more dependent on judicial quality. The regressions reported in Table VI show this is actually not the case in the data.

Columns (1) and (2) in Table VI show the results of the simple correlation reported initially in column (1) of Table I, after splitting the set of industries in two subsamples: low contract intensity vs. high contract intensity. To do so, we take the measure of contract intensity by industries from Nunn (2007), and split the sample of industries according to whether they rank below or above the median value of contract intensity.[39] If the $Gini_k$ were simply proxying for

[38] Both articles used the Herfindahl index of concentration instead of the Gini as their benchmark measure.

[39] Nunn (2007) reports contract intensity measures for 222 industries coded according to NAICS 1997. We lose some of the original industries in Table I when matching the NAICS 1997 codes to those of BEA 2002.

TABLE VI

Regressions on Industry Subsamples: Effects at Different Leves of Contract Intensity

	(1)	(2)	(3)
Road Density x Input Narrowness	-3.443***	-1.929***	-2.070***
	(0.652)	(0.483)	(0.440)
Rule of Law x Contract Intensity			0.441***
			(0.057)
Rule of Law x Input Narrowness			-1.974**
			(0.926)
log (Priv Credit/GDP) x Input Narrowness			-0.533
			(1.082)
log GDP x Input Narrowness			0.897
			(0.772)
Capital Intensity x log $(K/L)_c$			0.007***
			(0.002)
Skill Intensity x log H_c			0.008*
			(0.005)
Observations	13,179	14,231	20,823
R-squared	0.704	0.820	0.790
Contract Intensity	low	high	all
Number of Countries	166	166	134
Number of Industries	91	91	163

Robust standard errors in parentheses. All regressions include country and industry fixed effects. The dependent variable is log($Expo_{c,k}$) in year 2014. Contract intensity by industry measures are taken from Nunn (2007). The original measures are coded according to the NAICS 1997 classification and matched to the BEA codes. Nunn (2007) measures contract intensity in k as the proportion of inputs of k classified as differentiated by Rauch (1999). Rule of law is from the World Governance Indicators (year 2014). Private credit over GDP is from the World Bank Indicators (averaged for 2005-14). GDP per capita, total GDP, the stock of physical capital (per capita), and the human capital index (H_c) are all taken from the Penn Tables (year 2014). Capital and skill intensity by industry are from the NBER-CES Manuf. Industry Database (for year 2011). *** p<0.01, ** p<0.05, * p<0.1

how sensitive to efficient contract enforcement industry k is, then the estimate in column (1) should turn out to be significantly milder than that one in column (2). The regressions show, however, that the negative correlation is significant in both subsamples, and moreover the magnitude of the estimates are not significantly different from one another.

Finally, to complement our previous results, column (3) displays the outcomes of a regression analogous to that one in column (4) of Table II, but including the interaction term between rule of law in country c and contract intensity of industry k (namely, 'Rule of Law $\times$ Contract Intensity'). Consistently with the previous results in the literature, the regression shows that countries with better institutions exhibit a comparative advantage in the industries with higher contract intensity. Moreover, the regression results are in line with those in column (4) of Table II, and support the prediction that countries with denser road networks export relatively more in sectors that require a broader variety of intermediate inputs.

6 Further Discussion: Clustering and Coagglomeration of Industries

The empirical results in the previous sections align with the model's prediction that economies with denser road networks exhibit a comparative advantage in industries with broad input bases. The underlying mechanism of the model rests crucially on the idea that intermediate producers (and industries in general) are *unevenly* distributed across space. As a consequence, industries that require a wider set of inputs will also turn out to be in higher need of costly transportation for many of them. This section discusses the empirical plausibility of the notion that industries using a large variety of inputs will be sourcing a vast number of them from diffuse locations.

If the set of industries in the economy were uniformly distributed across space, then whether a particular sector requires a wide or a narrow set of intermediate inputs would in principle have no differential effect on their incurred transport costs. The differential effect of road density across sectors with broad versus narrow input bases is, in fact, intrinsically linked to two features of the geographic distribution of economic activities: *i*) concentration of specific industries in certain geographic locations; *ii*) coagglomeration of industries with strong input-output links. Both of these features have been vastly documented in different empirical studies.

Geographic Concentration by Industry: Examples of geographic concentration of specific industries abound. Probably, the most often-cited ones are the high-tech firms in Silicon Valley and the automobile industry in Detroit. In addition to these paradigmatic cases, a growing number of articles have shown that industry geographic clustering is a quite prevalent feature among a vast number of different industries, and also in different countries. For example, Ellison and Glaeser (1997) study the degree of concentration of U.S. manufacturing industries, and find that 446 out of 495 four-digit SIC sectors display excess geographic concentration (relative to the degree of geographic concentration that would be observed if firms in all industries would pick their locations following an identical random process). Moreover, they find that over one quarter of the U.S. manufacturing industries exhibit what they deem as 'high geographic concentration'. Similar results are found for France by Maurel and Sedillot (1999), for the U.K. by Devereux, Griffith and Simpson (2004) and by Duranton and Overman (2005), for Japan by Mori, Nishikimi and Smith (2005), and for Belgium by Bertinelli and Decrop (2005). Our model in Sections 2 and 3 has assumed a dispersed location of input sources. The rationale behind that assumption is to generate geographic clustering of firms by industry.

Coagglomeration of Strongly Linked Industries: One other crucial aspect of the model leading to a differential impact of road density on the cost of input transportation in different industries is the (endogenous) location of final sectors near their main input source. This result of the model also aims at recreating a feature of the geographic distribution of industries documented in the data. Ellison and Glaeser (1997) and Ellison, Glaeser and Kerr (2010) show that manufacturing industries in the U.S. with strong input-output links tend to locate in close physical proximity, whereas Duranton and Overman (2008) produce similar evidence for the case of the U.K. Furthermore, Ellison, Glaeser and Kerr (2010) show that the presence of input-output links between upstream and downstream industries represents the strongest factor leading to coagglomeration (amongst the three traditional Marshallian reasons for coagglomeration),[40] and that economizing on transport cost via physical proximity constitutes a key channel for this.

Input Narrowness and Geographic Concentration: An implicit feature in our model is the heterogeneous surplus from coagglomeration across sectors differing in their α_j. In particular, the input transport cost savings arising from coagglomeration near the main input source increase as α_j approaches either of the two extremes of the unit interval. In the benchmark model this specific feature does not arise in very transparent way, as the use of iceberg transport cost that are linear in distance lead to corner solutions in eq. (6), which depend only on whether $\alpha_j < 0.5$ or $\alpha_j > 0.5$.[41] Despite that, the knife-edge case when $\alpha_j = 0.5$ in eq. (6) means that firms in that industry will be indifferent between location 0 and 1. As a result, one can think that those firms will choose amongst the two locations (possibly) in a random way. Bridging this aspect to the data would imply that industries with smaller values of $Gini_j$ (i.e., those with intermediate values of α_j) will tend to be more dispersedly located than those with higher values of $Gini_j$ (i.e., those with either low or high values of α_j). Figure 3 shows that this fact seems to be the verified in the case of U.S. manufacturing industries.

[40] These three reasons are: *i*) to save on transport cost of goods; *ii*) to allow pooling of workers and save thus on transport of people; *iii*) to allow spillovers of ideas across firms/industries.

[41] See eqs. (33) and (34) in Appendix D for a case where the cut-off value of α_j depends also on other factors (e.g., wages, sectoral productivities, transport cost per unit of travelled distance). Recall also footnote 12 concerning the effect of convex cost in distance, and the possibility of interior solutions for sectors with values of α_j that lie far from the ends of the interval $[0, 1]$. Finally, the three-input case presented in Appendix D can also lead to solutions where the intensity of agglomeration depends on the degree of disparity between the Cobb-Douglas weights across the three intermediate goods, as showcased by eqs. (40) and (41).

