

ANALYZING THE EFFECTS OF TRADE FACILITATION ON INTERNATIONAL TRADE USING A SIMULTANEOUS APPROACH

1. Introduction

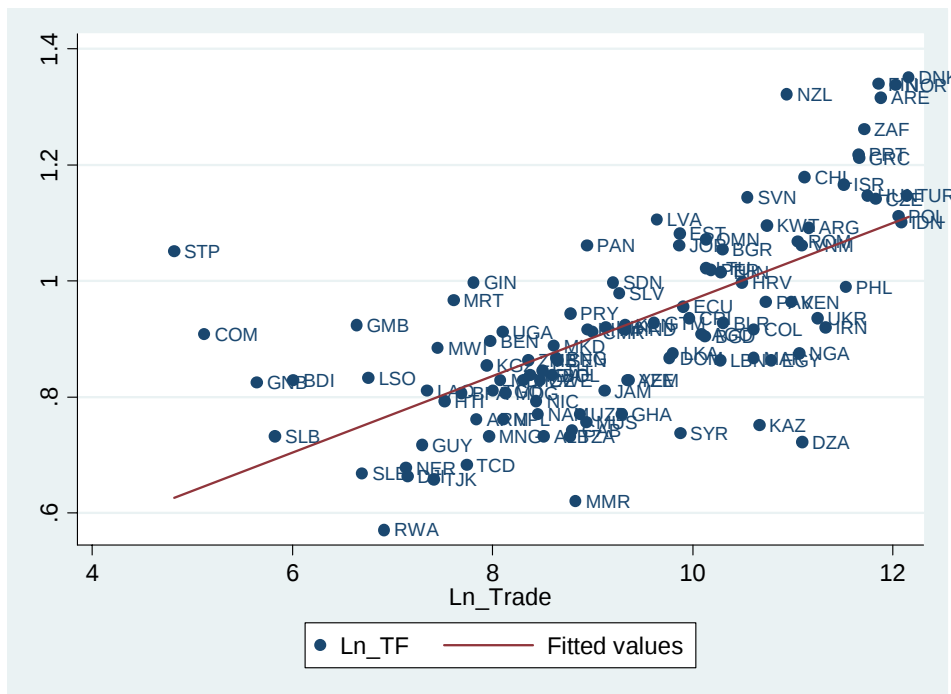
Trading infrastructure establishes the ease and efficiency with which goods are transferred from producers to consumers overseas. A blueprint of cross-country exchange comprises of physical transportation networks, such as port and berthing facilities, as well as institutional entities at borders that oversee legal procedures and provide auxiliary services (Francois and Manchin, 2007). The delivery of merchandise from the producer warehouse onto shipping docks involves usage of a series of services and facilities including inland transportation, completion of customs documents, banking services, and logistics associated with the loading of goods to docks. Together, the range of amenities used is referred to as ‘trade facilitation’ that summarizes the series of complex procedures associated with trading across borders (Ivanic & Wilson, 2003).

Recent trade facilitation efforts from multilateral development banks, trade institutes, and rapidly-globalizing economies have been far-fetched. The World Bank has taken significant initiatives on trade and transport facilitation in developing countries to enhance export potentials as a means to attain the Millennium Development Goals¹. Building supply capacity and trade-related infrastructure is well-documented in the Doha Declaration Work Program Document, and has been largely implemented in LDCs by the Aid for Trade Program under the WTO. Among individual countries, for example, China’s trade policy focused largely on strengthening maritime and developing ports to cater to the demands for larger volumes of trade in the last decade (Stopford, 2007). Singapore being a ‘re-export economy’, maintains the state-of-art technologies and automated procedures at borders that position her as the country with the best facilities for trade (Arvis, et al., 2007). These examples illustrate that incentive for capacity developments are driven by two factors: (1) a ladder for LDCs to attain greater global integration; (2) greater demand for frictionless trade in more trade-dependent economies, or where trade is growing rapidly.

¹ See the Bank’s page on trade facilitation

This leads to the question ‘do limitations of supply capacity restrict trade, or is the quality of infrastructure demand-dependent?’ We argue that both are true. The first case refers to low income economies in Africa, Eastern Europe, and South Asia that lack trading infrastructures and receive aid from development organizations. The second case refers to economies where trade is growing quickly, such as China, Hong Kong, Taiwan and India, that calls for a rise in demand for infrastructure-related to trade; or where there are greater incentives for investments simply because the economies are largely trade-dependent and fixed expenditures are spread over more goods, such as Singapore, USA and Japan. Evidence from data suggests that in general countries with improved perceived border quality trade more than others. A simple scatter plot in Figure 1 shows that countries with larger trade volumes have better trade facilitation. The main goal of this paper is to formalize the causes of bidirectional causality and estimate the relationship between trade facilitation and trade flows.

Figure 1: Trade increases with Facilitation



Data sources: Total Trade flow data (exports and imports), GTAP V7 (2004); Trade Facilitation: Arvis et al. (2007)

The literature suggests that inefficiencies in transactions across borders impose high monetary (Anderson & van Wincoop, 2004) and time costs (Djankov, Freund and Pham, 2007; Nordas, Pinali and Grosso, 2006; Hummels, 2001) of trade. The incidence of higher transaction costs lower trade volumes and the probability of trade (Wilson, Mann, & Otsuki, 2005; Soloado, Wilson and Mejía, 2006; Perrson, 2007) thus reducing the potential for larger market integration. A limitation of this literature is that it assumes investments on facilitation to be exogenous and does not take into account incentives for investments that are driven by demand forces. Exploring single dimension causality implies that estimates on coefficients from ordinary least squares are likely to be biased. This paper departs from the assumption of exogeneity, and determines optimal levels of facilitation assuming endogenous investment decisions.

Two strands of literature allude to a similar problem of endogeneity and the relevance of careful estimation techniques. The literature on endogenous trade policy highlights the importance of appropriate modeling approaches for estimating consistent elasticities for trade with respect to tariffs. The literature on endogenous tariffs suggests that a social welfare function is maximized to determine optimal protectionism (Lee & Swagel, 1997; Baldwin, 1982; Mayer, 1984; Helpman and Grossman, 1994). For example, Baier and Bergstrand (2001b) predict an empirical model to evaluate the major determinants of FTA formation; they find that the impacts of trade protection are much higher when barriers are modeled endogenously. Another literature on the relationship between output growth and infrastructure development presents a similar dilemma with causality running in both directions. The complexity of the problem leads to a debate among economists on the magnitude of effects (Aschauer, 1990, Eberts & Fogarty, 1987; Munell, 1990; Holz-Eakin, 1988; Aaron, 1990; Hulten and Schwab, 1991; Jorgenson, 1991). For example, Röller and Waverman (2001) estimate a simultaneous-equations model that appropriately identifies demand and supply equations for telecommunications and its relation to economic growth.

In this paper the correct effect on trade is untied by developing a concrete model that characterizes the demand and supply of trading infrastructure. Firstly, investments on infrastructure that facilitate trade reduce fixed costs of overseas delivery. Demand for infrastructure is dominated by the extent to which exports and imports expand, and the impact on household welfare from

increased trade. Investments on infrastructure development are certainly costly which deters consistent development of high-quality borders. The supply side is built by bringing together some simple intuitions on why some countries invest less relative to others. Supply factors depend upon the various endowed features of the economy, such as resource availability and the quality of governance. An interaction of the marginal costs of investments and marginal welfare gains from reforms determines optimal decisions for investments.

