Staff Working Paper ERSD-2018-05 **24 April 2018**

World Trade Organization

Economic Research and Statistics Division

SPECIALIZATION *WITHIN* GLOBAL VALUE CHAINS:

THE ROLE OF ADDITIVE TRANSPORT COSTS

Rainer Lanz and Roberta Piermartini

Manuscript date: April 2018

SPECIALIZATION *WITHIN* GLOBAL VALUE CHAINS: THE ROLE OF ADDITIVE TRANSPORT COSTS

Rainer Lanz and Roberta Piermartini[1]

Abstract

This paper studies the factors of comparative advantage within global value chains relying on a framework where comparative advantage is measured through the interaction of country and industry characteristics. We find that good institutions give a comparative advantage in the later stages of the production process, whereas good transport infrastructure gives an advantage in the early stages of production. We explain these results with a simple theoretical framework that shows how predicted patterns of specializations depend on whether trade costs are additive or multiplicative.

Keywords: Global value chains, quality of transport infrastructure, quality of institutions, comparative advantage, upstreamness, production networks, trade costs.

JEL Classifications: F13, F14, L60.

[1] WTO, Rue de Lausanne 154, CH - 1211 Geneva 21. Email: Rainer Lanz (rainer.lanz@wto.org); Roberta Piermartini (roberta.piermartini@wto.org). We thank Elisa Gamberoni for her contribution at the initial stages of this research. We also thank Stela Rubinova, Robert Koopman, Victor Kummritz and Davin Chor for their useful comments at different stages of this research.

1 INTRODUCTION

There has been an increasing trend towards the internationalisation of production in the last two decades or so. About 50% of world exports relate to global value chains (GVCs). For some countries, such as Singapore and the Philippines this share is as high as 70 % (WTO, 2014). There is also a lot of variation in the position of countries, especially poorer countries, in the production chain (Antràs et al, 2012). This implies that countries largely rely on other countries to source inputs for their domestic production and on foreign demand to sell the goods they produce. Whether they import or export more inputs depends on their position in the supply chain.

The question we address in this paper is what determines the organization of production chains across countries. What are the factors of comparative advantage that drive a firm's choice to locate a certain stage of production in one country rather than another one? This question is important because these factors shape trade links among nations as well as the effectiveness of government actions, such as decisions to invest in infrastructure or education, to drive specialization along the supply chains.[2]

The positioning of countries in value chains has been subject to recent empirical and theoretical research. A key insight of the existing literature is that institutions, infrastructure and trade costs matter more as production moves downstream. Institutions matter as a source of comparative advantage in downstream stages of production through several channels. First, institutions matter because cross-country differences in contract enforcement make faulty products more likely in some countries than in others.[3] Costinot et al. (2013) point at countries' differences in the rate to make mistakes in production to explain countries' patterns of specialization along the supply chain.[4] They assume that production is sequential in nature. First raw materials are processed into basic inputs. Then, these inputs are combined with other components to produce more complicated inputs. Finally, these inputs are assembled into final goods. They assume that a mistake at a certain stage of the production chain implies that the intermediate good is completely lost. In this context, they show that countries with lower probability to make mistakes at all stages specialize downstream. This is because the cost of making mistakes is higher in later stages of the production chain when the value of the good is high.

Second, good institutions provide a comparative advantage in downstream stages of production through the better enforcement of property rights. Antràs and Chor (2013) develop a property-rights model of the firm to describe the relationship between vertical integration and its relative position in the value chain, and how it depends on the demand elasticity faced by the final-good producer. Building a measure of industry "upstreamness" (or average distance from final use), Antràs et al. (2012) show that stronger institutions provide a comparative advantage to export in relatively more downstream industries. In the later stages of the production process, the good has a higher value. Therefore, it is key that the producer sees her rights protected at later stages of the production process.[5]

Closeness to final consumption also provides a comparative advantage in downstream stages of production because there is less "melting" on more valuable goods during shipment. Assuming that trade costs are proportional to the gross value of the traded good (iceberg trade costs), Antràs and de Gortari (2017) show that the trade cost elasticity increases with the downstreamness of a stage of production.

[2] A growing literature stresses the importance of participating in GVCs for growth (IMF, 2013; WTO, 2014). GVCs provide developing countries with the opportunity to access international markets at lower costs, because firms no longer have to produce the entire good to be able to export but they can just specialise in a particular task. Participation in GVCs also provides firms with the opportunity to acquire the knowledge from their lead firms. This fosters their productivity (Iacovone et al. 2015), and hence growth.

[3] By the same token, a country with better quality of infrastructure that make delays in production less likely will be expected to specialize downstream.

[4] Costinot et al. (2013) also consider the case when there are coordination costs (costs increasing with the number of stages in which a product is produced). Coordination costs affect the number of stages at which a product is produced and lead countries with low coordination costs to specialize in more complex goods downstream. The intuition is the same as above: there is less "melting" on more valuable goods at the latest stage of production.

[5] A wider literature has looked at the importance of institutions in GVC-related trade. Levchenko (2007) shows that countries with better institutions specialize in the production of complex goods -characterised by the use of a more diversified set of intermediate inputs. Nunn (2007) finds that countries with good contract enforcement specialize in the production of industries using intensively intermediate inputs that require relationship-specific investments. Bernard et al. (2010), Nunn and Trefler (2008), and Corcos et al. (2013) show that the ability to enforce contracts is an important determinant of the share of intra-firm trade.

Therefore, it is optimal to locate the later stages of production in relatively central locations. The reason is that as the value of the good raises along the supply chain, so does the trade cost to exchange a good across locations.

This paper contributes to the literature on specialization along the supply chain by focussing on transportation costs. Efficient transport infrastructure and border procedures matter for trade related to international supply chains because slow or delayed delivery increase the cost of holding stocks, impede rapid responses to changes in customer orders and limit the ability to rapidly replace defective components. The late arrival of any one component may disrupt production, and thus can impose a very high cost in terms of percentage of the cost of the single component. There is evidence that timeliness matter in GVCs. Nordås (2006) shows that the quality of infrastructure matters for trade in intermediate inputs. Hummels and Schaur (2013) show that firms are more willing to pay the premium of fast air shipping (more expensive than ocean shipping) for intermediate goods than total trade. However, these studies do not look at specialization across stages of the production chain.