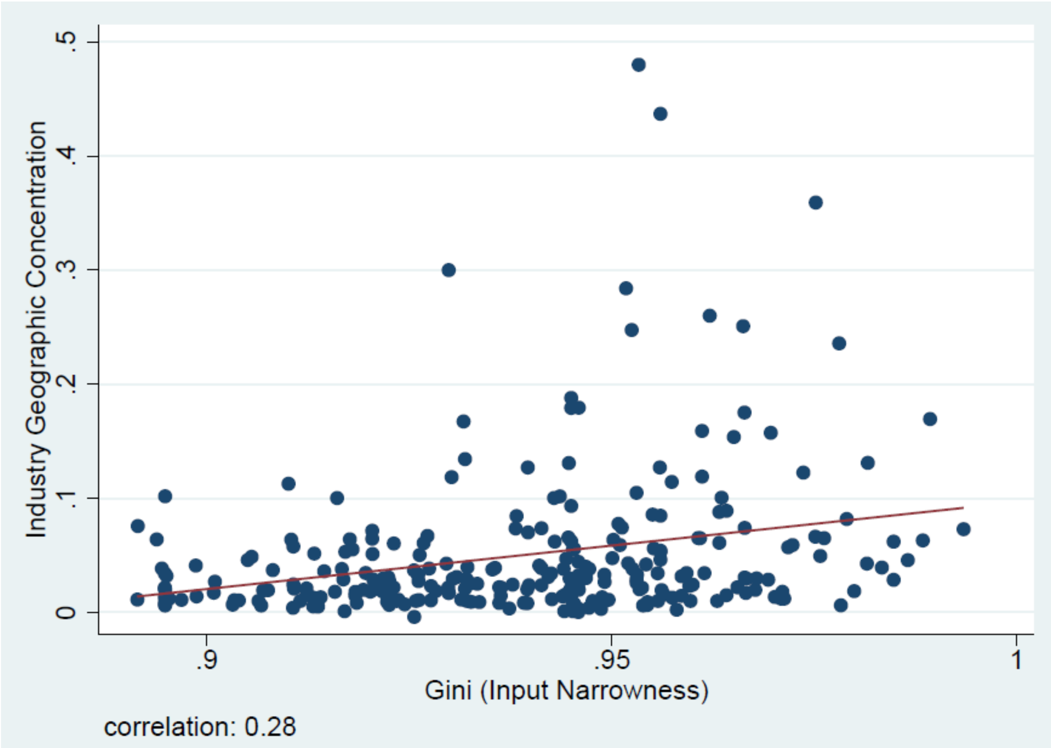

Figure 3: Geographic Concentration and Input Narrowness across Industries

Figure 3 displays a scatterplot showing the correlation between our measure of input narrowness by industries and an index of their degree of geographic concentration. The index of geographic concentration is taken from Ellison and Glaeser (1997).[42] The higher the value of the index, the more strongly concentrated the industry is. In addition, a value of the index of geographic concentration above zero means that the industry exhibits stronger geographic concentration than what would be observed if firms within the industry chose their location randomly. As the figure shows, industries with narrower input bases tend to be geographically more concentrated. This observation is consistent with the notion that industries with narrow input bases are those that tend to benefit more strongly from locating in close proximity to their main intermediate input providers, and thus they will show up in the data as geographically more concentrated that those with lower values of the Gini coefficient.

[42] The index of geographic concentration in Ellison and Glaeser (1997) is computed for U.S. manufacturing industries classified according to the 4-digit SIC codes. We matched the 4-digit SIC classification to the BEA industry classification of the U.S. input-output matrix. Figure 3 plots the correlation between input narrowness and geographic concentration using the BEA industry classification.

7 Concluding Remarks

We proposed a simple trade model where the density of the internal transport network represents a key factor in shaping comparative advantage and specialization. The underlying mechanism rests on the idea that shipping intermediate inputs across spatial locations is costly. As a consequence, industries that rely on a wide set of intermediate inputs become heavier users of the internal transport network. The model shows that countries with denser transport infrastructures exhibit a comparative advantage in industries that combine a large variety intermediate goods. Furthermore, when disparities in the internal transport network across countries are sufficiently pronounced, they can sometimes even overturn more standard Ricardian patterns of specialization driven by heterogeneities in labor productivities across sectors.

Drawing on intermediate goods transactions from the US input-output matrix to measure industries' input breadth, we have also shown that the patterns of specialization predicted by the model are broadly consistent with the trade flows observed in the data. In particular, our empirical analysis shows that countries with denser road networks tend to export relatively more in industries that rely on a wide set of intermediate inputs.

Several caveats apply nonetheless to the empirical evidence. First, patterns of specialization could be influencing investment in road infrastructure, and thus be behind the correlation found in the data. In that respect, the fact that the same correlation appears when substituting roadway density by waterway density seems reassuring, as waterways are harder to expand in response to increased transport needs. Furthermore, our empirical results also remain in line with the predictions of the model when we instrument the density of countries' road networks with indicators of roughness of their terrain. Second, the measure of input breadth by industries could alternatively be capturing a stronger need for contract enforcement when the input base is wider. We showed however that the correlation predicted by our model is still present when the confounding effect of institutional quality (by country) and judiciary intensity (by industry) is also taken into account. Finally, our measure of road density is a relatively imprecise way to capture the efficiency in connectedness of different locations. Road networks not only differ in length, but also in terms of width, quality, etc. In addition, our measure of road density fails to account for inefficiencies in the layout of internal roads, and it also aggregates together paved and unpaved roads. It would be certainly desirable to use of a more detailed and refined measure of internal road networks by countries. Yet, it is hard envision a clear reason why the above sources of measurement error in the road density indicator can end up systematically biasing the previous empirical results in the direction predicted by the model.

Appendix A: Proofs and Additional Theoretical Results

Proof of Lemma 1. To prove that $c_j^*(r_1)/c_j^*(r_2) \geq 1$ for all $\alpha_j \in [0,1]$ with strict inequality if and only if $\alpha_j \in (0,1)$, notice that $\varphi'(r) < 0$ implies that $1 + \varphi(r_1)t > 1 + \varphi(r_2)t$, and using (7) we have:

$$c_j^*(r_1)/c_j^*(r_2) = \begin{cases} \left[(1+\varphi(r_1)t) \,/\, (1+\varphi(r_2)t)\right]^{\alpha_j} & \text{for } 0 \leq \alpha_j \leq 0.5, \\ \left[(1+\varphi(r_1)t) \,/\, (1+\varphi(r_2)t)\right]^{1-\alpha_j} & \text{for } 0.5 \leq \alpha_j \leq 1. \end{cases} \tag{24}$$

To prove the second part of the lemma, apply logs to $c_j^*(r_1)/c_j^*(r_2)$ in (24), and differentiate w.r.t. α_j, to obtain that $\partial\left(\ln\left(c_j^*(r_1)/c_j^*(r_2)\right)\right)/\partial\alpha_j > 0$ for $0 \leq \alpha_j < 0.5$ and $\partial\left(\ln\left(c_j^*(r_1)/c_j^*(r_2)\right)\right)/\partial\alpha_j < 0$ for $0.5 < \alpha_j \leq 1$. ■

Proof of Proposition 1. We first prove by contradiction that $\omega = 1$ cannot hold in equilibrium. Given that the expression in (16) entails that total imports from F by H increase with ω, while total exports by H to F decrease with ω, it will then follow that in equilibrium we must necessarily have $\omega^* > 1$, and that this equilibrium will be unique. We carry out the proof of $\omega^* > 1$ by splitting the possible parametric configurations of the model in three subsets.

i) Case 1: $\delta \leq (1+\tau)^2$. In this case, when $\omega = 1$, using the LHS of (16), it follows that total exports by H are equal to:

$$Expo_H = \frac{\ln(1+\varepsilon) - \ln(1+\tau)}{2\ln(1+\varepsilon) - \ln(\delta)}. \tag{25}$$

Notice that $(1+\tau)^2 \geq \delta$ implies the RHS of (25) is never greater than one half, while Assumption 2 implies it is strictly above zero. Using now the RHS of (16), we can obtain that total imports by H are:

$$Impo_H = 1 - \frac{\ln(1+\varepsilon) + \ln(1+\tau) + \ln(\delta)}{2\ln(1+\varepsilon) + \ln(\delta)}. \tag{26}$$

Comparing (25) versus (26), while bearing in mind $\delta > 1$, yields $Expo_H > Impo_H$. Hence, when $(1+\tau)^2 \geq \delta$, the equilibrium must necessarily encompass $\omega > 1$.

ii) Case 2: $(1+\tau)^2 < \delta < (1+\varepsilon)^2$. Using setting again (16), we obtain:

$$Expo_H = \frac{\ln(1+\varepsilon) - \ln(1+\tau) + \ln(\delta)}{2\ln(1+\varepsilon) + \ln(\delta)}, \tag{27}$$

while total imports by H are still given by (26). When $(1+\tau)^2 < \delta$, the RHS of (27) yields a value strictly larger than one half, while the RHS of (26) is always strictly smaller than one half. As a consequence, $Expo_H > Impo_H$ also when $(1+\tau)^2 < \delta < (1+\varepsilon)^2$, and the equilibrium must necessarily encompass $\omega > 1$ in that range too.

iii) Case 3: $(1+\varepsilon)^2 < \delta$. Using once again (16), notice that total exports by H are still given by (27), which yields a value strictly above 0.5 and strictly below 1. In addition, total imports by H are still given by (26), which yields a value strictly above 0, but strictly below one half. Hence, when $(1+\tau)^2 \geq \delta$, the equilibrium must encompass $\omega > 1$ as well.

Next, to prove that ω^* is strictly increasing in δ, it suffices to note that the boundaries in all the expressions of the indicator functions $\mathbb{I}\{\cdot\}$ in (16) are all strictly increasing in δ.