The theory provides basis for the derivation of a simultaneous model which is estimated using data on aggregated bilateral trade flows for a set of 109 countries for the year 2004. Results from estimation support the idea that increased efforts in facilitating border transactions minimize frictions in international transactions providing countries with better opportunities for trade. The magnitude of elasticity is even larger than earlier estimates from single-equations models. Post-regression diagnostics empirically validate the legitimacy of the instruments used, and robustness checks validate the stability on the magnitude of estimates across various choices of instruments.

The rest of the paper is organized in the following way. Section 2 develops an export sector-based model that characterizes the relevance of infrastructure in international trade. The theory develops several predictions on the relationship between infrastructure and trade that are tested empirically and used to design a simultaneous model of trade. The empirical model is estimated in section 3. Data sources are described in this section. Section 4 presents econometric results and robustness checks. The last section provides a summary.

2. Theoretical Model

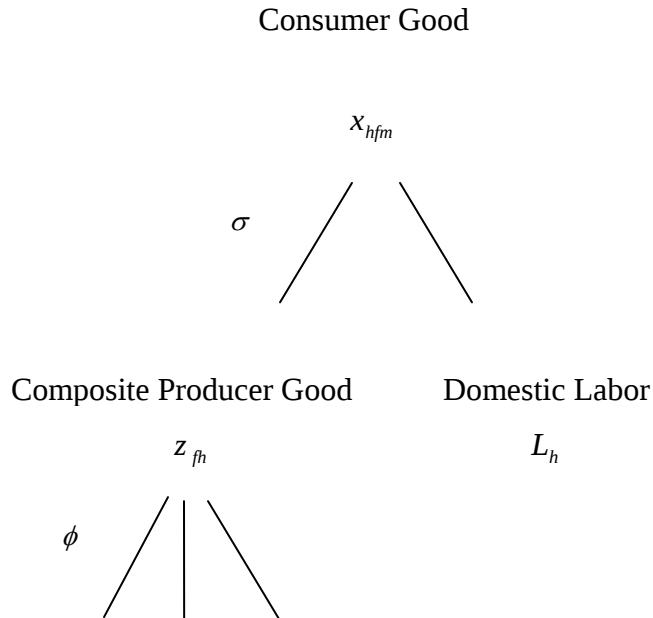
The motivation for this model comes from changes in recent trade patterns. The trend of international trade flows have shifted to greater trade in intermediates (WTO Annual Report, 1990-2008). Often referred to as ‘global production sharing’ (Feenstra and Hanson, 2001), ‘vertical specialization’ (Hummels, Ishii and Yi, 2001) or ‘splitting up the value chain’ (Krugman, 1995), all of them describe how the production structure have become geographically dispersed. Countries now specialize in producing very specific products depending on where they enjoy a competitive edge. The design of the model reflects characteristics of economies like Singapore or Hong Kong who

engage in large volumes of trade in intermediates, contribute to value-added in a specialized dimension, and redirect products for exports. The goal of a hypothetical social planner is to maximize trade such that returns to a fixed factor increases.

A partial equilibrium export-sector model is designed to capture the role of trade facilitation. A small open economy denoted by h for home produces a single monopolistically competitive good, x_{hfm} , with many varieties m , consumed in a foreign region f . Region f is assumed to be large, and can be thought of as the ‘rest of the world’. Each variety is produced using domestically-

supplied labor, L_h , and composite intermediate inputs imported from abroad, $\left(\sum_n z_{fhn}^{\frac{\phi-1}{\phi}} \right)^{\frac{\phi}{\phi-1}}$. There are many varieties, n , of intermediate inputs produced in f and supplied to h . The nested CES structure is shown in Figure 2. The top CES nest characterizes the consumer good with σ as the constant elasticity of substitution across varieties. The composite intermediate z_{fh} has an elasticity of substitution denoted by ϕ . Trading infrastructure is a produced public good that uses capital inputs. To keep the model simple there is no competition between endowments across uses. A graphical exposition of the model is included as Figure 7 in the Appendix.

Figure 2: Production Structure



2.1 Final Demand

Final good consumers in region f have identical preferences and derive utility from consuming all varieties, $x_1, \dots, x_m$, such that preferences are represented by CES over varieties.

$$U_f = \left(\sum_{m=1}^M x_{hfm}^\theta \right)^{\frac{1}{\theta}}, \text{ where } \theta < 1 \text{ for concavity, and } \sigma = \frac{1}{1-\theta} > 0. \text{ Demand for a particular}$$

variety in the foreign market depends upon disposable income weighted by the share of price for that variety relative to the price index.

$$x_{hfm}^D = (D_f) \frac{p_{hfm}^{-\sigma}}{P_{hfm}^{1-\sigma}}, \text{ where } P_{hfm} = \left(\sum_{m=1}^M p_{hfm}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

All final goods produced at home are consumed in the rest of the world. Consumer demand prices are assumed to be in their 'cif' formulation including transportation and tariff costs. The objective of region h is to maximize income through greater sales to region f .

2.2 Consumer Good

Region h brings semi-processed goods from abroad which is furnished to a finished product using labor input. The domestic economy is assumed to be rich in labor endowment specializing in the outsourcing of labor services. Labor abundant countries often engage in global production sharing by providing labor-intensive services. For example, Pakistan and Bangladesh that are abundant in unskilled labor manufactures textiles and wearing apparel that are exported to foreign markets (Chapter 4). Similarly, the USA being abundant in skilled labor dominates in the production of more sophisticated manufacturing goods, such as hard disk drives, while outsourcing low-technology computer parts mostly to Southeast Asia (Gourevitch, Peter, Roger Bohn and David McKendrick (2000).

The consumer good is produced using domestic labor and foreign intermediates. Per unit cost of producing the final good becomes a function of labor wages, w_h , and the composite price

of intermediates, $Q_{fhn} = \left(\sum_{n=1}^N q_{fhn}^{1-\phi} \right)^{\frac{1}{1-\phi}}$. Since all goods produced are exported abroad, each firm entering the market faces two forms of fixed costs: fixed production cost and fixed trading cost. Fixed production cost is a constant, a_h . Fixed trading cost is inversely related to the quality of the home country's border infrastructure, $1/G_h^\gamma$, where $\gamma > 0$ is the cost elasticity of infrastructure for exports i.e. it measures the ease with which improved quality of logistics lowers fixed costs of exporting. The cost function of a representative firm is given by:

$$C(x_{hfm}) = \frac{a_h}{G_h^\gamma} + Q_{fhn}^\alpha w_h^{1-\alpha} x_{hfm}$$

Since firms face the same production and border costs, with no differences in productivity, all firms are homogeneous and behave similarly in equilibrium. Price is a constant markup over marginal costs obtained by maximizing profits; assuming free entry and exit implies firms earn zero profits, which determines the supply bundle of each firm.

$$p_{hfm}^*(x_{hfm}) = \left(\frac{\sigma}{\sigma-1} \right) Q_{fhn}^\alpha w_h^{1-\alpha} \quad x_{hm}^S = \frac{a_h(\sigma-1)}{G_h^\gamma (Q_{fhn}^\alpha w_h^{1-\alpha})}$$

Since all firms face the same marginal and fixed costs, $p_{hfm} = p_{hf}$ and $x_{hfm} = x_{hf}$, $\forall m \in (1, \dots, M)$, i.e. prices and output are symmetric across varieties. The consumer good's market clearing condition determines the equilibrium number of firms.

$$x_{hfm}^D = x_h^S \Rightarrow M_{hf}^* = \frac{D_f G_h^\gamma}{a_h \sigma}$$

The above expression shows that varieties of exports increase with infrastructure, lower fixed costs of production, reduced substitutability across varieties, and larger market size abroad. The effect of infrastructure on the number of export varieties establishes the first relationship between trade facilitation and trade. From the input side, infrastructure affects productivity of exported goods by reducing fixed costs. As infrastructure improves, fixed costs are lowered, and the number of export variety grows. Hence an impact on productivity from the input side channels through an increase in export sales on the output side. A second relationship in the reverse direction is established later in the paper.