A common characteristic of existing theoretical models is that they model trade costs proportional to the value of the good. When trade costs are *ad valorem* or iceberg type, the country with low trade costs will specialise in downstream stages of the production chain. However, a special feature of transportation costs is that they contain both ad valorem and additive components. In fact, while import duties and insurance costs are largely ad valorem (that is, proportional to the value of the good) other transport costs are not. Hummels and Skiba (2004) provide strong evidence against the traditional assumption that transportation costs are of the "iceberg" form, proportional to goods prices. Shipping costs are mainly based on the weight and the volume, not value. It costs the same to transport a can of high quality fish or an equally sized can of low quality fish.

To get a sense of how *additive* transportation costs may affect patterns of specialization within the supply chain, we develop a simple theoretical model where a good is produced in a fixed number of sequential stages and transportation costs are additive. We show, in the context of this simple model, that when trade costs are additive they may matter especially at the earlier stages of the production process. The intuition is that additive trade costs at the initial stages of production increase the price of the good and then get magnified by the ad-valorem trade costs paid at subsequent stages of production. Therefore, low transport costs (at least as far as the additive component of these costs is concerned) provide a country with a comparative advantage in *upstream* stages of production. This simple model makes the point that theoretical predictions as to how transport costs affect specialization within the supply chains depend on how transport costs are modelled. Therefore, the question of whether transport costs provide a comparative advantage in downstream or upstream stages of production is an empirical one.

We test our predictions by estimating a factor-content model of trade (Romalis, 2004), where specialization is explained by the interaction between the factor intensity of a sector and a country's factor abundance. To this purpose, we use the measure of upstreamness developed by Antràs et al. (2012) to measure an industry's position in value chains and quality of transport infrastructure and logistic services as a measure of factor abundance. We test the robustness of our results to the use of alternative measures of upstreamness and of quality of infrastructure, and account for other factors of comparative advantage that the literature has identified, i.e. capital, labour and quality of institution. We are the first to estimate the impact of transport infrastructure along the supply chains and the first to look at patterns of specialization in such a general set up.

We find that a good quality of transport infrastructure provides a comparative advantage in upstream stages. We also confirm the result of the existing literature that quality of institutions is a key driver for specialization in downstream stages of the production chain. Overall, we show that supply chains enhance the importance of transport infrastructure and institutions as factors of comparative advantage.

Our findings support the view that the common assumption that transport costs are ad valorem or iceberg type is not trivial and that more needs to be done to develop models that test the implications of the presence of additive costs. This becomes more important when considering that several trade policy measures (e.g. specific tariff rates or quotas when there is an associate licence or even technical regulations) represent additive costs.

The rest of the paper is organized as follow: Section 2 presents a simple theoretical model to show how modelling trade cost as additive rather than multiplicative can change the predictions as to whether transport infrastructure provide a comparative advantage in downstream or upstream stages of the production chain. Section 3 discusses our methodological approach. Section 4 describes the data and provides summary statistics. In section 5 we present our main results and robustness checks. Finally, section 6 concludes.

2 MAGNIFICATION EFFECTS OF TRADE COSTS ALONG THE SUPPLY CHAIN

In general, the economic literature on GVCs has assumed that the trade costs for moving a product from one country to another one is *ad valorem* (iceberg type costs), that is proportional to the value of the good traded. This is typically the case for tariffs and insurance costs of trade. An important insight from this literature is that the effects of trade costs are compounded and that the effect of a marginal increase in trade cost everywhere in the supply chain increases with the extent of fragmentation of production across countries. Therefore, changes in trade costs affect not only trade in final goods, but also the extent of production fragmentation across countries (see Feenstra and Hanson, 1996; Yi, 2003 and Grossman and Rossi-Hansberg, 2008). Another important insight is that trade costs shape interdependences among nations. Antràs and de Gortari (2017) show that with costly trade, other things equal, it is optimal to locate relatively downstream stages of production in relatively central locations. This is because *ad valorem* trade costs erode more value in downstream stages than upstream stages.

How are these predictions affected if trade costs are additive? In this section we provide a simple framework to understand the potential sorting of countries along the supply chain when trade costs have an ad valorem and an additive component. For simplicity we assume away geographical characteristics other than borders. Production is sequential. A good is produced in *S* stages in *N* countries. Each country *i* imports intermediate goods from the country specialised in the previous stage of production and adds the value v_i. After production, the good is exported to its destination. At each stage *s* the price of the good facing the consumer, $c_{(s)}$, depends on the f.o.b. price and a two-part trade cost, which includes both an ad valorem trade cost t_s and a per-unit shipping cost F_s. The latter costs include additive costs to transport a good from a country to another one, as well as transportation costs incurred domestically to transport the product from the port to the firm and vice versa. Firms are perfectly competitive and the optimal location *i* of a stage *s* is determined by cost minimisation. Let $c_{(s)}$ be the total cost of a good delivered to the final consumers when it is produced in *S* stages. It follows that, in general:

$$c_{(s)} = (1+t_s)\,[(1+t_{s-1})\,v_{(s-1)} + F_{s-1}] + (1+t_s)\,v_s + F_s \qquad (1)$$

Equation (1) shows that because of ad-valorem trade costs, per unit shipping costs F_{s-1} are magnified along the supply chain. An implication of this compounding effect is that firms will be relatively more concerned in decreasing per unit trade costs in relatively upstream stages of production than downstream stages.

We illustrate this point with a simple example. Assume that a good is produced sequentially in three stages by three countries. Suppose that the additive transport cost F_s differ by country. Suppose also that ad valorem trade costs differ in each country, and let's define $\tau_s = (1+t_s)$..