Lastly, to prove the different bounds on ω^* we proceed by contradiction for each of them. First, suppose that $(1+\varepsilon)^2 > \delta$. Notice that if $\omega^* \geq (1+\tau)\delta^{0.5}$, then using (16) we can observe that the mass of final goods exported by F would be at least one half. However, this is incompatible with the fact that in equilibrium $\omega^* > 1$. Hence, it must be that $\omega^* < (1+\tau)\delta^{0.5}$. Next, notice that when $\omega^* \geq (1+\varepsilon)/(1+\tau)$, the exports by H fall to zero, while H's imports are strictly positive; hence, this cannot hold in equilibrium either, and it must be that $\omega^* < (1+\varepsilon)/(1+\tau)$. Second, suppose now that $(1+\varepsilon)^2 < \delta$. In this case when $\omega^* \geq (1+\tau)^{-1}\delta^{0.5}$, exports by H would fall to zero, while H's imports would still be strictly positive. Hence, it must be the case that $\omega^* < (1+\tau)^{-1}\delta^{0.5}$. ■

Additional Results of Proposition 2. We plot below that additional two sub-cases encompassed by Proposition 2 – *case 1 (bis)* and *case 2 (bis).*

Case 1 (bis) occurs when $\delta < (1+\varepsilon)^2$ and the parametric configuration of the model is such that, in equilibrium, $\omega^* < (1+\tau)^{-1}\delta^{\frac{1}{2}}$. The graph is qualitatively similar to case 1 in Figure 1 of the main text, with the difference that country H exports goods with $\alpha_j \in [0, \overline{\alpha}_H)$, where $\overline{\alpha}_H$ lies above one half.

Case 2 (bis) takes place when $\delta > (1+\varepsilon)^2$ and the parametric configuration of the model is such that, in equilibrium, $\omega^* > (1+\varepsilon)(1+\tau)$. The main qualitative difference between this one and case 2 in Figure 1 is that here country F exports only those goods on the upper end of $[0,1]$, namely those with $\alpha_j \in (\overline{\alpha}_F, 1]$.

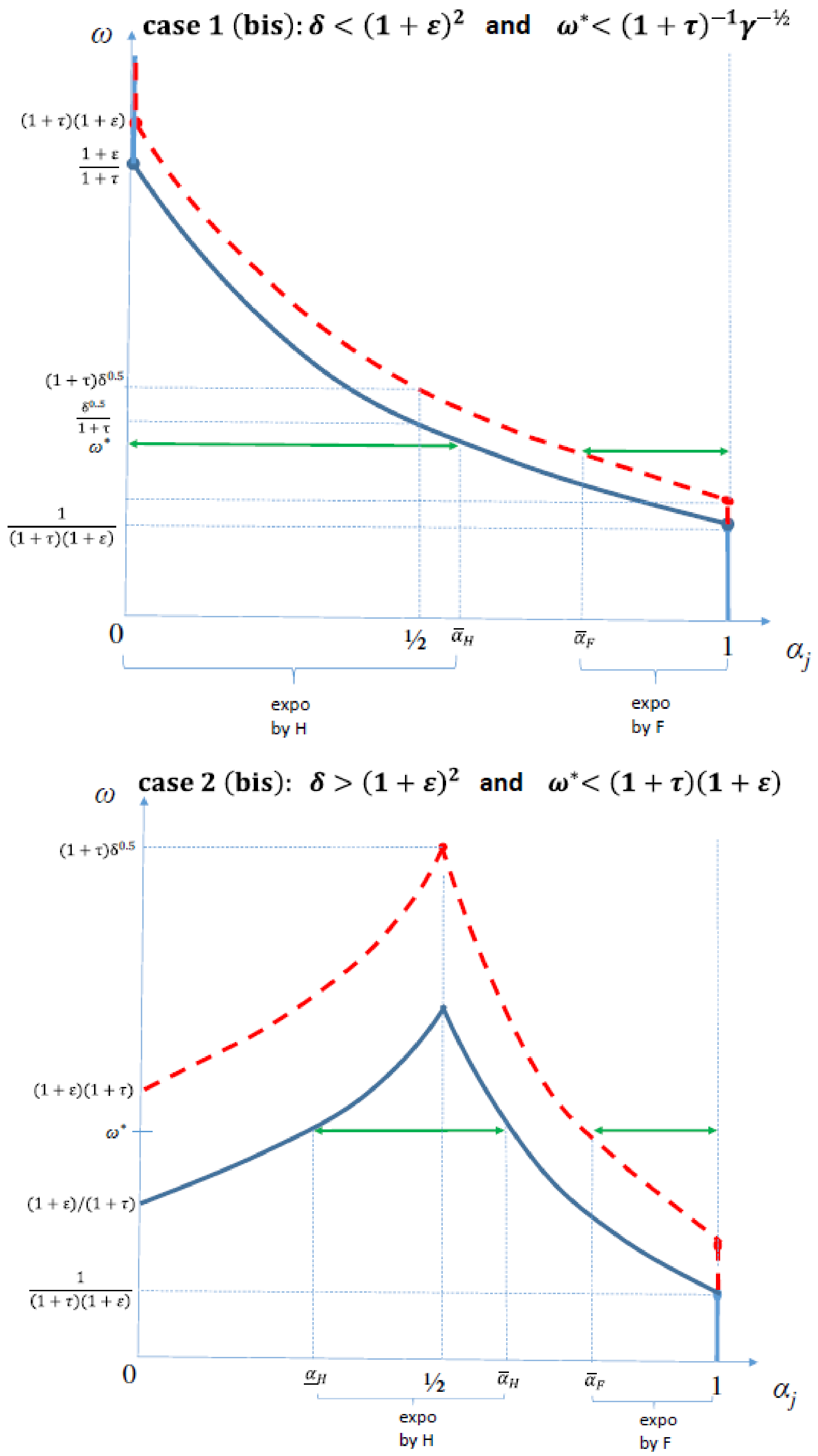

Figure 1 (bis): Patterns of Trade and Specialization

A Simple Microfoundation of the Distance Function $\varphi(r)$

We provide here a simple illustration of the geographical structure an the economy that serves as microfoundation of the function $\varphi(r)$ assumed in Section 2.2.

Suppose there exists an infrastructure network connecting location 0 and 1 that comprise two two types of pathways. One is a semi-circular path of total length $\pi/2$, which represents the *least* direct path between the two locations. The other one is a road of length $r \in [0, 1]$, which allows shortening the distance between the two locations given by the semi-circular path.

The infrastructure network structure is plotted in Figure 4 for two different roads lengths, namely $0 < r_1 < r_2 < 1$. (Without any loss of generality, we will arbitrarily place the starting point of the roads always in location 0.) The two extreme cases $r = 0$ and $r = 1$ would correspond, respectively, to the case where the only path available from location 0 to location 1 is via the semi-circular arch of length $\pi/2$, and the case where the two locations are connected by a straight horizontal line of length one.[43]

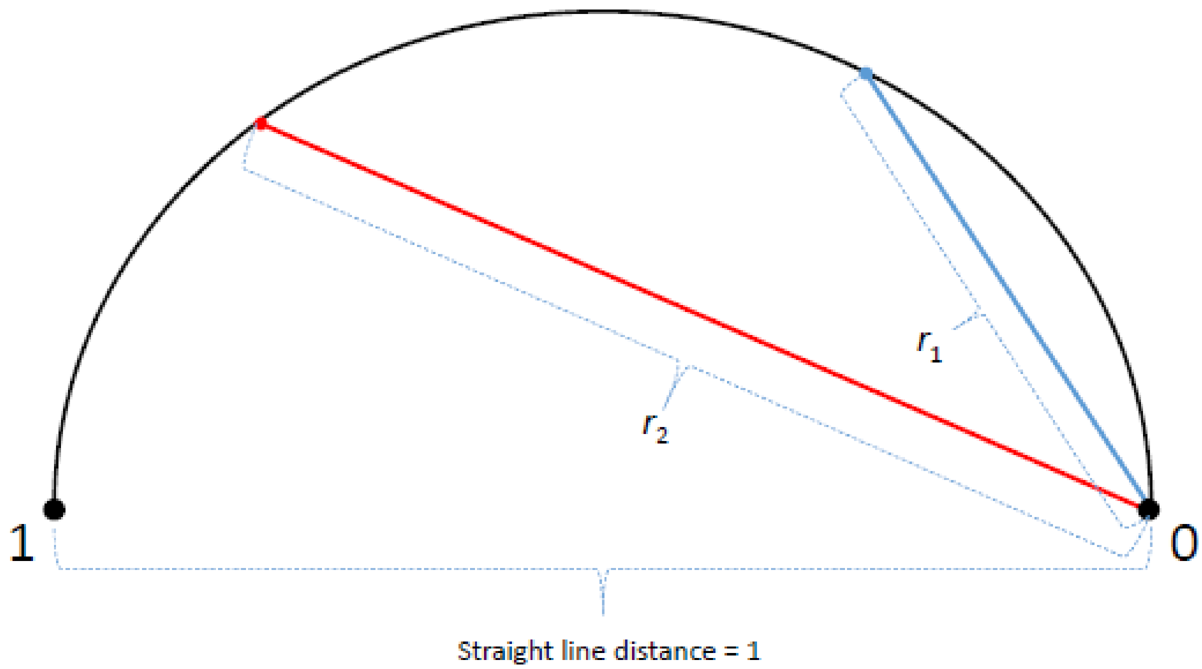

Figure 4: Geographic Structure of the Economy

[43]Conceptually, Figure 4 intends to represent the notion that road networks facilitate transportation across location 0 and 1, relative to the (lengthier) semi-circular path of length $\pi/2$. Nothing precludes the fact that a road network of length r could comprise several segments, whose lengths sum up to r. As it will become clear next, this would not be optimal. More precisely, given a total length of road network equal to $r \in [0, 1]$, the shortest distance to connect inputs locations is achieved by building one single straight line.