The total supply of labor is assumed to be fixed, $L_h = \bar{L}$. Full employment and wage equalization across sectors implies the equilibrium wage rate is determined using the Envelope theorem:

$$\frac{\partial C_{hfm}(x_{hfm})}{\partial w_h} = (1-\alpha) \left(\frac{Q_{fhn}}{w_h} \right)^\alpha x_{hfm} = \frac{L_h}{M_{hf}^*} \Rightarrow w_h = \left(\frac{(1-\alpha)x_{hfm}M_{hf}^*}{L_h} \right)^{\frac{1}{\alpha}} Q_{fhn}$$

Equilibrium wage is an increasing function of derived demand for labor, $x_{hfm}M_{hf}^*$, cost share of labor $(1-\alpha)$, and the composite price of intermediates, Q_{fhn} .

2.3 Producer Good

Production of intermediate inputs takes place in the rest of the world, z_{fhn} . Intermediate input firms face a constant variable production cost, c_f , identical across all firms n . Maximizing profits implies that the supply price is a constant markup over the variable cost.

$$q_f^s = \left(\frac{\phi c_f}{\phi - 1} \right)$$

where, $\phi > 0$ is the elasticity of derived demand for intermediates. Assuming perfect competition, the marginal physical product of intermediate inputs must equate the marginal cost.

$$\frac{\partial C_{hfm}(x_{hfm})}{\partial Q_f} = \left(\sum_{n=1}^N z_{fhn}^{\frac{\phi-1}{\phi}} \right)^{\frac{\phi}{\phi-1}} (= N^{\frac{\phi}{\phi-1}} z_{fhn}, \text{ since firms are symmetric})$$

Replacing the marginal cost expression and rearranging above gives output per firm as:

$$z_{fhn}^* = \alpha x_{hfm} N_f^{\frac{\phi}{1-\phi}} g(x_{hfm}, M_{hf})^{\frac{1-\alpha}{\alpha}}, \text{ where } g(x_{hfm}, M_{hf}) \equiv \frac{(1-\alpha)x_{hfm}M_{hf}^*}{L_h}$$

Similar to exports, imported goods crossing borders incur frictions that are determined by the effective quality of infrastructure in h , G_h , abstracting away from the quality of infrastructure in

the foreign region f . The fixed cost of importing goods into h is given by: $FC_h = \frac{1}{G_h^\eta}$, where $\eta > 0$ is the cost elasticity of infrastructure for imports. Since firms may freely enter the market of intermediates, revenue net of production costs must equal fixed costs of trade. Following Romer (1994) this determines the number of firms in equilibrium.

$$FC_h = \text{Rev}_{fhn} \Rightarrow \frac{1}{G_h^\eta} = \frac{c_f z_{fhn}^*}{\phi - 1}$$

$$\Rightarrow N_{fh}^* = \left[\frac{\alpha c_f x_{hfm} G_h^\eta}{\phi - 1} g(x_{hfm}, M_{hf})^{\frac{1-\alpha}{\alpha}} \right]^{\frac{1-\phi}{\phi}}$$

The equilibrium number of firms participating in the market depend upon fixed costs of importing in the home region, G_h^η , ceteris paribus. The number of firms also increase with derived demand, $g(x_{hfm}, M_{hf})$, lower elasticity of substitution across varieties, ϕ , and cost share of intermediates, α .

2.4 Infrastructure

Integration into international markets increase demand for infrastructure that facilitates trade. A simple technology using capital inputs is implemented to characterize production of trading infrastructure. One unit of infrastructure is produced using ν units of capital inputs, such that the total cost function is given by $c(G_h) = \nu r_h G_h$, where r_h is the rental rate of capital. Since infrastructure is a public good, it is funded from the national budget raised from income tax revenues. Total tax revenue collected in the home region, T_h , is fully exhausted on the development of trading infrastructure such that, $T_h \varepsilon_h = \nu r_h G_h$, where, ε_h is the efficiency with which a dollar raised in public revenues is transformed into tangible public goods.²

² Several assumptions make the model partial equilibrium in nature. A Table in the Appendix provides a complete list of all endogenous and exogenous variables in the model.

2.4.1 *Alternative Assumptions*

Infrastructure capital, such as roads and railways, are built using economic resources such as capital and labor. In this model so far we have assumed away the allocation of fixed resources across alternative uses of public vs. private (or export goods) production. Other researchers have explored this dimension (Bougheas, Demetriades, and Morgenroth, 2003 and Dornbusche, Fishcher, and Samuelson, 1977), where a single endowment is used in producing public and private goods, such that the endowment itself becomes a constraining factor in the provision of public goods. Similarly, this section explores the effects of using a fixed input, say labor, in producing both infrastructure and private goods. Particularly, the production function for infrastructure is augmented by incorporating labor as an input along with capital in a Cobb-Douglas formulation: $G(L_G, K) = L_G^{1-\beta} K^\beta$. This further implies that the labor supply is now imperfectly elastic from the perspective of the private goods producers.

If the public sector behaves competitively, in equilibrium the derived demand for labor used in infrastructure is given by: $L_G = \left(\frac{r}{w} * \frac{1-\beta}{\beta} \right)^\beta$. Since labor is used in both sectors the market clearing condition for labor becomes: $\bar{L} = L_x + L_G = (1-\alpha) \left(\frac{Q_{fm}}{w} \right)^\alpha x_{hfm} M_{hf}^* + \left(\frac{r}{w} * \frac{1-\beta}{\beta} \right)^\beta$. Assuming wages equalize in the two sectors, equilibrium wages now depend upon variables and parameters in both sectors. Particularly, wages now are also a function of $(1-\beta)$, the cost share of labor and r , the rental rate of capital.

As indicated by equilibrium outcomes, the additional complexity affects labor supply in two ways. First, the available pool of labor in the private sector shrinks which bids up equilibrium wages. Since endowment resources are now more costly, this has a negative effect on the production of export goods. Second, the elasticity of labor supply to the private sector changes. Instead of labor supply being perfectly inelastic, there is some scope for expansion by attracting away labor from the public sector. This means that the elasticity of wages to changes in private production is now larger than before. These results are likely to have impacts on how wages respond to changes in exports,

which impact welfare calculations. However, the objective of the model is not necessarily to estimate the magnitude of wage changes, but to illustrate that benefits of infrastructure reforms are dependent on trade volumes. While this sub-case highlights an interesting dimension, it is assumed away from the rest of the model for simplicity.

2.5 Political Equilibrium

The literature on endogenous trade policy derives optimal choice of public policy by maximizing a social welfare function. For example, in Brock and Magee (1978), Baldwin (1982), Mayer (1984), and Helpman and Grossman (1994), and Bougheas, Demetriades, and Morgenroth (2003), the social planner maximizes consumers' welfare to determine the optimal degree of protectionism. Slightly differently in this model a hypothetical social planner chooses optimal investments such that total regional income is maximized.

$$\max_{G_h} (w_h^* L_h - T_h), \text{ where } T_h = \frac{vr_h}{\varepsilon_h} G_h$$

The first-order condition from this maximization determines a political equilibrium that equates the marginal increase in income from trade expansions with marginal costs of higher taxes.