It follows that:

$$C_{(1)} = \tau_1 v_1 + F_1$$

$$C_{(2)} = \tau_2 (\tau_1 v_1 + F_1) + \tau_2 v_2 + F_2 = \tau_2 \tau_1 v_1 + \tau_2 v_2 + \tau_2 F_1 + F_2$$

$$C_{(3)} = \tau_3 [\tau_2 (\tau_1 v_1 + F_1) + \tau_2 v_2 + F_2] + \tau_3 v_3 + F_3 = \tau_3 \tau_2 \tau_1 v_1 + \tau_3 \tau_2 v_2 + \tau_3 v_3 + \tau_3 \tau_2 F_1 + \tau_3 F_2 + F_3$$

Consider the problem of a firm that chooses the location of its various stages of production, in an environment where trade is costly and the good is produced in three stages that need to be performed sequentially. The firm will chose to locate its different stages of production in a way to minimize total costs $c_{(3)}$. It will therefore have an incentive to locate the more upstream stage in the country where the per unit cost $F_{i(1)}$ is lower, because this cost is magnified along the supply chain.[6] It will have an incentive

[6] Assuming that a country, *i*, with better quality of infrastructure and logistic services has lower transport costs at all stages of production compared to another country, *j*, with worse infrastructure and logistics (that is, $F_{si}<F_{sj}$), this holds as long as $\tau_3 \tau_2 (F_{1j} - F_{1i}) > \tau_3 (F_{2j} - F_{2i})$ and $\tau_3 \tau_2 (F_{1j} - F_{1i}) > (F_{3j} - F_{3i})$. That is the magnification effect has to be important enough or the cost advantage of locating the first stage of production in country i in terms of additive cost component has not to be small compared to the cost advantage of locating there stage 3.

to produce the more downstream stages of production where the ad valorem rate is lower because this is paid on the entire value of the good or, equivalently, there is more "melting".

The result that countries that have lower "melting" costs tend to specialize in later stages of the production chain is one of the key insight of the literature on specialization within supply chains. This is the key insight in Costinot et al. (2013) where countries with better quality of institutions specialize in downstream production because the rate of making a mistake is lower. It is also a key ingredient of Antràs and de Gortari (2017)'s paper where the iceberg trade costs, proportional to the gross value of the traded good, explain the comparative advantage of central location in downstream sectors.

Critical to our simple demonstration above is the idea that trade costs are applied on a per unit rather than ad valorem basis. Hence, countries with lower "additive" costs may tend to specialize upstream. In our empirical specification we capture low additive costs with good quality of transport infrastructure. We are aware that transport costs, in general, have both an ad valorem and an additive component. Transport costs have an ad valorem component because insurance charges and handling requirements increase with the value of the good, higher value goods tend to travel by air (more expensive) rather than by ocean, and shipping companies in monopolistic position can differentiate prices. However, shipping companies usually set a fixed charge per unit (e.g. per pound or cubic meter), that is shipping prices structure is not ad valorem. Also, Hummels and Skiba (2004) and Irarrazabal et al. (2015) show that additive trade costs are important. Distribution costs are also partly additive costs (e.g. Corsetti and Dedola, 2005).

3 METHODOLOGICAL APPROACH

We assess what factors affect comparative advantage at different stages of the supply chain by estimating a factor-content model of trade (Romalis, 2004), where export patterns are explained in terms of industry factor intensities and country endowments. Our benchmark equation is:

$$X_{ij} = \beta_0 + \beta_1 u_j T_i + \sum \beta u_j U_i + \sum \beta s_j S_i + \mu_j + \gamma_i + \varepsilon_{ij} \qquad (2)$$

Where X_{ij} is the logarithm of average exports of country i to the world in the 6-digit NAICS manufacturing industry j over the three-year period 2006-2008.[7] All regressors are interactions between industry intensities and country endowments, which are denoted in lower case and upper case letters, respectively. The interaction terms allow testing whether certain production and policy factors determine countries' export specialization in industries that intensively use these factors.

Our variable of interest is the interaction term between the upstreamness of industry j and a country's quality of transport infrastructure (u_jT_i) – a key determinant of transport costs. As suggested by the theoretical arguments above, we expect that good quality of infrastructure is associated with specialization in upstream sectors if additive costs are an important component of transport costs.

In addition, we test which further country characteristics affect a country's positioning in GVCs ($\Sigma\beta u_jU_i$), including the quality of institutions Q_i and remoteness R_i (inversely related to centrality). We expect a negative relationship between quality of institution and specialization in upstream sector (Costinot et al., 2013) and a positive relationship between upstreamness and remoteness (Antràs and de Gortari, 2017).

Finally, we control for the standard sources of comparative advantage ($\Sigma\beta s_jS_i$), i.e. interaction terms between an industry's capital intensity and a country's capital endowment (k_jK_i), between an industry's skill labour intensity and a country's human capital endowment (h_jH_i), between an industry's time sensitivity and a country's level of transport infrastructure (t_jT_i) and between an industry's contract-intensity and a country's ability to enforce a contract (q_jQ_i). The set of dummies γ_i and μ_j control for country- and industry-specific fixed effects, respectively.

[7] Export data at the SITC Rev.3 5-digit level are from UN Comtrade and mapped to 6-digit NAICS 1997 industries using the correspondence table from Feenstra et al. (2002). Available at: http://cid.econ.ucdavis.edu/usix.html. Average exports for the three-year period 2006-2008 are calculated when data for at least two years are available. The findings of the paper do not change when we use alternative years (2000, 2007) for the dependent variable.

4 DATA

The key variable of interest in our regressions is the interaction between a sector position in the supply chain and a country's quality of infrastructure and logistics services. To measure the upstreamness (or distance from final demand) of an industry, we employ the supplementary use table of the US 1997 benchmark input-output tables and calculate the indicator developed by Antràs et al. (2012).[8] Using a correspondence of the U.S. Bureau of Economic Analysis (BEA), we map the measure in terms of input-output codes to NAICS 1997 industries.

Industries which operate at the initial stages of the supply chain are located "upstream", while industries operating close to final demand are located "downstream". Upstreamness for industry *j* is given by the following system of linear equations:

$$upstream_j = 1 + \sum_k^N \frac{d_{jk}Y_k}{Y_j} upstream_k \quad (3)$$

where, d_{jk} is the dollar amount of industry *j*'s output that is needed to produce one dollar of industry *k*'s output, Y_k is output of manufacturing industry *k* and Y_j is domestic absorption of industry *j*'s output. Hence, the term $d_{jk}Y_k/Y_j$ measures the share of industry *j*'s output that is used as intermediate input by industry $k \in \{1,2,\ldots N\}$. Using matrix algebra, one can solve the system of equations and calculate the vector of industry measures as $upstream_j=[I-\Delta]^{-1}{}^*1$, where Δ is a matrix with $d_{jk}Y_k/Y_j$ in entry (*j,k*).[9] The index $upstream_j$ is one if all output of industry *j* goes directly to final use. It should be noted that an industry's upstreamness depends on the strength of forward linkages, i.e. the share of domestically-absorbed industry *j* output that is used as intermediate input, as well as on the number and upstreamness of the stages *k* separating industry *j* from final demand.