Denoting by $\varphi(r)$ the *shortest* distance between location 0 and 1, given a road network of length $r \in [0,1]$, the following lemma characterizes the main properties of $\varphi(r)$.

Lemma 3 *The shortest distance between location* 0 *and* 1 *is a strictly decreasing function of the road length; i.e.,* $\varphi'(r) < 0$*. In addition,* $\varphi''(r) < 0$.[44]

Proof. To prove the lemma we first find the closed-form expression of the function $\varphi(r)$. Notice that any straight segment connecting two points of the semi-circle linking location 0 to location 1 could be seen as a chord within a circle. We can then use the formula for the *chord length* in circle, which in this case of only one straight segment of length r would state that

$$r = 2 \cdot radius \cdot \sin\left(f \cdot \frac{\pi}{2}\right), \tag{28}$$

where f equals the share of the whole semi-circle that is covered by the straight line of length r.[45] From (28), bearing in mind that $radius = 0.5$, it follows that the share of the semi-circle covered by the road of length r is given by $f = \frac{2}{\pi} \cdot \arcsin(r)$. Therefore, since the semi-circle has total length equal to $\pi/2$, the total distance *not* covered by r is equal to $\pi/2 - \arcsin(r)$. Summing up to this last amount the total length of the road, r, we finally obtain that:

$$\varphi(r) = \frac{\pi}{2} + r - \arcsin(r), \tag{29}$$

Next, differentiating (29), we obtain

$$\varphi'(r) = 1 - (1 - r^2)^{-\frac{1}{2}}, \tag{30}$$

which is strictly negative for any $0 < r \leq 1$.

Finally, differentiating (30) , we can also observe that $\varphi''(r) = -r/(1-r^2)^{-\frac{3}{2}}$, which is also strictly negative for any $0 < r \leq 1$. Finally, notice that $\varphi''(r) < 0$ in turn implies that the shortest way to link location 0 and 1 when the road length is $r \in [0,1]$ is through one single straight segment of length r. ■

[44] The *only* crucial feature that the model needs is $\varphi'(r) < 0$, which implies that road length lowers the cost of internal transportation of goods. This is in fact the only assumption placed in the main text in Section 2.2. The only implication of $\varphi''(r) < 0$ for the model is that, for a given road length r, the shortest distance between location 0 and 1 is achieved by building one single straight segment of length r, as plotted in Figure 3.

[45] More formally, f equals the ratio between the angle formed by a straight line going from the center of the semi-circle to the endpoint of the chord of length r, and an angle of 180°.

Appendix B: Additional Empirical Results

This appendix displays some additional empirical results that complement those in the main text. For neatness, we split this appendix in two separate subsections.

Complementary Results for Section 4.3

This section first reports some summary statistics in Table A.1 corresponding to the main variables of interest in Section 4.3. Next, Table A.2 and A.3 show the results of some regressions, analogous to some of those previously presented in Section 4.3, but where the measure of the density of the transport network is either changed or expanded. Finally, Table A.4 provides some further robustness checks to the regressions in Section 4.3.

TABLE A.1

Summary Statistics

Variable	Mean	Std Dev	Min	Max	Obs
Gini Coef.	0.93949	0.02314	0.88882	0.99342	294
Herfindahl Index	0.10087	0.08036	0.02883	0.77590	294
Coef. Var.	5.8063	2.03478	3.1955	17.2480	294
Log-Variance	-8.4915	0.62126	-9.5830	-6.2111	294
Roadways per sq km	0.78873	1.33132	0.00639	9.79747	166
Railways per sq km	0.02148	0.02792	0.00007	0.13693	122
Waterways per sq km	0.01360	0.02720	0.00005	0.17264	100

TABLE A.2

Transport Density measured by Railway Density

	(1)	(2)	(3)	(4)
Railway Density x Input Narrowness	-2.281***	-1.189***	-0.903***	-0.885***
	(0.133)	(0.159)	(0.162)	(0.163)
Rule of Law x Input Narrowness		-1.567**	-2.408***	-2.359***
		(0.766)	(0.824)	(0.828)
log (Priv Credit/GDP) x Input Narrowness		-4.328***	-2.048**	-2.031**
		(0.936)	(1.006)	(1.007)
log GDP per capita x Input Narrowness		-0.442	0.574	0.979
		(0.746)	(0.782)	(0.775)
Capital Intensity x log $(K/L)_c$			0.009*	
			(0.005)	
Skill Intensity x log H_c			0.007***	
			(0.001)	
Observations	33,099	32,153	26,444	26,444
R-squared	0.754	0.756	0.794	0.793
Number of Countries	122	118	109	109
Number of Industries	294	294	259	259

Robust standard errors in parentheses. All regressions include country and industry fixed effects. Railway density equals the total length of the railway network in km, divided by the area measured in sq km. Data of railway network length is taken from the CIA factbook. *** p<0.01, ** p<0.05, * p<0.1

TABLE A.3

Transport density measured by sum of roadways, railways and waterways per square km

	(1)	(2)	(3)	(4)	(5)	(6)
Transp. (road + rail + waterway) Density x Input Nwness	-7.268***	-2.680***	-1.519***	-4.108***	-2.376***	-1.881***
	(0.519)	(0.598)	(0.587)	(0.302)	(0.361)	(0.375)
Rule of Law x Input Narrowness		-2.381***	-2.892***		-2.394***	-3.091***
		(0.900)	(0.936)		(0.703)	(0.764)
log (Priv Credit/GDP) x Input Narrowness		-4.304***	-2.487**		-3.537***	-1.698*
		(1.072)	(1.114)		(0.822)	(0.913)
log GDP per capita x Input Narrowness		-0.872	-0.054		-0.410	0.911
		(0.874)	(0.933)		(0.602)	(0.656)
Capital Intensity x log $(K/L)_c$			0.009			0.010**
			(0.006)			(0.004)
Skill Intensity x log H_c			0.007***			0.008***
			(0.002)			(0.001)
Observations	25,180	24,234	21,014	42,578	40,692	31,892
R-squared	0.768	0.769	0.805	0.765	0.764	0.794
Number of Countries	92	88	86	166	157	134
Number of Industries	294	294	259	294	294	259

Robust standard errors in parentheses. All regressions include country and industry fixed effects. Columns (1) to (3) only include observations where information on all transport measures (i.e., roadway, railway and waterway) is available. Columns (4) to (6) also include observations where information on either railway or waterway (or both) are missing, replacing the missing values by zero. *** p<0.01, ** p<0.05, * p<0.1

In Table A.2, road density is replaced by railway density, as our main measure of depth of local transport network. All the results follow a similar pattern as those in Section 4.3. In Table A.3, we expand the measure of transport network density to include, in addition to roadways, also railways and waterways. In this case, the density of the transport network of country c is measured as the sum of total kilometers of roadways, railways and waterways, divided by the area of the country. Again, all the results follow a similar pattern as those in Section 4.3.[46]

Table A.4 provides some final robustness checks, by restricting the samples of the regressions reported in column (4) of Table 2 on a number of dimensions, and also by adding a few additional covariates to that regression. Column (1) restricts the sample to countries with area greater than 10,000 sq km, while column (2) restricts the sample to countries with population larger than half million inhabitants. As we can see, results remain qualitatively unaltered when we exclude small countries (either in size or population) from the sample. Column (3) excludes very large countries in terms of their size. In particular, we drop from the sample countries whose area is larger than 3,000,000 sq km.[47] The rationale for this additional robustness check

[46]Note that for many countries we do not have information on railways or waterways, while we do have information on roadways. This means that the total sample of the regressions in columns (1), (2) and (3) falls substantially. For additional comparison, in columns (4), (5) and (6), we also include countries with missing information on either railways or waterways (or in both), replacing the missing values by zeros.