2.5.1 Marginal Costs of Investments

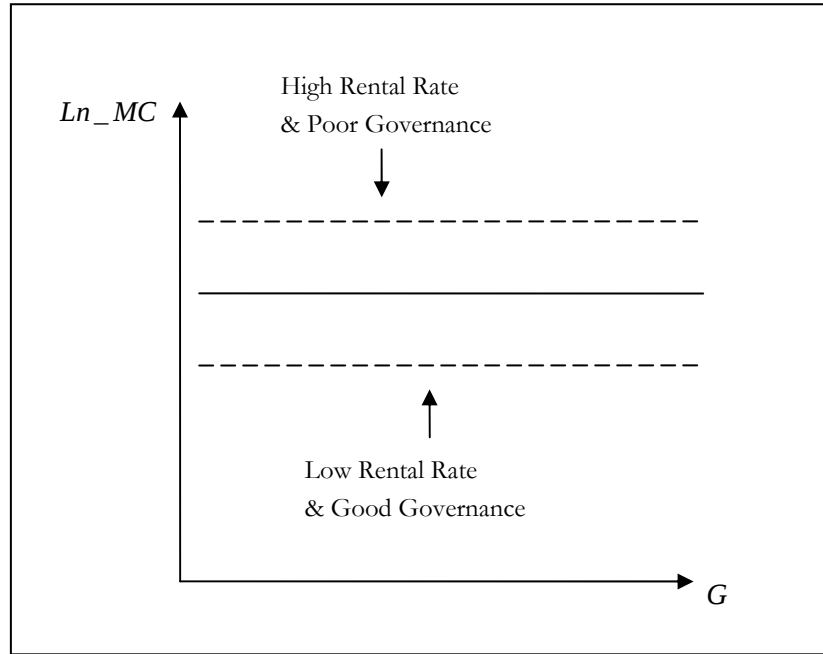
It is simple to derive marginal costs of investments. For each additional unit of infrastructure, consumers' must raise $\frac{vr_h}{\varepsilon_h}$ in taxes. Assuming a dollar paid in taxes reduces income by one unit, the implied marginal cost to the economy is:

$$\frac{\partial D_h}{\partial T_h} \frac{\partial T_h}{\partial G_h} \Rightarrow MC_h = \frac{\partial D_h}{\partial T_h} \frac{\partial T_h}{\partial G_h} = 1 \cdot \frac{vr_h}{\varepsilon_h} = C_0$$

Taking logs on both sides the above equation can be written as: $\ln MC = \ln C_0$. The marginal cost curve is perfectly elastic as shown in Figure 3. Costs are assumed to be independent of the existing level of infrastructure. The intercept depends upon the cost of capital, r_h , and the

quality of governance, ε_h . Countries with better governance and lower investment costs have lower costs for investments in infrastructure.

Figure 3: Marginal Cost Schedule



2.5.2 Marginal Benefits of Investments

This section measures the elasticity of income with trade facilitation and marginal benefits from investments. Larger export varieties increase domestic production that increases returns to the scarce factor of labor. The impact on wage from increases in export variety from trade facilitation is calculated by:

$$^3 \frac{\partial w_h}{\partial M_h} \frac{\partial M_h}{\partial G_h} = Z G_h^{\gamma/\alpha-1}, \text{ where } Z \equiv \frac{\gamma}{\alpha} \left(\frac{(1-\alpha)x_{hfm} D_f}{\alpha \sigma L_h} \right)^{\frac{1}{\alpha}} N_f^{\frac{1}{1-\phi}} q$$

$\frac{\partial w_h}{\partial M_h} \frac{\partial M_h}{\partial G_h} > 0$, implies factor returns increase with investments in G_h . Z shows that the elasticity

of wages with respect to exporting technology depends upon a number of factors. The impact on wages increases with γ , the rate at which infrastructure lowers fixed costs of exporting; the effect

³ See derivation in Appendix, under proof of Proposition 1

decreases with, α , which determines the relative dependence on labor versus intermediates, since larger dependence on labor increases wages more quickly due to the inelasticity of labor supply. The elasticity of wages also depends upon the size of exports, $(x_{hfm} * M_h)$; for larger exports the impact on wages from trade reforms is larger since production increases more quickly creating pressure on fixed resources. Higher prices of intermediates, $Q_f = N_f^{\frac{1}{1-\phi}} q$ leads to higher substitution away from intermediates to labor inputs which increases wages more quickly.

Improvements in importing technology in country h also increase wages channeled through larger import varieties⁴. Since the final goods sector uses all varieties of intermediate inputs, an increase in the number of varieties increases productivity that shifts the supply curve right. This finding is also consistent with R  ller and Waverman (2001) and Anwar (2007) who demonstrates positive wage effects from increases in the number intermediate varieties. The impact on wages is further augmented if the home country exports more, $(x_{hfm} * M_h)$, imports more intermediates, $(z_{hfm} * N_{hf})$, and other model parameters, including the cost-share of labor, $(1-\alpha)$, and importing technology, η .

The above formulations lead to Proposition 1:

Proposition 1:
$$\frac{\partial w_h}{\partial M_{hf}} \frac{\partial M_{hf}}{\partial G_h} + \frac{\partial w_h}{\partial N_{fh}} \frac{\partial N_{fh}}{\partial G_h} > 0$$

Trade-related infrastructural investments have a positive effect on wages through the increase in final goods varieties exported, and the varieties of imported intermediates that enhances productivity.

Proof: See Appendix.

⁴ The derivation is detailed in the Appendix, under proof of Proposition 1

The marginal increase in wage or the marginal benefit curve is given by $\frac{\partial^2 w_h}{\partial (G_h)^2}$.

$\frac{\partial^2 w_h}{\partial (G_h)^2} = f\left\{\left(x_{hfm} * M_h\right), \left(z_{hfm} * N_{hf}\right), \Theta\right\} * G^{g\{\alpha, \gamma, \phi, \eta\}}$, where Θ is a function of parameters and

exogenous variables. The above can be re-written in a log-linear form: $\ln MB_h = B_{0X} + B_{1X} \ln G_h$,

where the intercept is $B_{0X} \equiv f\left\{\left(x_{hfm} * M_h\right), \left(z_{hfm} * N_{hf}\right), \Theta\right\}$, and the slope is $B_{1X} \equiv g\{\alpha, \gamma, \phi, \eta\}$. The

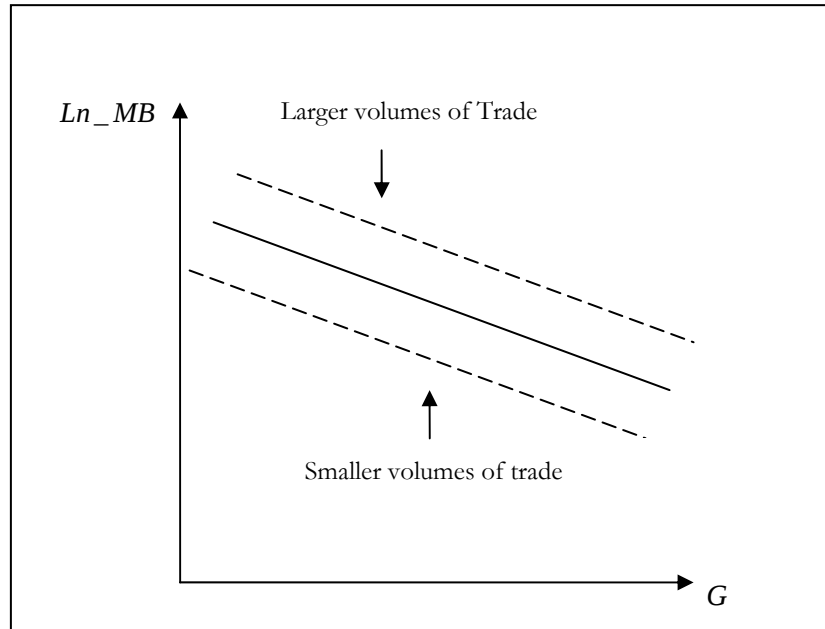
intercept of the marginal benefit curve, $B_{0X} \equiv f\left\{\left(x_{hfm} * M_h\right), \left(z_{hfm} * N_{hf}\right), \Theta\right\}$, is a function of exports and imports, which leads to the next proposition.