We also calculate the share of intermediates in an industry's exports at the world level as an alternative measure for upstreamness and forward linkages. Applying the Broad Economic Categories (BEC) classification, we calculate the share of intermediates in world exports of NAICS industry *j* ($shint_j$) in the year 2000.[10] Among the 357 manufacturing industries, 27% of industries export only final products, 34% export both intermediates and final products, and 39% export only intermediates. The exports of the median industry consist to 56% of intermediates.

Our two measures for an industry's position in GVCs, $upstream_j$ and $shint_j$, are closely related. They both measure forward linkages. However, in contrast to $upstream_j$, the measure $shint_j$ does not take into account the number of stages through which the intermediate inputs have to pass before reaching final demand. And while $upstream_j$ is calculated for the US, $shint_j$ is calculated at the world level. Still, the two measures are strongly correlated displaying a correlation coefficient of 0.70. Table 1 shows the top 10 and bottom 10 industries in terms of $upstream_j$, as well as the respective $shint_j$ measure for the industries' share of intermediates in exports. Smelting and refining of copper is the most upstream industry as its output goes through five more stages before reaching final use ($upstream_j$=5.066). In contrast, automobile manufacturing and cigarette manufacturing are among the most downstream industries with all output going to final use ($upstream_j$=1). As one could expect, all top and bottom 10 industries in terms of $upstream_j$, export either only intermediates ($shint_j$=1) or only final products ($shint_j$=0), respectively.

---

[8] Benchmark US input-output tables are available at: http://www.bea.gov/industry/io_benchmark.htm

[9] Antràs et al. (2012) use the detailed supplementary use table of the 2002 US input-output tables. We adapt the STATA code provided by the authors to calculate the measure based on the 1997 US input-output tables. Downloaded from Davin Chor's website: https://sites.google.com/site/davinchor/.

[10] We use the correspondence table from Feenstra et al. (2002) to map SITC Rev.3 product level exports to 6-digit NAICS 1997 industries.

Table 1. Top 10 and bottom 10 industries in terms of upstreamness

Top 10				*Bottom 10*			
NAICS	**Industry**	**up-stream$_j$**	**shint$_j$**	**NAICS**	**Industry**	**up-stream$_j$**	**shint$_j$**
331411	Primary Smelting and Refining of Copper	5.066	1.00	316211	Rubber and Plastics Footwear Manufacturing	1.004	0.00
331311	Alumina Refining	5.051	1.00	316213	Men's Footwear (except Athletic) Manufacturing	1.004	0.00
325110	Petrochemical Manufacturing	4.413	1.00	316214	Women's Footwear (except Athletic) Manufacturing	1.004	0.00
325311	Nitrogenous Fertilizer Manufacturing	4.242	1.00	316219	Other Footwear Manufacturing	1.004	0.00
327125	Nonclay Refractory Manufacturing	4.136	1.00	333913	Measuring and Dispensing Pump Manufacturing	1.003	0.00
331112	Electrometallurgical Ferroalloy Product Manufacturing	4.040	1.00	337910	Mattress Manufacturing	1.003	0.00
331312	Primary Aluminum Production	4.006	1.00	321991	Manufactured Home (Mobile Home) Manufacturing	1.002	0.00
322110	Pulp Mills	3.916	1.00	336111	Automobile Manufacturing	1.000	0.00
327410	Lime Manufacturing	3.874	1.00	312221	Cigarette Manufacturing	1.000	0.00
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	3.831	1.00	336992	Military Armored Vehicle, Tank, and Tank Component Manufacturing	1.000	0.00

Our benchmark measure for a country's quality of transport infrastructure, T_i, is a component of the World Bank (WB) Logistics Performance Index (LPI) that captures the "quality of trade and transport-related infrastructure (e.g. ports, railroads, roads, information technology)" on a scale from 1 (very low) to 5 (very high) for the year 2007.

In robustness regressions, we use three additional measures for a country's quality of infrastructure and logistics services: the overall LPI ($T2_i$); the cost to export ($T3_i$) and the liner shipping connectivity index ($T4_i$). The overall LPI is a broad index that covers: i) efficiency of customs; ii) quality of trade and transport infrastructure; iii) ease of arranging shipments; iv) quality of logistics services; v) tracking and tracing and vi) timeliness. The cost to export indicator ($T3_i$) measures the cost (administrative, logistics, transport) required to export a 20-foot container from the warehouse to the departure of the container ship. It relates to 2005 and is sourced from the World Bank Doing Business Indicators. Finally, the UNCTAD Liner Shipping Connectivity Index (LSCI) measures a country's integration into global liner shipping networks. The LSCI varies between 0 and 100 is based on five components: i) number of ships; (ii) total container-carrying capacity of those ships; (iii) maximum vessel size; (iv) number of services; and (v) number of companies that deploy container ships from and to a country's ports. Data for the LSCI are for 2004.

Table 2 shows that our four measures of quality of transport infrastructure and logistic services display moderate to very strong correlations. As one could expect, the infrastructure component of the LPI (T_i) and the overall LPI ($T2_i$) are highly correlated. Furthermore, the two LPI measures are strongly correlated with the LSCI. Only the correlation of the cost to export indicator with the other three variables is not that high.

Table 2. Pairwise correlation coefficients of transport infrastructure variables

	T_i	$T2_i$	$T3_i$	$T4_i$
Quality of trade and transport infrastructure (T_i)	1			
Logistics Performance Index (LPI) ($T2_i$)	0.972	1		
Cost to export ($T3_i$)	-0.463	-0.438	1	
Liner Shipping Connectivity Index (LSCI) ($T4_i$)	0.628	0.630	-0.355	1

As regards the other sectoral characteristics and factor abundance variables, we follow the existing literature. Following Hummels and Schaur (2013), we define time sensitive products according to their probability of being transported by air. Using data on US imports and shipping mode at the HS 10-digit level for 1997, we calculate the time sensitivity t_j of NAICS industry j as the simple average of the shares of HS 10-digit imports that are shipped by air.[11] We capture institutional intensity q_j of industry *j* using Nunn's (2007) measure of contract intensity. In particular, q_j measures the share of relationship-specific inputs in the production of industry *j*, i.e. inputs that are neither reference priced nor sold on an organised exchange. Industries that use a higher share of relationship-specific inputs are in need of better contract enforcement to avoid possible underinvestment by suppliers. Capital intensity, k_j, and skilled labour intensity, h_j, of 6-digit NAICS industries for the year 2000 are taken from the U.S. NBER-CES Manufacturing Industry Database. They are measured as the total real capital stock per worker and the share of non-production workers in total employment in industry *j*, respectively.