[47]This excludes the following seven countries from the sample: Russia, Canada, United States, China, Brazil, Australia and India. The results are robust to setting the area-threshold for exclusion on alternative levels, such

TABLE A.4

Additional Robustness Checks: area, population and year of roads in sample

	(1)	(2)	(3)	(4)	(5)	(6)
Road Density x Input Narrowness	-2.589***	-1.767***	-2.034***	-1.584***	-1.733***	-1.748***
	(0.579)	(0.399)	(0.514)	(0.485)	(0.512)	(0.511)
Rule of Law x Input Narrowness	-2.869***	-3.929***	-3.172***	-3.363***	-3.350***	-2.888***
	(0.804)	(0.833)	(0.788)	(0.769)	(0.770)	(0.842)
log (Priv Credit/GDP) x Input Narrowness	-1.687*	-0.793	-1.611*	-1.422*	-1.600*	-2.123**
	(0.950)	(0.961)	(0.928)	(0.922)	(0.940)	(1.099)
log GDP per capita x Input Narrowness	0.889	0.797	0.983	0.736	5.417	0.207
	(0.676)	(0.677)	(0.663)	(0.665)	(5.263)	(0.821)
Capital Intensity x log $(K/L)_c$	0.009***	0.011**	0.009**	0.010**	0.010**	0.017***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
Skill Intensity x log H_c	0.007***	0.006***	0.007***	0.008***	0.008***	0.012***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
log area x Input Narrowness				0.606	0.572	
				(0.397)	(0.398)	
log population x Input Narrowness				-1.107**	3.599	
				(0.453)	(5.310)	
log GDP x Input Narrowness					-4.666	
					(5.229)	
Observations	29,760	30,085	30,817	31,892	31,892	24,467
R-squared	0.796	0.780	0.794	0.794	0.794	0.792
Number of Countries	125	127	129	134	134	101
Number of Industries	259	259	259	259	259	294
Sample	> 10 000 km^2	> 500,000 pop	< 3 million km^2	all countries	all countries	year roads 2010+

Robust standard errors in parentheses. All regressions include country and industry fixed effects. Column (1) excludes countries whose area is smaller than 10,000 km^2. Column (2) excludes countries whose population is below 500,000 inhabitants. Column (3) excludes countries with area larger than 3,000,000 km^2. Column (6) excludes countries for which the measure of road density in the dataset was recorded before 2010. *** p<0.01, ** p<0.05, * p<0.1

is to account for the possibility that results may be affected by the fact that some very large countries may also have large swaths of uninhabitable land. Next, column (4) uses again the entire sample of countries, but adds interactions terms between countries log area and $Gini_k$, and between log population and $Gini_k$. This would control for the possibility that larger countries may offer more opportunity for input diversity than smaller countries. Column (5) includes an interaction term log GDP and $Gini_k$, in case the aggregate size of the economy may have some impact on specialization in sectors with different degrees of input narrowness. Finally, column (6) excludes from the sample countries whose road network was measured before year 2010, which corresponds to the median year in the sample (see details in Table A.8 in Appendix C). The results remain also qualitatively unaltered when restricting the sample to countries whose road networks are more recently measured.

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as at 7,000,000 km^2 (which would leave India within the sample), or at 2,000,000 km^2 (which would additionally remove Argentina, Algeria, Congo, and Saudi Arabia from the sample).

Complementary Results for Section 5.1.1

Table A.5 shows the results of regressions analogous to those in Table IV in the main text, but instead of splitting the sample of countries according to their income per head, it introduces a triple interaction term between waterway density, the degree of input narrowness and the (log) income per head of countries.

The results on Table A.5 are consistent with those of Table IV. In particular, we can see that the triple interaction term carries always a positive and significant coefficient. This suggests that the positive effect of waterways density on specialization in industries with broad input bases tends to be lower for richer economies than it is for lower-income countries.

TABLE A.5

Additional Robustness Checks: Waterways Density

	(1)	(2)	(3)	(4)
Waterways Density x Input Narrowness	-1.634***	-1.921***	-2.037***	-2.155***
	(0.584)	(0.606)	(0.592)	(0.614)
Waterways Density x Input Narrowness x log Income	0.486***	0.554***	0.738***	0.702***
	(0.174)	(0.180)	(0.183)	(0.189)
Rule of Law x Input Narrowness	-4.968***	-4.731***	-3.420***	-3.811***
	(0.822)	(0.853)	(0.875)	(0.904)
log (Priv Credit/GDP) x Input Narrowness	-2.745**	-1.037	-2.793***	-1.076
	(1.071)	(1.112)	(1.071)	(1.113)
log GDP per capita x Input Narrowness	-1.174	-0.235	-1.052	-0.145
	(0.854)	(0.905)	(0.854)	(0.906)
Capital Intensity x log $(K/L)_c$		0.007		0.007
		(0.006)		(0.006)
Skill Intensity x log H_c		0.007***		0.007***
		(0.001)		(0.001)
Road Density x Input Narrowness			-3.903***	-2.328***
			(0.757)	(0.744)
Observations	25,975	22,357	25,975	22,357
R-squared	0.775	0.811	0.775	0.811
Number of Countries	96	93	96	93
Number of Industries	294	259	294	259

Robust standard errors in parentheses. All regressions include country and industry fixed effects. The dependent variable is log($Expo_{c,k}$) in year 2014. Waterways data id taken from the CIA World Factbook, and comprises total length of navigable rivers, canals and other inland water bodies. Waterway density equals internal waterways per square km. ***p<0.01, **p<0.05, *p<0.1

Complementary Results for Section 5.1.2

Table A.6 shows in columns (1) - (3) the simple correlation between the different used measures of terrain roughness in country c and road density in c. In all three cases the simple correlation between the variables is negative and highly significant. Next, in columns (4) - (6), we add some additional country-level controls that may be affecting road density (and which are used in the regressions in the main text interacted with industry-level variables). As it can be readily seen, the partial correlation between the three measures of terrain roughness and road density always remains negative and highly significant.

TABLE A.6

Terrain Roughness and Road Density

	Dependent Variable: Roads per Km^2					
	(1)	(2)	(3)	(4)	(5)	(6)
Elevation Difference	-0.020***			-0.012**		
	(0.006)			(0.005)		
Std. Dev. Elevation		-0.591***			-0.363**	
		(0.184)			(0.153)	
% Mountainous			-0.835***			-0.534**
			(0.296)			(0.232)
Ruggedness						
Rule of Law				0.371***	0.329***	0.404***
				(0.117)	(0.112)	(0.118)
Financial Development				0.045	-0.038	-0.046
				(0.133)	(0.114)	(0.098)
log Income				-0.091	-0.275	-0.167
				(0.219)	(0.204)	(0.164)
Human Capital Index				-0.028	-0.076	-0.099
				(0.202)	(0.232)	(0.237)
log $(K/L)_c$				0.257	0.468***	0.364***
				(0.188)	(0.146)	(0.134)
Observations	166	140	142	134	122	126
R-squared	0.100	0.051	0.037	0.306	0.366	0.383

Robust standard reported errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A.7 displays the results of a set of regressions that simultaneously include together as independent variables $r_c \times Gini_k$ and terrain roughness interacted with $Gini_k$. The rationale for these regressions is to try to get some sense of whether, after controlling for the effect of the internal roadway network, terrain roughness may still display a systematic impact on specialization across industries with different degrees of input narrowness. As it can be observed, once the regressions control for the effect of road density, the measures of terrain roughness tend not to exhibit a significant effect on industry specialization.[48] Table A.7 does not represent any

[48]The only exception is column (1), where the coefficient is positive and significant at 10%. This estimate would imply that terrain roughness is associated with lower specialization in industries with wide input bases,

TABLE A.7

Direct Effect of Terrain Roughness

	(1)	(2)	(3)	(4)	(5)	(6)
Road Density x Input Narrowness	-2.180***	-1.771***	-3.252***	-2.086***	-3.277***	-1.884***
	(0.380)	(0.394)	(0.521)	(0.554)	(0.516)	(0.526)
Rule of Law x Input Narrowness	-2.233***	-2.995***	-2.160***	-2.693***	-2.047***	-3.095***
	(0.707)	(0.777)	(0.729)	(0.802)	(0.739)	(0.792)
Fin Dev x Input Narrowness	-3.648***	-1.761**	-4.174***	-2.728***	-4.051***	-1.600*
	(0.822)	(0.910)	(0.877)	(0.953)	(0.872)	(0.937)
log GDP per capita x Input Narrowness	-0.494	0.844	0.133	1.106	0.078	0.948
	(0.605)	(0.665)	(0.669)	(0.720)	(0.641)	(0.675)
Capital Intensity x log $(K/L)_c$		0.010**		0.009**		0.008*
		(0.004)		(0.005)		(0.004)
Skill Intensity x log H_c		0.008***		0.007***		0.008***
		(0.001)		(0.001)		(0.001)
Terrain Roughness x Input Narrowness	***0.376****	***0.186***	***1.331***	***1.601***	***0.015***	***0.027***
	(0.210)	***(0.228)***	***(1.293)***	***(1.427)***	***(0.022)***	***(0.025)***
Measure of Terrain Roughness	Elevation Difference (CIA Wolrd Factbook)		Std. Dev. Elevation (Ramcharan, 2009)		% Mountainous Terrain (Fearon and Laitin, 2003)	
Observations	40,692	31,892	35,988	29,229	36,544	30,067
R-squared	0.764	0.794	0.764	0.794	0.757	0.795
Number of Countries	157	134	137	122	138	126
Number of Industries	294	259	294	259	294	259