Proposition 2: *Marginal benefits of trade facilitation increase with greater volumes of trade.*

Put differently, if two countries (similar in all other aspects) undertake infrastructural investments, then the marginal benefit of reform will be higher in the country with larger trade. This is consistent with the idea that returns are larger when fixed costs of investments are spread over more tradable. This explains why countries such as China and Singapore have greater incentives for investments.

The slope, B_{1X} , may be positive or negative depending on model parameters. For example, the marginal benefit curve of exporting alone slopes downwards for lower γ i.e. the ease with which infrastructure lowers fixed costs of trade. Figure 4 plots a hypothetical marginal benefit curve that slopes downwards. Proposition 2 suggests that the curve lies higher or lower depending upon the volume of trade.

Figure 4: Marginal Benefit Schedule

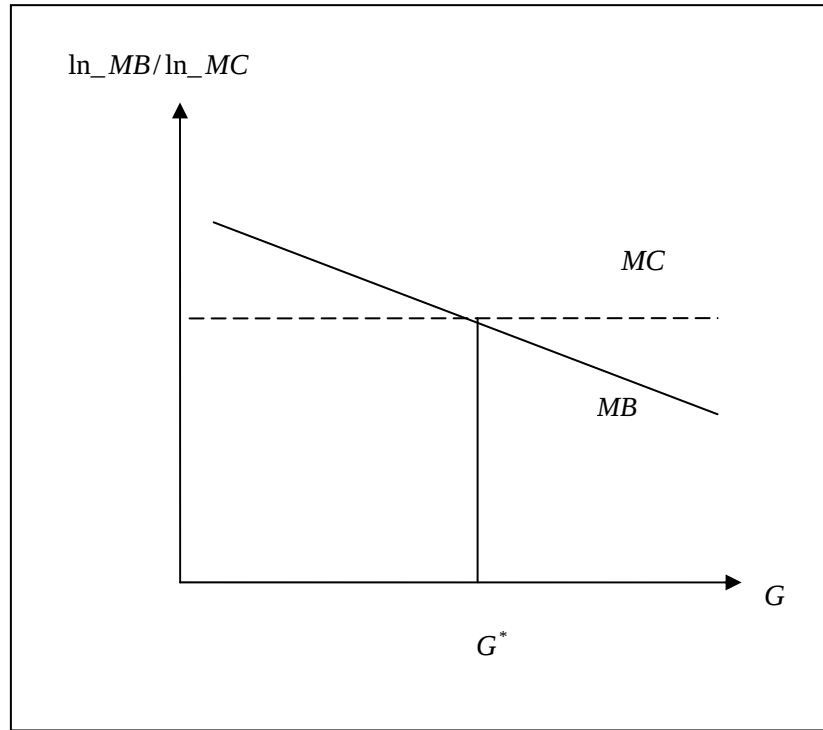


2.5.3 Optimal Investments in Infrastructure

Equating the marginal benefit and cost schedules determines optimal investments in trading infrastructure.

$$\begin{aligned} \ln MB_h &= \ln MC_h \\ \Rightarrow B_0 + B_1 \ln G_h &= C_0 \\ \Rightarrow \ln(G_h^*) &= \frac{B_0 - C_0}{B_1} \end{aligned}$$

Figure 5: Political Equilibrium



This equation explicitly illustrates how the forces of demand and supply interact to determine investment levels. The marginal cost schedule highlights supply constraints of why some countries invest more than others. Low income countries are faced with financial constraints to fund development projects; they also have poor institutional structures and governance that reduce the effectiveness in the use of resources. From the demand side, countries that are more globalized have better incentives to build infrastructure. This further emphasizes the reverse direction of causality, where volumes of trade determine facilitation efforts across countries.

Bidirectional causality implies that estimates of trade elasticity with respect to infrastructure from a single-equations model will be biased. In the following a simultaneous equations model is defined that can be used to obtain unbiased estimates. Exports from home to abroad are determined

by the following equation: $M_f^* p_{hfm}^* x_{hf}^* = \Omega_{hf} (I_h I_f) \frac{p_{hfm}^{-\sigma}}{p_{hfm}^{1-\sigma}} G_h^\gamma$, where Ω_{hf} determines relevant

bilateral characteristics. The goal is to estimate γ the elasticity of trade with respect to

infrastructure. Since G_h is endogenous the equation for optimal infrastructure, $\ln(G_h^*) = \frac{B_0 + C_0}{B_1}$, determines the first stage of the regression.

3. Empirical Model and Data

Bilateral trade between two countries is determined by various country and bilateral-specific characteristics as described in the literature of gravity modeling (Anderson and van Wincoop, 2003). Size and income is denoted using the product of real GDP and real GDP per capita of trading partners. Other independent variables include distance, tariffs, landlockedness, common language and common border.

The first stage of the regression estimates trade facilitation across countries using instrumental variables. Factors that determine optimal investments on infrastructure as derived from the theory serve as exogenous shifters of trade facilitation. From the supply side of the model, r and ε , are country characteristics that affect trade facilitation. r reflects the cost of capital in building infrastructure. Since both the private and public sectors are involved in developing infrastructure, we use proxies for the cost of capital for both on the empirical estimation. The private sector borrowing cost is measured by the ‘interest rate on private sector borrowing for long term investments’. The cost of publicly-financed projects is measured using data on ‘national deficits relative to income’ that characterizes the country’s potential to borrow from abroad. ε is efficiency of transforming tax revenues into public projects. This is measured using a governance indicator that reflects the efficiency in successfully implementing public projects.