We measure $Remoteness_i$ as the logarithm of country *i*'s GDP-weighted distance from other countries: $Remoteness_i = \Sigma_c[dist_{ic}/(GDP_i/GDP_{RoW})]$. A country's quality of institutions Q_i is measured by the rule of law indicator from the WB Worldwide Governance Indicators for the year 2000. The rule of law indicator ranges from -2.5 to 2.5 and captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. Country endowments of capital K_i and human capital H_i are measured by the capital stock per worker and the human capital index for the year 2000, and are taken from the Penn World Table 9.0 (Feenstra et al. 2015).

Table 3. Summary statistics for industry-level and country-level variables

Variables	Obs	Mean	Std. Dev.	Min	Max	Year
Upstreamness (*upstream* $_j$)	357	2.09	0.85	1	5.07	1997
Share of intermediates (*shint* $_j$)	357	0.54	0.45	0	1	2000
Share of imports shipped by air (t_j)	357	0.18	0.22	0	1	1997
Share of relationship-specific inputs (q_j)	357	0.53	0.22	0.02	0.98	1997
Capital intensity (k_j)	357	11.49	0.88	9.55	14.30	2000
Skilled labour intensity (h_j)	357	0.29	0.11	0.09	0.68	2000
Quality of trade and transport infrastructure (T_i)	113	2.74	0.73	1.40	4.29	2007
Logistics Performance Index (LPI) ($T2_i$)	113	2.89	0.62	1.97	4.19	2007
Cost to export ($T3_i$)	118	6.89	0.52	5.37	8.43	2005
Liner Shipping Connectivity Index (LSCI) ($T4_i$)	98	2.66	0.98	-0.92	4.61	2004
Rule of law (Q_i)	124	0.10	0.97	-1.56	1.94	2000
Remoteness (R_i)	124	25.00	0.15	24.44	25.24	2000
Capital per worker (K_i)	124	10.70	1.40	7.24	13.40	2000
Human capital index (H_i)	124	2.39	0.67	1.07	3.58	2000
GDP p.c. $_i$	124	8.90	1.28	6.30	11.57	2000

Notes: The variables k_j, $T3_i$, $T4_i$, $LSCI_i$, R_i, K_i, and *GDP p.c.* $_i$ are in logarithms.

5 RESULTS

5.1 Main results

Table 4 reports the OLS estimates of our empirical model. Column (1) presents results for the interaction between industry upstreamness and transport infrastructure, while controlling for other sources of comparative advantage, as well as for country and industry fixed effects. Standard errors are clustered to take into account likely correlation in the disturbance terms at the country level.

[11] Data on US imports and shipping mode at the HS 10-digit level are collected by the U.S. Census Bureau and accessible at the website of Peter Schott: http://faculty.som.yale.edu/peterschott/sub_international.htm. We use the HS10 to NAICS 1997 correspondence table from Feenstra et al. (2002). Results are very similar if a trade-weighted average is used to calculate the time sensitivity of industries.

Our interaction of interest between upstreamness and transport infrastructure has the expected sign. The coefficient is positive and highly significant, indicating that countries with better transport infrastructure tend to specialize in upstream industries. This result remains robust as we stepwise expand the model to include interactions between *upstream*$_i$ and quality of institutions and remoteness in column (2), as well as capital and human capital in column (3).

In columns (4)-(7), we test the robustness of our finding by controlling for the possibility that a country's development level drives specialization within GVCs. In particular, we include interactions between upstreamness and a country's GDP p.c. (col. 4), as well as between all industry intensities and GDP p.c. (col. 5). The interaction between upstreamness and transport infrastructure remains positive and significant at 10%. The result also holds if we include interactions between industry fixed effects and GDP p.c. (col. 6 and col. 7), thereby allowing GDP p.c. to have a specific effect on export specialization for each industry.

The coefficients of the other sources of comparative advantage in upstream/downstream sectors are in line with the existing literature. We support the theoretical predictions on the role of institutions (Costinot et al., 2013) and remoteness (Antràs and de Gortari, 2017) for the GVC positioning of countries (columns 3-7). Countries with better institutions and which are less remote tend to specialize in downstream industries. While both interaction terms have the expected sign, only the one involving institutions is significant at 10%. Furthermore, the result of our baseline regression (column 3) suggests that capital-abundant countries tend to specialize in upstream industries.

Other control variables ($t_j x T_i$; $q_j x Q_i$; $k_j x K_i$; $h_j x H_i$) have the expected sign, even though the human capital interaction is never significant. In line with the existing literature [12], we find that countries with good transport infrastructure specialize in time-sensitive industries and those with good rule of law specialise in institutional-intensive industries. This finding is also relevant for GVCs, as many of them are time-sensitive and institutional-intensive.

In terms of economic magnitude, our results show that quality of transport infrastructure is of similar importance to capital in determining a country's comparative advantage, and has a larger impact than quality of institutions and human capital together. Capital is the most important factor for comparative advantage in upstream sectors, followed by transport infrastructure.[13]

[12] Levchenko (2007), Nunn (2007), Li and Wilson (2009), Djankov et al. (2010) and Freund and Rocha (2011).

[13] According to estimates of our benchmark model in column 3, a one standard deviation increase in the interaction terms $u_j T_i$ and $t_j T_i$ increases industry-level exports by 0.31 standard deviations. One standard deviation increases of the respective interaction terms involving K_i, H_i and Q_i, increase exports by 0.36, 0.05 and 0.01 standard deviations, respectively. A one standard deviation increase in $u_j T_i$ increases exports by 0.16 standard deviations, while a one standard deviation increase in $u_j K_i$, $u_j H_i$ *and* $u_j Q_i$ increases exports by 0.25, 0.01 and -0.08 standard deviations, respectively.