Robust standard errors in parentheses. All regressions include country and industry fixed effects. 'Terrain Roughness' is measured in column (1) and (2) by the difference between the max and min elevation within country *c* (source: CIA Factbook), in columns (3) and (4) by the std dev of elevation in country c at the 30" resolution (source: Ramcharan, 2009), and in columns (8) and (10) by the percentage of mountainous in terrain in country *c* (source: Fearon and Laitin, 2003).
*** p<0.01, ** p<0.05, * p<0.1

sort of test about the validity of the exclusion restriction in the regressions in Table V. (In fact, there is no way to test the validity of the exclusion restriction in the context of our paper.) Yet, those results are comforting, in the sense that they somehow tame the concerns that the instrument may be capturing some direct effect of topography on specialization in industries with broad input bases, besides the effect mediated through its impact on road density.

even after controlling for the impact of road density. Notice, however, that the significance disappears in column (2), after we control for the effect of factor endowments.

Appendix C: Further Data Details

TABLE A.8

country	roads (km)	year (roads)	roads/sq km	gdp pc (2014)	country	roads (km)	year (roads)	roads/sq km	gdp pc (2014)
Angola	51,429	2001	0.04125	7,968	Germany	645,000	2010	1.80661	45,961
Albania	18,000	2002	0.62613	10,664	Djibouti	3,065	2000	0.13211	3,200
UAE	4,080	2008	0.04880	64,398	Dominica	1,512	2010	2.01332	10,188
Argentina	231,374	2004	0.08322	20,222	Denmark	74,497	2016	1.72871	44,924
Armenia	7,792	2013	0.26198	8,586	Dominican Rep.	19,705	2002	0.40487	12,511
Antigua & Barbuda	1,170	2011	2.64108	21,002	Algeria	113,655	2010	0.04772	12,812
Australia	823,217	2011	0.10634	43,071	Ecuador	43,670	2007	0.15401	10,968
Austria	133,597	2016	1.59289	47,744	Egypt	137,430	2010	0.13723	9,909
Azerbaijan	52,942	2006	0.61134	15,887	Spain	683,175	2011	1.35183	33,864
Burundi	12,322	2004	0.44276	772	Estonia	58,412	2011	1.29150	28,538
Belgium	154,012	2010	5.04494	43,668	Ethiopia	110,414	2015	0.09999	1,323
Benin	16,000	2006	0.14207	1,922	Finland	454,000	2012	1.34262	40,401
Burkina Faso	15,272	2010	0.05570	1,565	Fiji	3,440	2011	0.18825	7,909
Bangladesh	21,269	2010	0.14326	2,885	France	1,028,446	2010	1.59746	39,374
Bulgaria	19,512	2011	0.17598	17,462	Gabon	9,170	2007	0.03426	14,161
Bahrain	4,122	2010	5.42368	41,626	United Kingdom	394,428	2009	1.61910	40,242
Bahamas, The	2,700	2011	0.19452	23,452	Georgia	19,109	2010	0.27416	9,362
Bosnia and Herz.	22,926	2010	0.44780	10,028	Ghana	109,515	2009	0.45912	3,570
Belarus	86,392	2010	0.41615	20,290	Guinea	44,348	2003	0.18038	1,429
Belize	2,870	2011	0.12497	8,393	Gambia, The	3,740	2011	0.33097	1,544
Bermuda	447	2010	8.27778	57,531	Guinea-Bissau	3,455	2002	0.09564	1,251
Bolivia	80,488	2010	0.07327	6,013	Equatorial Guinea	2,880	2000	0.10267	40,133
Brazil	1,580,964	2010	0.18565	14,871	Greece	116,960	2010	0.88635	25,990
Barbados	1,600	2011	3.72093	14,220	Grenada	1,127	2001	3.27616	11,155
Bhutan	10,578	2013	0.27551	6,880	Guatemala	17,332	2015	0.15917	6,851
Central African Rep.	20,278	2010	0.03255	594	Hong Kong	2,100	2015	1.89531	51,808
Canada	1,042,300	2011	0.10439	42,352	Honduras	14,742	2012	0.13152	4,424
Switzerland	71,464	2011	1.73133	58,469	Croatia	26,958	2015	0.47634	21,675
Chile	77,764	2010	0.10285	21,581	Haiti	4,266	2009	0.15373	1,562
China	4,106,387	2011	0.42788	12,473	Hungary	203,601	2014	2.18860	25,758
Cote d'Ivoire	81,996	2007	0.25428	3,352	Indonesia	496,607	2011	0.26075	9,707
Cameroon	51,350	2011	0.10801	2,682	India	4,699,024	2015	1.42946	5,224
Congo, Dem. Rep.	153,497	2004	0.06546	1,217	Ireland	96,036	2014	1.36661	48,767
Congo, Rep.	17,000	2006	0.04971	4,426	Iran	198,866	2010	0.12066	15,547
Colombia	204,855	2015	0.17987	12,599	Iraq	59,623	2012	0.13603	12,096
Comoros	880	2002	0.39374	1,460	Iceland	12,890	2012	0.12515	42,876
Cabo Verde	1,350	2013	0.33474	6,290	Israel	18,566	2011	0.89389	33,270
Costa Rica	39,018	2010	0.76356	14,186	Italy	487,700	2007	1.61844	35,807
Curacao	550	*N.A.*	1.23874	25,965	Jamaica	22,121	2011	2.01265	7,449
Cayman Islands	785	2007	2.97348	51,465	Jordan	7,203	2011	0.08062	10,456
Cyprus	20,006	2011	2.16258	28,602	Japan	1,218,772	2015	3.22499	35,358
Czech Republic	130,661	2011	1.65673	31,856	Kazakhstan	97,418	2012	0.03575	23,450

TABLE A.8 (cont.)