Using log-linearized forms of each equation, the specification of the described model is given by:

$$\ln Trade_{ij} = \beta + \beta_{TFX} \ln Lo\hat{g}is_i + \beta_{TFM} Lo\hat{g}is_j + \beta_\tau \ln \tau_{ij} + \beta_{GDP} \ln GDP_i GDP_j + \beta_{GDPpc} \ln GDPpc_i GDPpc_j + \beta_D \ln Dist_{ij} + \beta_L \ln Lang_{ij} + \beta_{LL} \ln LanLock_{ij} + \beta_B \ln Border_{ij} + \varepsilon_{ij}$$

$$\ln Logis_\phi = \alpha + \alpha_c \ln Gov_\phi + \alpha_r \ln Priv_\phi + \alpha_D \ln Pub_\phi + \mu_{ij}$$

where,

i = exporting country

j = importing country

$\phi \equiv \{i, j\}$

$Trade_{ij}$: Value of trade at *cif* prices from i to j

$Logis_i$: Trade facilitation indicator of exporting country i

$Logis_j$: Trade facilitation indicator of importing country j

τ_{ij} : Bilateral preferential tariff rate aggregated for all goods weighted by trade

$GDP_i GDP_j$: Product of real GDPs of trading countries

$GDPpc_i GDPpc_j$: Product of real GDP per capita of trading countries

$Dist_{ij}$: Great arc distance

$Lang_{ij}$: Common Language dummy

$Border_{ij}$: Common Border dummy

Gov_{ϕ} : Governance Indicator

$Pr iv_{\phi}$: Interest rate on private sector borrowing

Pub_{ϕ} : Scope of Public Sector Borrowing measured with national deficit standardized by GDP

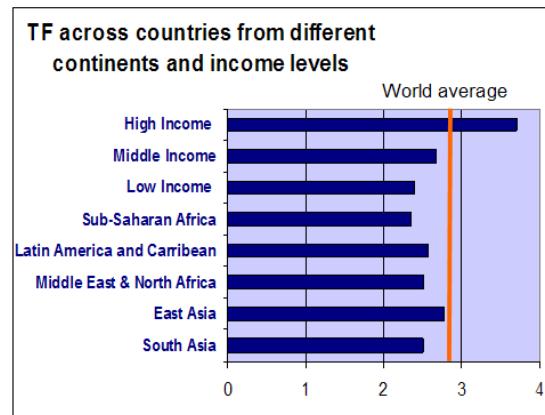
This completes the characterization of the econometric model which is estimated using the two-stage least squares approach. This model is estimated using observations on bilateral trade flows for 109 countries as shown in Table 3.

3.1 Data for Measuring Trade Facilitation

The logistics of international shipments is a complex combination of services and procedures involving many public and private operations that is not easy to capture. From the quality of customs services, port efficiencies, per unit railway costs and infrastructural quality to the provision of automated procedures and e-business facilities, the complexity and details of the entire procedure makes it difficult to measure. Hence developing indices to capture trade facilitation at an international level is not an easy task. There are a few datasets emerging in the field that provide basis cross-country comparability. For example, 'Doing Business' survey from the World Bank reports data on trading time. This dataset is limited to some extent as the data on time is approximated from a few sampled goods.

This paper uses another dataset for measuring trade facilitation called the Logistics Performance Index (LPI) published by the World Bank's International Trade and Transport Department in 2007 (World Bank, forthcoming), as it provides a broader perspective on the quality of logistics across countries. It is one of the best-known datasets that is sufficiently robust and comprehensive in coverage, including a total of 150 countries. The index ranges from 1 to 5, a score of 5 indicating countries with better facilitation. Figure 6 depicts the levels of LPI across various regions and income groups. The world average level of LPI lies at about 2.8.

Figure 6: LPI index across continents and income groups



In order to grasp the entire supply chain of exports and imports, this dataset comprises of seven components, namely, *customs*, *infrastructure*, *ease of shipment*, *logistic services*, *ease of tracking*, *internal log costs*, and *timeliness*. A web-based questionnaire is designed which covers questions on a wide variety of topics to develop each of these indicators. For instance, questions regarding direct costs ask about the percentage of damaged shipments, the relative cost of rail services, trucking costs, etc; questions regarding *timeliness* may ask about the average number of days between customs declaration and customs clearance, frequency of shipments reaching consignees at the scheduled delivery time, delays associated with pre-shipment inspections, etc. The survey-based questionnaire is completed by freight forwarders and express carriers who are in charge of shipping products in and out of countries. Since these professional operators work in multinational companies that manage trade with multiple partners they are in an excellent position to make knowledgeable assessments about

border logistics across countries. Each surveyor chooses a set of 8 countries, emphasizing those they have most frequently served, to be able to provide accurate information. Confidence intervals and correlation matrices illustrate that these indicators appear robust and meaningful with respect to the general objective of providing a consistent, cross-country performance measure. Once these individual indices are obtained, an overall LPI is developed using the principal components analysis method. This method is superior to the simple averaging method since it reduces noise in the final index.

3.2 Data Sources for Trade, Tariff and other variables

In addition to the trade facilitation data, improved data is used to measure tariff and trade flows obtained from the GTAP version 7 database that reflects global data for year 2004 (Narayanan and Walsmley, 2008). Bilateral tariff data in GTAP is obtained from the Market Access Maps (MacMap) contributed by the Centre d'Etudes Prospectives et d'Information Internationales (CEPII). The MACMap Data Base is compiled from UNCTAD TRAINS data, country notifications to the WTO, AMAD (Agricultural Market Access Database), and from national customs information. The data used is trade-weighted preferential rates data on ad valorem tariffs (including tariff rate quotas) plus the ad valorem equivalents (AVEs) of specific tariffs. It incorporates tariff preferences from recent trade agreements. This dataset is more sophisticated in terms of sourcing and coverage, nature and quality, and data processing. The Trade data that incorporates reconciled bilateral merchandise trade at *cif* prices is obtained from COMTRADE. The data on trade is aggregated over all merchandise trade, and tariffs are aggregated by taking trade-weighted sums.

Data on real GDP and real GDP per capita are obtained from the WB. Distance, landlocked, common border, and common language are obtained from CIA's World Factbook. Common border, common language and currency are dummy variables that take a value of 0 or 1; the landlocked dummy variable takes a value of 0, 1, and 2 for none, either and both countries being landlocked, respectively. The 'Corruption Perceptions Index' constructed by Transparency International is used to measure the governance. Data on costs of borrowing by the private and public sectors are obtained from the Global Market Info. Database (GMID). National Deficit is standardized by GDP levels and is also obtained from the GMID dataset.

4. Econometric Estimation

4.1 Instrumental Variables

To empirically illustrate the importance of using a simultaneous model over OLS, it is first relevant to establish that there exists an endogenous relationship between the indicators of trade facilitation and trade flows. The Durbin-Wu-Hausman test is conducted to test this hypothesis in the data. A test-statistic estimate of 42.75 with a p-value of 0.0000, suggests that the null-hypothesis of exogeneity of the regressor can be rejected.

It is also important to establish that the instrumental variables are exogenous shifters of trade facilitation and have no impacts on trade. Exclusion restrictions discussed in the following primarily highlights the idea that each of the 3 instruments has no effect on trade, or only has an indirect effect trade through border quality. (i) There is a literature that finds the impact of corruption on trade to be statistically significant. Most of the literature, however, discusses the impacts of the various channels of how poor governance impacts trade. Particularly, poor governance leads to the formation of poor trade policy and institutional settings which then impact trade (Bandyopadhyay and Roy, 2006; Gatti, 1999). The same argument is applied in this paper, where trade facilitation is perceived to be a channel for indirectly affecting trade; corruption impacts the efficacy of institutions designed for facilitating trade that in turn negatively impacts trade. (ii) Lower costs of private investments may attract more FDI due to better business climate. However, there is no reason to believe why this may have any direct effect on bilateral exports and imports; (iii) The capacity to finance greater public projects are likely to increase trade through the construction of better trading facilities. Here again there is no expectation of why this may directly affect trade. If one believes that each of these instruments may somehow indirectly affect trade by having a positive effect on GDP or GDP per capita, these are already controlled for by including them directly in the equation for trade.

It is possible to further check whether each of the instruments is legitimate i.e. whether the instrumental variables have a direct impact on trade or only an indirect impact through trade facilitation. This is done by including each instrument directly in the equation for trade following

Card (1995). For example, corruption is included directly in the equation for trade while using the other instruments to exogenously identify trade facilitation. Estimation results illustrate that corruption has impacts on trade that are small and insignificantly different from 0. This is repeated for each of the other instruments and for each case the estimates are observed to be insignificant. This preliminary analysis suggests that there is no evidence against the assumption that each of the instruments is exogenous.