Table 4. Transport infrastructure, institutions and upstreamness in global value chains

Dependent var.: X_{ij}	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$upstream_j$ x T_i	0.189***	0.300***	0.230**	0.182''	0.195*	0.186*	0.193*
	(0.050)	(0.094)	(0.101)	(0.110)	(0.109)	(0.105)	(0.110)
$upstream_j$ x Q_i		-0.083	-0.148*	-0.163**	-0.146*	-0.142*	-0.142*
		(0.072)	(0.078)	(0.079)	(0.077)	(0.075)	(0.076)
$upstream_j$ x $Remoteness_i$		0.364	0.387	0.369	0.368	0.360	0.363
		(0.263)	(0.274)	(0.275)	(0.276)	(0.266)	(0.276)
$upstream_j$ x K_i			0.110**	0.030	0.032		0.036
			(0.045)	(0.090)	(0.072)		(0.071)
$upstream_j$ x H_i			0.012	-0.003	-0.004		0.002
			(0.090)	(0.091)	(0.092)		(0.092)
$upstream_j$ x GDP p.c.$_i$				0.129	0.107		
				(0.132)	(0.118)		
t_j x GDP p.c.$_i$					-0.230		
					(0.190)		
q_j x GDP p.c.$_i$					-0.128		
					(0.226)		
k_j x GDP p.c.$_i$					-0.007		
					(0.092)		
h_j x GDP p.c.$_i$					0.186		
					(0.273)		
t_j x T_i	0.978***	0.998***	0.977***	0.976***	1.261***	1.257***	1.258***
	(0.213)	(0.210)	(0.211)	(0.211)	(0.372)	(0.373)	(0.373)
q_j x Q_i	0.753***	0.703***	0.663***	0.663***	0.780***	0.794***	0.796***
	(0.133)	(0.125)	(0.125)	(0.125)	(0.275)	(0.277)	(0.277)
k_j x K_i	0.049''	0.050''	0.023	0.023	0.019	0.035	0.019
	(0.033)	(0.032)	(0.029)	(0.029)	(0.089)	(0.101)	(0.089)
h_j x H_i	0.412	0.406	0.523''	0.525''	0.418	0.415	0.421
	(0.344)	(0.344)	(0.354)	(0.354)	(0.586)	(0.577)	(0.594)
Industry f.e. x GDP p.c.	no	no	no	no	no	yes	yes
R-squared	0.759	0.760	0.760	0.760	0.760	0.983	0.983
Numb. of observations	35,969	35,969	35,969	35,969	35,969	35,969	35,969

Notes: All regressions models include country and industry fixed effects. The sample covers 113 countries and 357 manufacturing industries. Standard errors clustered at the country-level are reported in brackets. *** Significant at 1%, ** at 5%, * at 10%, '' at 15%.

5.2 Robustness analysis

Table 5 shows results for our baseline regressions when using the share of intermediates in world industry exports ($shint_j$) as measure for an industries' position in GVCs. In all specifications, the interaction between $shint_j$ and transport infrastructure has the expected sign and is highly significant. Countries with better transport infrastructure export relatively more in industries whose output contains a higher share of intermediates.

Furthermore, Table 5 provides further evidence that also institutions, remoteness and capital matter for a countries' positioning in GVCs. In our baseline regression (column 2), all three interactions are significant. Countries with better rule of law will export relatively more in industries that have a lower share of intermediates, while countries that are remote and endowed with more capital will export relatively more in industries with strong forward linkages.

Table 5. Transport infrastructure, institutions and specialization in intermediates

Dependent var.: X_{ij}	(1)	(2)	(3)	(4)
$shint_j$ x T_i	0.559***	0.446***	0.356**	0.367**
	(0.145)	(0.153)	(0.158)	(0.163)
$shint_j$ x Q_i	-0.143	-0.261**	-0.232**	-0.242**
	(0.109)	(0.112)	(0.108)	(0.107)
$shint_j$ x $Remoteness_i$	0.689''	0.809*	0.695''	0.769''
	(0.454)	(0.471)	(0.452)	(0.471)
$shint_j$ x K_i		0.142**		0.003
		(0.070)		(0.119)
$shint_j$ x H_i		0.108		0.082
		(0.134)		(0.134)
t_j x T_i	0.961***	0.947***	1.231***	1.231***
	(0.212)	(0.212)	(0.373)	(0.373)
q_j x Q_i	0.682***	0.652***	0.864***	0.865***
	(0.123)	(0.122)	(0.275)	(0.275)
k_j x K_i	0.056*	0.040	0.034	0.031
	(0.032)	(0.030)	(0.102)	(0.096)
h_j x H_i	0.423	0.506	0.419	0.433
	(0.344)	(0.351)	(0.576)	(0.584)
Industry f.e. x GDP p.c.	no	no	yes	yes
R-squared	0.760	0.760	0.983	0.983
Numb. of observations	35,969	35,969	35,969	35,969

Notes: All regressions models include country and industry fixed effects. The sample covers 113 countries and 357 manufacturing industries. Standard errors clustered at the country-level are reported in brackets. *** Significant at 1%, ** at 5%, * at 10%, '' at 15%.

As a second robustness test, we re-estimate our benchmark model employing alternative measures for quality of transport infrastructure and logistic services. In particular, we use i) the overall LPI, which captures a broader set of transport and logistics costs; ii) Cost to export, which captures administrative, logistics and transport costs between the warehouse and the container ship; and iii) the LSCI, which measures a country's integration level into global liner shipping networks.

Results shown in Table 6 confirm our main finding that countries with better quality of transport infrastructure tend to specialize in upstream industries.[14] The interaction terms between $upstream_j$ and the three indicators of quality of infrastructure have all the expected sign and are significant (columns 1-3). Furthermore, we obtain similar results when interacting an industry's intermediate share ($shint_j$) with the three alternative measures of quality of transport infrastructure (columns 4-6).

[14] For all three measures of transport infrastructure, results are robust to the inclusion of interactions between industry fixed effects and GDP per capita.