country	roads (km)	year (roads)	roads/sq km	gdp pc (2014)	country	roads (km)	year (roads)	roads/sq km	gdp pc (2014)
Kenya	160,878	2013	0.27720	2,769	Paraguay	32,059	2010	0.07882	8,284
Kyrgyzstan	34,000	2007	0.17004	3,359	Qatar	9,830	2010	0.84844	144,340
Cambodia	44,709	2010	0.24696	2,995	Romania	84,185	2012	0.35314	20,817
Korea, South	104,983	2009	1.05278	35,104	Russia	1,283,387	2012	0.07506	24,039
Kuwait	6,608	2010	0.37086	63,886	Rwanda	4,700	2012	0.17845	1,565
Laos	39,586	2009	0.16717	5,544	Saudi Arabia	221,372	2006	0.10298	48,025
Lebanon	6,970	2005	0.67019	13,999	Sudan	11,900	2000	0.00639	3,781
Liberia	10,600	2000	0.09518	838	Senegal	15,000	2015	0.07625	2,247
Sri Lanka	114,093	2010	1.73896	10,342	Singapore	3,425	2012	4.91392	72,583
Lithuania	84,166	2012	1.28891	28,208	Sierra Leone	11,300	2002	0.15751	1,419
Latvia	72,440	2013	1.12155	23,679	El Salvador	6,918	2010	0.32879	7,843
Morocco	58,395	2010	0.13077	7,163	Serbia	44,248	2010	0.57113	13,441
Moldova	9,352	2012	0.27627	4,811	Sao Tome & Princ.	320	2000	0.33195	3,239
Madagascar	37,476	2010	0.06384	1,237	Suriname	4,304	2003	0.02627	15,655
Maldives	88	2013	0.29530	14,391	Slovakia	54,869	2012	1.11898	28,609
Mexico	377,660	2012	0.19225	15,853	Slovenia	38,985	2012	1.92300	30,488
Macedonia	14,182	2014	0.55155	13,151	Sweden	579,564	2010	1.28708	44,598
Mali	22,474	2009	0.01812	1,434	Seychelles	526	2015	1.15604	25,822
Malta	3,096	2008	9.79747	31,644	Syria	69,873	2010	0.37732	4,200
Burma	34,377	2010	0.05081	5,344	Turks and Caicos	121	2003	0.12764	20,853
Montenegro	7,762	2010	0.56198	14,567	Chad	40,000	2011	0.03115	2,013
Mongolia	49,249	2013	0.03149	11,526	Togo	11,652	2007	0.20520	1,384
Mozambique	30,331	2009	0.03794	1,137	Thailand	180,053	2006	0.35090	13,967
Mauritania	10,628	2010	0.01031	3,409	Tajikistan	27,767	2000	0.19269	2,747
Mauritius	2,149	2012	1.05343	17,942	Turkmenistan	58,592	2002	0.12004	20,953
Malawi	15,450	2011	0.13040	949	Trinidad & Tobago	9,592	2015	1.87051	31,196
Malaysia	144,403	2010	0.43779	23,158	Tunisia	19,418	2010	0.11868	10,365
Niger	18,949	2010	0.01496	852	Turkey	385,754	2012	0.49231	19,236
Nigeria	193,200	2004	0.20914	5,501	Tanzania	86,472	2010	0.09128	2,213
Nicaragua	23,897	2014	0.18330	4,453	Uganda	20,000	2011	0.08297	1,839
Netherlands	138,641	2014	3.33729	47,240	Ukraine	169,694	2012	0.28116	10,335
Norway	93,870	2013	0.28990	64,274	Uruguay	77,732	2010	0.44112	20,396
Nepal	10,844	2010	0.07368	2,173	United States	6,586,610	2012	0.66981	52,292
New Zealand	94,902	2012	0.35301	34,735	Uzbekistan	86,496	2000	0.19333	8,195
Oman	60,230	2012	0.19460	38,527	Venezuela	96,189	2014	0.10546	14,134
Pakistan	263,942	2014	0.33155	4,646	British Virgin Isl.	200	2007	1.32450	26,976
Panama	15,137	2010	0.20070	19,702	Vietnam	195,468	2013	0.59016	5,353
Peru	140,672	2012	0.10945	10,993	Yemen	71,300	2005	0.13505	3,355
Philippines	216,387	2014	0.72129	6,659	South Africa	747,014	2014	0.61276	12,128
Poland	412,035	2012	1.31773	25,156	Zambia	40,454	2005	0.05375	3,726
Portugal	82,900	2008	0.90021	28,476	Zimbabwe	97,267	2002	0.24892	1,869

Appendix D: Robustness of Theoretical Results

1. Additive Linear Transport Cost of Intermediate Inputs

The benchmark model has used the assumption of multiplicative iceberg transport cost that increase linearly with distance. Suppose instead that transport cost of input i to location j is linearly additive in distance. That would imply that, given $l_j \in [0,1]$, producer j faces

$$p_{0,j} = (1+\varepsilon_0)\,w + l_j \varphi(r)t \quad \text{and} \quad p_{1,j} = (1+\varepsilon_1)\,w + (1-l_j)\,\varphi(r)t$$

As a result, producer j will choose his optimal location by solving:

$$\min_{l_j \in [0,1]} : \ln\left[c_j(l_j)\right] = (1-\alpha_j)\ln\left[(1+\varepsilon_0)\,w + l_j\varphi(r)t\right] + \alpha_j \ln\left[(1+\varepsilon_1)\,w + (1-l_j)\,\varphi(r)t\right], \quad (31)$$

where (31) is using the logarithm of $c_j(l_j)$ for algebraic convenience. Computing the second derivative of $\ln\left[c_j(l_j)\right]$ with respect to l_j yields:

$$\frac{\partial^2 \ln\left[c_j(l_j)\right]}{(\partial l_j)^2} = -\frac{(1-\alpha_j)\,(\varphi(r)t)^2}{\left[(1+\varepsilon_0)\,w + l_j\varphi(r)t\right]^2} - \frac{\alpha_j\,(\varphi(r)t)^2}{\left[(1+\varepsilon_1)\,w + (1-l_j)\,\varphi(r)t\right]^2} < 0. \quad (32)$$

Therefore the FOC of (31) would yield a maximum instead of a minimum. Also, due to (32), the solution of (31) would always be a corner solution, with either $l_j^* = 0$ or $l_j^* = 1$.

Despite being given by a corner solution, the optimal location choices by final producers differ slightly from those in (6), because in the case of additive transport cost the values of ε_0 and ε_1 also affect the optimal location of j. To see this, let $\widetilde{\alpha}$ be defined by the value of $\alpha_j \in (0,1)$ that solves the following equation

$$\frac{\left[(1+\varepsilon_0)\,w\right]^{1-\widetilde{\alpha}}}{\left[(1+\varepsilon_1)\,w\right]^{\widetilde{\alpha}}} = \frac{\left[(1+\varepsilon_0)\,w + \varphi(r)t\right]^{1-\widetilde{\alpha}}}{\left[(1+\varepsilon_1)\,w + \varphi(r)t\right]^{\widetilde{\alpha}}}. \quad (33)$$

The optimal location by producer j is given by

$$l_j^* = \begin{cases} 0 & \text{if } \alpha_j \leq \widetilde{\alpha} \\ 1 & \text{if } \alpha_j \geq \widetilde{\alpha} \end{cases}. \quad (34)$$

Using the result in (34), we can also obtain that

$$c_j^* = \begin{cases} \left[(1+\varepsilon_0)\,w\right]^{\alpha_j} \left[(1+\varepsilon_1)\,w + \varphi(r)t\right]^{1-\alpha_j} & \text{if} \quad \alpha_j \leq \widetilde{\alpha} \\ \left[(1+\varepsilon_0)\,w + \varphi(r)t\right]^{\alpha_j} \left[(1+\varepsilon_1)\,w\right]^{1-\alpha_j} & \text{if} \quad \alpha_j \geq \widetilde{\alpha} \end{cases},$$

from where an analogous result to that one Lemma 1 follows.

Finally, as a last remark, notice that in the special case in which $\varepsilon_0 = \varepsilon_1$, we have that (33) yields $\widetilde{\alpha} = 0.5$, and thus the optimal location choice (34) becomes identical to that in (6).

2. General CES Production Function

Here we show that the main results of Section 2 hold true when (3) is replaced by a more general CES production function. We let now total output of final good $j \in [0,1]$ be represented by:

$$Y_j = [(1-\alpha_j)\ X_{0,j}^{\rho} + \alpha_j\, X_{1,j}^{\rho}]^{1/\rho}, \quad \text{with } \alpha_j \in [0,1] \quad \text{and} \quad \rho < 1.$$

In this case, it can be shown that the marginal cost of producing good j is given by:

$$c_j = \left[\frac{(1-\alpha_j)^{1/(1-\rho)}}{p_{0,j}^{\rho/(1-\rho)}} + \frac{\alpha_j^{1/(1-\rho)}}{p_{1,j}^{\rho/(1-\rho)}}\right]^{-(1-\rho)/\rho}. \tag{35}$$

Producer j will choose $l_j \in [0,1]$ in order to minimize c_j, bearing in mind input prices as functions of l_j; namely $p_{0,j} = [1 + l_j\varphi(r)t]\,(1+\varepsilon_0)\,w$ and $p_{1,j} = [1 + (1-l_j)\,\varphi(r)t]\,(1+\varepsilon_1)\,w$. Defining:

$$\Upsilon(l_j) \equiv \frac{(1-\alpha_j)^{1/(1-\rho)}}{[1+l_j\varphi(r)t]^{\rho/(1-\rho)}\,(1+\varepsilon_0)^{\rho/(1-\rho)}} + \frac{\alpha_j^{1/(1-\rho)}}{[1+(1-l_j)\,\varphi(r)t]^{\rho/(1-\rho)}\,(1+\varepsilon_1)^{\rho/(1-\rho)}},$$

notice that finding the $l_j \in [0,1]$ that minimizes (35) is an isomorphic to maximizing $\Upsilon(l_j)$. Furthermore, computing the second derivative of $\Upsilon(l_j)$ with respect to l_j yields:

$$\frac{\partial^2\Upsilon}{(\partial l_j)^2} = \frac{\rho\,(\varphi(r)t)^2}{(1-\rho)^2}\left\{\frac{(1-\alpha_j)^{\frac{1}{1-\rho}}}{(1+\varepsilon_0)^{\frac{\rho}{1-\rho}}}\,[1+l_j\varphi(r)t]^{-\frac{1}{1-\rho}-1} + \frac{\alpha_j^{\frac{1}{1-\rho}}}{(1+\varepsilon_1)^{\frac{\rho}{1-\rho}}}\,[(1-l_j)\,\varphi(r)t]^{-\frac{1}{1-\rho}-1}\right\} > 0.$$

Therefore, the solution of $\Upsilon'(l_j) = 0$ would yield a minimum for $\Upsilon(l_j)$, which implies that it would yield a maximum for c_j. This in turn implies that the minimum of c_j must be on a corner solution; that is, either $l_j^* = 0$ or $l_j^* = 1$.