4.2 Econometric Results

The econometric model is estimated using cross-sectional data for the year 2004. In the benchmark model the effect of exporter and importer logistics on trade flows is assumed to be the same by using a single regressor that combines the trade effects of bilateral logistics. This variable is constructed by simply taking the product of border logistics of the exporter and the importer. Table 2.1 presents the first and second stage regression results for the bilateral gravity model. The second stage regression shows that the elasticity of bilateral trade flows with respect to the border logistics of the trading partners is estimated to be 2.54. This implies that a 1% increase in the trade facilitation of the exporter and importer combines increases trade by 2.54%. The elasticity of tariffs is approximately -1.88. A comparison of standardized coefficients illustrates that the impact of trade facilitation is larger in magnitude than all other trade barriers, such as tariffs or distance. The coefficient estimates of the other gravity model variables, such as distance (-1.01), and dummies of common language (0.81), landlockedness (-0.29) and common border (1.36) have the expected signs, and the magnitudes are also closely commensurate with that estimated in the literature. The model has a significantly high R-squared value of 0.81, illustrating that variations in trade flows across country pairs are well explained by variables in the model.

Table 1: Benchmark Regression Results*Second-Stage Regression*

	IV Model using LPI	
	Coefficient	Std. Error.
Log of Logistics	2.54	0.38
Log of Tariff	-1.88	0.39
Log product of Real GDPs	1.02	0.02
Log product of Per Capita Real GDPs	-0.14	0.03
Log Distance	-1.01	0.04
Common Language	0.81	0.08
Landlocked	-0.29	0.06
Common Border	1.36	0.22
Constant	-14.76	0.48

R-squared	0.81
F(9, 4604); Prob>F	2168.3; 0.0000
Number of observations	4613

Results are statistically significant at the 1% level for all variables.

First-Stage Regression

	IV Model using LPI	
	Coefficient	Std. Error.
Log of Tariff	-0.18	0.02
Log product of Real GDPs	0.05	0.00
Log product of Per Capita Real GDPs	0.01	0.00
Log Distance	0.00	0.00
Common Language	-0.01	0.01
Landlocked	0.01	0.00
Common Border	-0.01	0.01
Log of Governance	0.19	0.01
Log of Private Borrowing Cost	-0.01	0.00
Log of Public Funds	0.12	0.02
Constant	-0.56	0.21
R-squared	0.81	
F(11, 4602); Prob>F	2238.04; 0.0000	
Number of Observations	4613	

Results are statistically significant at the 1% level for all instrumental variables.

The signs for each instrument are consistent with expectations. The first stage of the regression illustrates that countries with more transparent governance (0.19) have higher quality border logistics. Where interest rates for borrowing from the private sector are high, investments on border infrastructure is low (-0.01). Countries that have greater scope for borrowing as reflected by higher deficits relative to GDP (0.12) also have better logistics than others. Results for each of the instruments are statistically significant at the 1% level.

In an additional specification the assumption of equal effects on bilateral trade from trade facilitation in the exporting vs. importing region is relaxed. This is done by including exporter and importer specific border logistics separately in the model. New estimates show that the effect of improving exporter's border logistics (2.50) is larger than the effect of improving importer's border

logistics (1.38). In other words, own-country trade facilitation efforts have a larger impact on bilateral trade relative to importing-country reforms. This result is also consistent with findings from Wilson, Mann and Otsuki (2003, 2005) and Persson (2007).

2.4.3 Post-Regression Diagnostics

An alternative OLS specification is used to estimate the impact of trade facilitation on trade. OLS predicts an elasticity of 1.3, which is smaller than the estimate from the simultaneous-equations model. Theory, however, suggests OLS estimates to be biased upwards. This calls for robustness checks to ensure the validity of the instruments. Two criteria determine the strength of instruments: (1) the endogenous variable must be well correlated with the instruments; and (2) the instrumental variables must be uncorrelated with the error term. The joint significance of all instruments is measured using the F-statistic. Predictions from the base model are presented as IV1 in Table 2. The F-statistic takes a value of 489.44 (p-value: 0). Since this value is significantly larger than 10, which is the minimum requirement for inference based on a single endogenous regressor (Stock, Wright, and Yogo, 2002), the null hypothesis that the instruments are weak can be rejected. While the R-squared of the first stage of the regression (0.81) is high, Shea's partial R-squared, that estimates the correlation between the endogenous regressor and the instruments by partialling out the correlation with the exogenous variables, takes a value of 0.25. While this is not very large, there is still reasonable explanatory power obtained from these instruments.

Table 2: Post-Regression Diagnostics

	OLS	IV1 (Gov, Priv, Pub)	IV2 (Gov, Priv)	IV3 (Pub)
Elasticity Estimate	1.3	2.54	2.54	2.46
F-test on excluded instruments	-	489	670	-
P-value	-	0.0000	0.0000	-
Shea's Partial R2	-	0.25	0.24	0.01
Partial R2	-	0.25	0.24	0.01

The next check is to see whether the instrumental variables are correlated with the error terms. Since the model contains more instruments than endogenous variables, the model is overidentified and it is possible to test for the endogenous regressor being correlated with the fitted

residuals using Sargan's (1958) χ^2 tests. Sargan's χ^2 test statistic takes a value of 4.92. While this is not very large, it still suggests that the null-hypothesis that the instruments are valid cannot be rejected.

To check the stability of the larger elasticity in 2SLS over the choice of instruments, alternative specifications are presented Table 2.2. IV2 uses two instruments, *Gov* and *Priv*, and IV3 uses *Pub* as the only instrument. In each case the choice of instruments prove to be valid since the F-statistic is estimated to be much larger than 10. Shea's partial R-squared is still reasonable for IV2, while it is much smaller for IV3 suggesting the explanatory power from using *Pub* as the only instrument is slightly weak. Using alternative sets of instruments the estimate of elasticity seems to vary insignificantly. For IV2 it takes the same value, 2.54, as for IV1, the baseline specification, and for IV3 it takes a value of 2.46. The estimates prove to be quite consistent across choice of instruments, and in each case larger than the OLS.

2.5 Conclusion

This paper provides a new perspective on trade facilitation by identifying an endogenous relationship with trade. While some countries invest in trading infrastructure as a means to lower costs at the borders, others invest in response to increased demand as trade expands. A sector model of trade helps to further explore this intuition and substantiate the existence of simultaneity. The theory derives the channels of supply and demand that determines optimal infrastructure investments. Supply constraints include factors such as financial feasibility and the quality of governance which impacts the provision of infrastructure. Several key relationships are derived from the model: (i) better infrastructure positively impacts trade which increases welfare; (ii) marginal benefits of reforms are higher for countries that trade more.

The empirical section of the paper estimates the elasticity of trading infrastructure on trade flows using a simultaneous approach. Cross-sectional on global merchandise trade is used for the year 2004. Having successfully accounted for endogeneity, the elasticity of trade with respect to infrastructure is positive (2.54), and larger than the OLS estimate (1.3). Robustness checks reassure

strength of instruments, and illustrate the elasticity estimate to be stable and consistently higher than OLS across choice of instruments.