Table 6. Using alternative measures for transport infrastructure

Dependent var.: Xij	$T2_i$ (LPI Overall) (1)	$T3_i$ (Cost to exp.) (2)	$T4_i$ (LSCI) (3)	$T2_i$ (LPI Overall) (4)	$T3_i$ (Cost to exp.) (5)	$T4_i$ (LSCI) (6)
$upstream_j$ x $T2_i$|$T3_i$|$T4_i$	0.269**	-0.175**	0.180***			
	(0.105)	(0.081)	(0.046)			
$upstream_j$ x Q_i	-0.148**	-0.054	-0.085			
	(0.072)	(0.060)	(0.059)			
$upstream_j$ x $Remoteness_i$	0.417''	0.457*	0.486*			
	(0.280)	(0.273)	(0.248)			
$upstream_j$ x K_i	0.115**	0.120***	0.080''			
	(0.044)	(0.039)	(0.049)			
$upstream_j$ x H_i	0.008	0.075	0.085			
	(0.089)	(0.087)	(0.097)			
$shint_j$ x $T2_i$|$T3_i$|$T4_i$				0.509***	-0.240**	0.289***
				(0.158)	(0.118)	(0.071)
$shint_j$ x Q_i				-0.256**	-0.070	-0.136''
				(0.105)	(0.082)	(0.082)
$shint_j$ x $Remoteness_i$				0.857*	0.831*	0.876**
				(0.491)	(0.459)	(0.426)
$shint_j$ x K_i				0.154**	0.186***	0.103
				(0.068)	(0.061)	(0.072)
$shint_j$ x H_i				0.099	0.177	0.231''
				(0.132)	(0.130)	(0.146)
t_j x $T2_i$|$T3_i$|$T4_i$	1.064***	-0.653**	0.649***	1.029***	-0.604**	0.599***
	(0.244)	(0.298)	(0.193)	(0.247)	(0.298)	(0.195)
q_j x Q_i	0.680***	0.906***	0.903***	0.669***	0.883***	0.898***
	(0.126)	(0.124)	(0.162)	(0.123)	(0.121)	(0.156)
k_j x K_i	0.022	0.016	0.056	0.039	0.033	0.073*
	(0.029)	(0.029)	(0.039)	(0.030)	(0.030)	(0.041)
h_j x H_i	0.561''	0.974***	1.088***	0.543''	0.946***	1.070***
	(0.350)	(0.353)	(0.400)	(0.348)	(0.351)	(0.404)
Industry f.e. x GDP p.c.	no	no	no	no	no	no
R-squared	0.760	0.763	0.754	0.760	0.763	0.754
Numb. of observations	35,969	36,822	30,764	35,969	36,822	30,764
Numb. of countries	113	118	98	113	118	98
Numb. of industries	357	357	357	357	357	357

Notes: All regressions models include country and industry fixed effects. Standard errors clustered at the country-level are reported in brackets. *** Significant at 1%, ** at 5%, * at 10%, '' at 15%.

Although our methodological approach as well as the inclusion of country and industry fixed effect limits the scope for endogeneity, one must be cautious in interpreting the OLS estimates as causal. It is in fact possible that the relationship between quality of infrastructure and trade on the other side is reversed. For example, countries that specialise in upstream industries may have a greater incentive to develop good infrastructure. To address such potential endogeneity bias, we use an instrumental variable approach whereby an instrumental variable is used to predict the exogenous part of the endogenous variable. An instrumental variable needs to fulfil two conditions in order to be valid: First, it needs to be relevant, i.e. correlated with the endogenous variable. Second, it needs to be exclusive, i.e. uncorrelated with the other determinants of the dependent variable. This means that the instrument affects the dependent variable only through its effect on the endogenous variable.

We instrument transport infrastructure using colonial origins.[15] It is well known that colonisers have historically invested in transport infrastructures. Roads and ports were essential to develop the traffic between the colony and the colonisers. One would expect that the quality of infrastructure in the colonised country was therefore related to that of its colonisers. At the same time, it is hard to argue that the quality of infrastructure in the colonising country can directly affect the specialization in upstream sector. At the time, GVCs were hardly developed.

Table 7 presents the results if we estimate our benchmark model using two-stage least squares instrumental variables (2SLS IV) regressions. Again, all coefficients show the correct signs and are significant: quality of transport infrastructure provides a comparative advantage in upstream stages of production; institutions and centrality (the inverse of remoteness) provide a comparative advantage in downstream sectors.

[15] To our knowledge, no recognised instrument for transport infrastructure exists. Djankov et al. (2010) use the average quality of infrastructure of landlocked neighbouring countries as instrument. But this index is viable only for a small sample of countries.

Table 7. Instrumenting transport infrastructure with colonial origins

	2SLS IV regressions - second stage	
Dependent var.: Xij	(1)	(2)
$upstream_j$ x T_i	0.473***	
	(0.164)	
$upstream_j$ x Q_i	-0.269**	
	(0.107)	
$upstream_j$ x $Remoteness_i$	0.602*	
	(0.312)	
$upstream_j$ x K_i	0.081*	
	(0.046)	
$upstream_j$ x H_i	0.016	
	(0.094)	
$shint_j$ x T_i		0.734***
		(0.254)
$shint_j$ x Q_i		-0.402**
		(0.155)
$shint_j$ x $Remoteness_i$		1.067**
		(0.518)
$shint_j$ x K_i		0.108''
		(0.072)
$shint_j$ x H_i		0.114
		(0.136)
t_j x T_i	0.879***	0.803**
	(0.306)	(0.312)
q_j x Q_i	0.683***	0.683***
	(0.133)	(0.133)
k_j x K_i	0.022	0.039
	(0.029)	(0.030)
h_j x H_i	0.575''	0.582''
	(0.378)	(0.377)
R-squared	0.760	0.760
Numb. of observations	35,969	35,969
Underidentifiation LM (p-value)	0.00	0.00
Weak identification test (Kleibergen-Paap Wald rk F-stat.)	71209.2	11662.2
Overidentification test (p-value)	0.49	0.80

Note: Table7 reports the second stage of Two-stage-least-squares (2SLS) regressions. Transport infrastructure T_i is instrumented by 13 dummies indicating a country's main colonizer. All regressions models include country and industry fixed effects. Standard errors clustered at the country-level are reported in brackets. *** Significant at 1%, ** at 5%, * at 10%, '' at 15%.

6 CONCLUSIONS

Traditionally, the theory of comparative advantage distinguishes between capital intensive and labour intensive goods, and it predicts that a country will export the good that uses intensively the factor that the country is relatively well-endowed with. More recently, trade literature has stressed other industry characteristics relevant for comparative advantage: institutional intensity and time sensitivity. Countries with better institutions will tend to specialize in institutional intensive goods. Countries with good transport infrastructure will specialize in time sensitive goods.