Computing now $c_j(0)$ and $c_j(1)$ from (35), together with the expressions for $p_{0,j}$ and $p_{1,j}$, and comparing them we can then obtain:

$$l_j^* = \begin{cases} 0 & \text{if } \alpha_j \leq \left[1 + \left(\frac{1+\varepsilon_1}{1+\varepsilon_0}\right)^{\rho}\right]^{-1} \\ 1 & \text{if } \alpha_j \geq \left[1 + \left(\frac{1+\varepsilon_1}{1+\varepsilon_0}\right)^{\rho}\right]^{-1} \end{cases}, \tag{36}$$

where notice that (36) boils down to (6) in the case of $\rho = 0$ (i.e., the Cobb-Douglas production case). Finally, combining (36) together with (35), we can observe that a result analogous to Lemma 1 obtains in this generalized case as well.

3. An Example with Three Intermediate Inputs

We provide now an example with three intermediate goods located in three different locations. (This example could be generalized to a case with N intermediate goods.) We denote the intermediate goods by the letters A, B and C. Each input is produced in a specific location, which label with the same letter as that of the input. To keep the analysis simple and brief, we assume that all three locations are equidistant from each other.

There exist three subsets of final goods, $g = A, B, C$. Each subset g comprises a continuum of final goods j. The production function of final good j in each subset are given by:

$$g = A: \quad Y_{A,j} = \left[\left(\tfrac{1}{3} + \gamma_j\right)^{\frac{1}{3}+\gamma_j} \left(\tfrac{1}{3} - \tfrac{\gamma_j}{2}\right)^{\frac{2}{3}-\gamma_j} \right]^{-1} X_{A,j}^{\frac{1}{3}+\gamma_j} X_{B,j}^{\frac{1}{3}-\frac{\gamma_j}{2}} X_{C,j}^{\frac{1}{3}-\frac{\gamma_j}{2}}, \tag{37}$$

$$g = B: \quad Y_{B,j} = \left[\left(\tfrac{1}{3} + \gamma_j\right)^{\frac{1}{3}+\gamma_j} \left(\tfrac{1}{3} - \tfrac{\gamma_j}{2}\right)^{\frac{2}{3}-\gamma_j} \right]^{-1} X_{A,j}^{\frac{1}{3}-\frac{\gamma_j}{2}} X_{B,j}^{\frac{1}{3}+\gamma_j} X_{C,j}^{\frac{1}{3}-\frac{\gamma_j}{2}}, \tag{38}$$

$$g = C: \quad Y_{C,j} = \left[\left(\tfrac{1}{3} + \gamma_j\right)^{\frac{1}{3}+\gamma_j} \left(\tfrac{1}{3} - \tfrac{\gamma_j}{2}\right)^{\frac{2}{3}-\gamma_j} \right]^{-1} X_{A,j}^{\frac{1}{3}-\frac{\gamma_j}{2}} X_{B,j}^{\frac{1}{3}-\frac{\gamma_j}{2}} X_{C,j}^{\frac{1}{3}+\gamma_j}, \tag{39}$$

where $\gamma_j \in \left[0, \frac{2}{3}\right]$.

The expressions in (37)-(39) imply that final goods in subset $g = A$ tend to use input A relatively more intensively, and so on and so forth forth for $g = B$ and $g = C$. Also, note that the degree of intensity of final good j in its most important intermediate input grows with γ_j, and $Y_{g,j} = X_{g,j}$, for $g = A, B, C$, when $\gamma_j = \frac{2}{3}$. Finally, notice that when $\gamma_j = 0$, all intermediate inputs are equally important. In that regard, the case with $\gamma_j = \frac{2}{3}$ would be analogous to the cases with either $\alpha_j = 0$ or $\alpha_j = 1$ in the main text, whereas the case with $\gamma_j = 0$ would be analogous to the case where $\alpha_j = \frac{1}{2}$.

Consider a generic good j of the subset $g = A$. (The results for $g = B$ and $g = C$ can be obtained by appropriately relabeling the variables.) The marginal cost of production would be

$$c_{A,j} = p_{A,j}^{\frac{1}{3}+\gamma_j} p_{B,j}^{\frac{1}{3}-\frac{\gamma_j}{2}} p_{C,j}^{\frac{1}{3}-\frac{\gamma_j}{2}}.$$

Let $l_{j,A} \in [0, 1]$ denote now the distance from the location chosen by this generic firm j to the location of intermediate input A. A complete analysis of the optimal location choice would require a thorough description of the geographic setup of the economy. In what follows, to keep the analysis brief, we show two simple cases under two alternative assumptions concerning location bilateral distances. We dub these cases as: *i*) straight-line bilateral choices; *ii*) diagonal-line choices.

1. *Straight-line bilateral location choices*: Assume that when $l_{j,A} = 0$, then $l_{j,B} = l_{j,C} = 1$. On the other hand, when $0 < l_{j,A} \leq 1$, we assume that $l_{j,B} = 1 - l_{j,A}$ and $l_{j,C} = 1$.[49]

[49] Nothing would change if we instead assumed that, when $0 < l_{j,A} \leq 1$, $l_{j,C} = 1 - l_{j,A}$ and $l_{j,B} = 1$.

Hence, a firm producing final good j of the subset $g = A$ would pick its location by solving

$$\min_{l_{j,A}\in[0,1]} : \ln\left[c_{A,j}\left(l_{j,A}\right)\right] = \left(\tfrac{1}{3}+\gamma_j\right)\ln\left(1+l_{j,A}\varphi(r)t\right)+\left(\tfrac{1}{3}-\tfrac{1}{2}\gamma_j\right)\ln\left[1+\left(1-l_{j,A}\right)\varphi(r)t\right]+\Xi,$$

where Ξ is a constant. This problem yields again corner solutions, where $l^*_{j,A} = 0$ whenever $\gamma_j \in \left(0, \frac{2}{3}\right]$, while when $\gamma_j = 0$ the firm is indifferent between any of the locations where intermediate goods are produced. In addition, a result analogous to that in Lemma 1 obtains: the cost-reduction effect of r is proportionally larger for sectors with small γ_j.

2. *Diagonal-line location choices*: Assume that when $l_{j,A} = 0$, then $l_{j,B} = l_{j,C} = 1$. On the other hand, when $0 < l_{j,A} \leq 1$, we assume that $l_{j,B} = 1 - \frac{1}{2}l_{j,A}$ and $l_{j,C} = 1 - \frac{1}{2}l_{j,A}$.[50] In this case, a firm producing final good j of the subset $g = A$ would pick its location by solving

$$\min_{l_{j,A}\in[0,1]} : \ln\left[c_{A,j}\left(l_{j,A}\right)\right] = \left(\tfrac{1}{3}+\gamma_j\right)\ln\left(1+l_{j,A}\varphi(r)t\right)+2\left(\tfrac{1}{3}-\tfrac{1}{2}\gamma_j\right)\ln\left[1+\left(1-\tfrac{1}{2}l_{j,A}\right)\varphi(r)t\right]+\Phi,$$

where Φ is a constant. This problem yields again corner solutions, where in the optimum either $l^*_{j,A} = 0$ or $l^*_{j,A} = 1$. However, different from *straight-line bilateral case* above, in this *diagonal-line case* we have that there may exist values of $\gamma_j > 0$ for which in the optimum $l^*_{j,A} = 1$. In particular,

$$l^*_{j,A} = \begin{cases} 0, & \text{if} \quad \gamma_j \geq \max\{0, \Psi\} \\ 1, & \text{if} \quad \gamma_j \leq \max\{0, \Psi\} \end{cases} \tag{40}$$

where,

$$\Psi \equiv \frac{1}{3}\frac{2\ln\left\{\left[1+\varphi(r)t\right]/\left[1+\frac{1}{2}\varphi(r)t\right]\right\}-\ln\left(1+\varphi(r)t\right)}{\ln\left\{\left[1+\varphi(r)t\right]/\left[1+\frac{1}{2}\varphi(r)t\right]\right\}+\ln\left(1+\varphi(r)t\right)}. \tag{41}$$

Notice from the expression in (41) that there may be feasible parametric configurations for which $\Psi > 0$. On the other hand, it must necessarily be the case that $\Psi < \frac{1}{3}$. One important difference implied by (40) is that the exact optimal location of final good producer j not only depends now on the value of γ_j, but also (possibly) on $\varphi(r)$ via Ψ. In any case, while the results are more nuanced than in the straight-line case, they keep the same qualitative features. Furthermore, an analogous result to Lemma 1 still applies to this case as well.

[50] This implicitly restricts the location choice of a final good producer of subset A to never set either $l_{j,C} < 0.5$ or $l_{j,B} < 0.5$. Nevertheless, given the structure of (37), this would never be optimal in this case.

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