This paper focuses on a fifth characteristic that shapes a country's comparative advantage in the production and export of a specific good: the stage in the production chain that the good occupies. Economic literature shows that when the production of a good is fragmented along a supply chain, erroneous or low quality components disrupt the whole supply chain. Therefore, it predicts that good institutions will give a comparative advantage in downstream sectors. It also shows that geographic location matters predicting that more central countries will tend to specialise in downstream sectors too.

Through a simple model, we show that transportation costs can play a key role in affecting patterns of specialization along the supply chain. We show that patterns of specializations depend on whether trade costs are additive or multiplicative. While multiplicative trade costs matter more in downstream sectors, additive trade costs have a greater impact in upstream sectors. Hence, since transport costs are in part additive in nature, we predict that good transport infrastructure gives a comparative advantage in upstream stages of the production process.

In order to assess what determines comparative advantage at various stages of the production chain, we estimate a factor content model of trade, where comparative advantage is estimated through the interaction of country and industry characteristics. We distinguish sectors according to their degree of upstreamness and test whether transport infrastructure explains specialization in upstream sectors. Our findings confirm our prediction that good transport infrastructure gives a comparative advantage in the early stages of production. The result is robust to the use of alternative measures of upstreamness and of quality of infrastructure as well as instrumental variable regression. We argue that this result suggests that additive costs are an important determinant of trade patterns and call for more research to be done to develop our understanding of their implications. We are also able to provide evidence that, as suggested by the literature, good institutions and centrality give a comparative advantage in the later stages of the production process. We do this in a more general framework than the existing literature.

Our findings have important policy implications by helping policy makers understand what limits some developing countries' participation in GVCs. In this paper we stress the importance of one specific factor: quality of transport infrastructure. We estimate that transport infrastructure is the most important factor for comparative advantage in upstream sectors after capital endowment. The development community, through initiatives such as the WTO-led Aid for Trade Initiative, has put emphasis on the importance of funding projects to develop trade-related infrastructures, implement trade facilitation measures and build institutional capacity to reduce trade costs and foster GVC participation. Our findings support the importance of these efforts.

7 REFERENCES

Antràs, P., D. Chor, T. Fally and R. Hillberry (2012), "Measuring the Upstreamness of Production and Trade Flows", *American Economic Review*, Papers and Proceedings, 102(3), 412-416.

Antràs, P. and D. Chor (2013), "Organizing the Global Value Chain", *Econometrica*, 81(6), 2127-2204.

Antràs, P. and A. de Gortari (2017), "On the Geography of Global Value Chains", NBER Working Papers 23456.

Bernard, A.B., J.B. Jensen, S.J. Redding and P.K. Schott (2010), "Intra-Firm Trade and Product Contractibility", *American Economic Review*, Papers and Proceedings, 100(2), 444-448.

Corcos, G., D. M. Irac, G. Mion, and T. Verdier (2013), "The Determinants of Intrafirm Trade: Evidence from French Firms", *Review of Economics and Statistics*, 95(3), 825-838.

Corsetti, G. and L. Dedola (2005), "A Macroeconomic Model of International Price Discrimination", *Journal of International Economics*, 67(1), 129-155.

Costinot, A., J. Vogel and S. Wang (2013), "An Elementary Theory of Global Supply Chains", *Review of Economic Studies*, 80(1), 109-144.

Djankov, S., C. Freund and C.S. Pham (2010), "Trading on Time", *Review of Economics and Statistics*, 92(1), 166-173.

Feenstra, R.C., J. Romalis and P.K. Schott (2002), "U.S. Imports, Exports, and Tariff Data, 1989-2001", NBER Working Paper 9387.

Feenstra, R.C. and G.H. Hanson (1996), "Globalization, Outsourcing, and Wage Inequality", *American Economic Review*, 86(2), 240-245.

Feenstra, R. C., R. Inklaar and M. P. Timmer (2015), "The Next Generation of the Penn World Table", *American Economic Review*, 105(10), 3150-3182.

Freund, C. and N. Rocha (2011), "What Constrains Africa's Exports?", *World Bank Economic Review*, 25(3), 361-386.

Grossman, G.M. and E. Rossi-Hansberg (2008), "Trading Tasks: A Simple Theory of Offshoring", *American Economic Review*, 98(5), 1978-1997.

Hummels, D. and A. Skiba (2004), "Shipping the Good Apples Out? An Empirical Confirmation of the Alchian-Allen Conjecture", *Journal of Political Economy*, 112(6), 1384-1402.

Hummels, D. and G. Schaur (2013), "Time as a Trade Barrier", *American Economic Review*, 103(7), 2935-2959.

Iacovone, L., B. Javorcik, W. Keller and J. Tybout (2015), "Supplier Responses to Walmart's Invasion in Mexico", *Journal of International Economics*, 95(1), 1-15.

International Monetary Fund (IMF) (2013) "Trade Interconnectedness: The World with Global Value Chains", Washington DC: IMF.

Irarrazabal, A., A. Moxnes and L.D. Opromolla (2015), "The Tip of the Iceberg: A Quantitative Framework for Estimating Trade Costs", *The Review of Economics and Statistics*, 97(4), 777-792.

Levchenko, A. (2007), "Institutional Quality and International Trade", *Review of Economic Studies*, 74(3), 791-819.

Li, Y. and J. S. Wilson (2009), "Time as a Determinant of Comparative Advantage", The World Bank Policy Research Working Paper Series 5128.

Nordås, H. K. (2006), "Time as a Trade Barrier: Implications for Low-Income Countries", *OECD Economic Studies*, 2006(1), 137-167.

Nunn, N. (2007), "Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade", *The Quarterly Journal of Economics*, 122(2), 569-600.

Nunn, N. and D. Trefler (2008), "The Boundaries of the Multinational Firm: An Empirical Analysis", in D. Marin and T. Verdier (eds.), *The Organization of Firms in a Global Economy*, Harvard University Press.

Romalis, J. (2004), "Factor Proportions and the Structure of Commodity Trade", *American Economic Review*, 94(1), 67-97.

Yi, K.-M. (2003), "Can Vertical Specialization Explain the Growth of World Trade?" *Journal of Political Economy*, 111(1), 52–102.

WTO (2014), *World Trade Report 2014: Trade and Development: Recent Trends and the Role of the WTO*, Geneva, WTO.