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6 Appendix

Figure 7: Model Overview

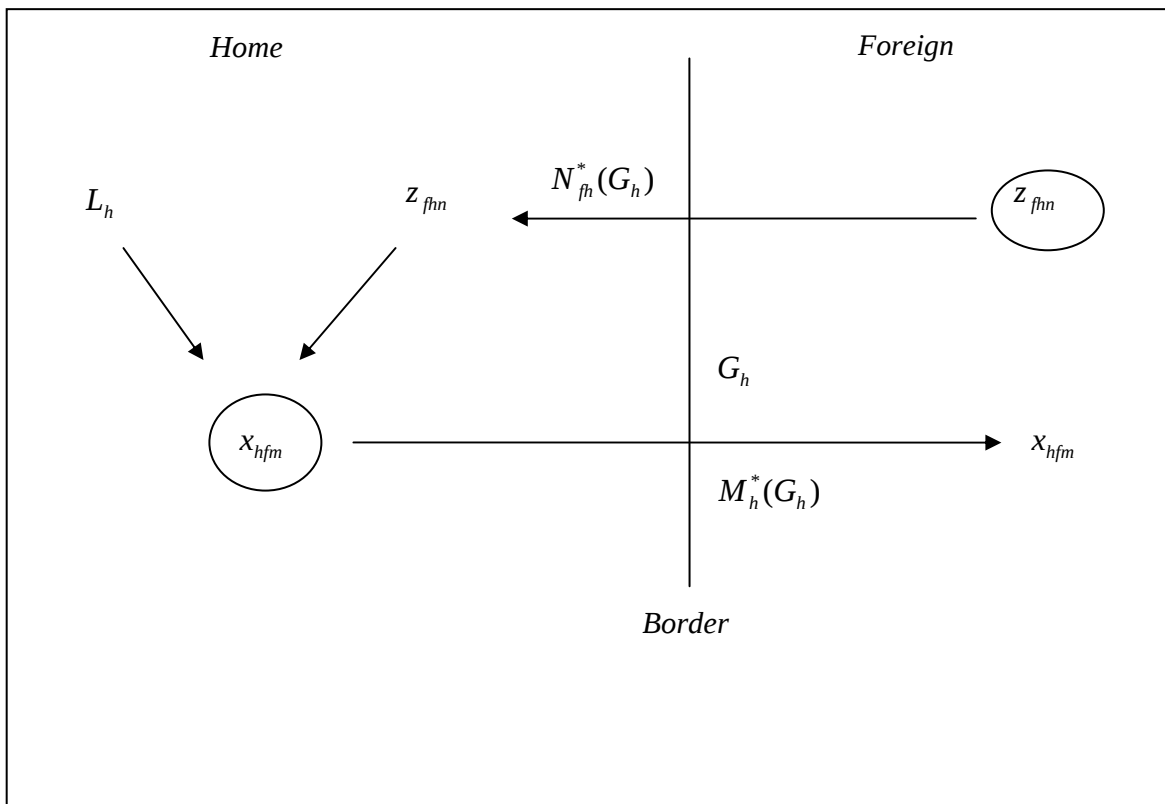


Table 3: Countries in the Econometric Model

1	Albania	31	Ecuador	61	Lebanon	91	Sao Tome & Principe
2	Algeria	32	El Salvador	62	Lesotho	92	Slovenia

3	Angola	33	Estonia	63	Lithuania	93	Solomon Islands
4	Argentina	34	Ethiopia	64	Madagascar	94	South Africa
5	Armenia	35	Finland	65	Malawi	95	Spain
6	Australia	36	France	66	Malaysia	96	Sri Lanka
7	Austria	37	Gabon	67	Mauritius	97	Sweden
8	Azerbaijan	38	Germany	68	Mexico	98	Switzerland
9	Bangladesh	39	Greece	69	Moldova	99	Syria
10	Belarus	40	Guatemala	70	Mongolia	100	Tajikistan
11	Belgium	41	Guinea	71	Morocco	101	Thailand
12	Bhutan	42	Guinea-Bissau	72	Mozambique	102	Turkey
13	Bolivia	43	Guyana	73	Namibia	103	Uganda
14	Brazil	44	Haiti	74	Nepal	104	Ukraine
15	Bulgaria	45	Honduras	75	Netherlands	105	United Kingdom
16	Burundi	46	Haiti	76	New Zealand	106	United States
17	Cambodia	47	Honduras	77	Nicaragua	107	Uruguay
18	Cameroon	48	Hungary	78	Nigeria	108	Zambia
19	Canada	49	India	79	Norway	109	Zimbabwe
20	Chad	50	Indonesia	80	Oman		
21	Chile	51	Ireland	81	Pakistan		
22	China	52	Israel	82	Panama		
23	Colombia	53	Italy	83	Papua New Guinea		
24	Comoros	54	Jamaica	84	Paraguay		
25	Costa Rica	55	Japan	85	Peru		
26	Croatia	56	Jordan	86	Philippines		
27	Czech Republic	57	Kazakhstan	87	Poland		
28	Denmark	58	Kenya	88	Portugal		
29	Djibouti	59	Kuwait	89	Russia		

Table 4: Partial Equilibrium Model Closure Assumptions

Home	Foreign
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Exogenous Variables ▪ Labor supply, L_h ▪ Fixed Production Costs, a_h ▪ Composite price of Intermediates, Q_f ▪ Costs of Investment, r ▪ Parameters: $\sigma, \alpha, \gamma, \nu$ Endogenous Variables ▪ Wages, w_h ▪ Output price, p_{hfm} ▪ Output per firm, x_{hm} ▪ Optimal number of firms, M_h ▪ Border Logistics, G_h	Exogenous Variables ▪ Marginal Production Cost, c_f ▪ Parameters: ϕ, η Endogenous Variables ▪ Prices of Intermediates, q_f ▪ Derived Demand for Intermediates, z_{fhn} ▪ Optimal number of firms, N_{fh}
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Elasticity of wage with respect to import variety:

$$\frac{\partial w_h}{\partial N_{fh}} \frac{\partial N_{fh}}{\partial G_h} = \Phi G_h^{\frac{1-\phi}{\phi} \left(\eta + \frac{\gamma(1-\alpha)}{\alpha} \right) - 1 + \frac{\gamma}{\alpha}}$$

where $\Phi \equiv \frac{\gamma}{\alpha} N_f^{\frac{1-\phi}{\phi}} q \left(\frac{\gamma\phi(1-\alpha)}{\alpha} + \eta\phi \right) \left(\frac{c}{\phi-1} \right)^{\frac{1-\phi}{\phi}} \left(\frac{(1-\alpha)x_{hfm}D_f}{\alpha\sigma L_h} \right)^{\frac{1}{\alpha} + \frac{(1-\alpha)(1-\phi)}{\alpha\phi}}$

Proof of Proposition 1:

We show: (i) $\frac{\partial w_h}{\partial M_{hf}} \frac{\partial M_{hf}}{\partial G_h} > 0$, and (ii) $\frac{\partial w_h}{\partial N_{fh}} \frac{\partial N_{fh}}{\partial G_h} > 0$.

(i) Given: The equilibrium wage: $w_h^* = \left(\frac{(1-\alpha)x_{hfm}M_{hf}^*}{L_h} \right)^{\frac{1}{\alpha}} Q_{fh}$, and the equilibrium number of

export varieties of the consumer good from country h , $M_{hf}^* = \frac{D_f G_h^\gamma}{a_h \sigma}$. We must derive,

$\frac{\partial w_h}{\partial M_{hf}} \frac{\partial M_{hf}}{\partial G_h}$, the impact on wages from improvements in exporting technology.

$$\frac{\partial w_h}{\partial M_{hf}} \frac{\partial M_{hf}}{\partial G_h} = \left[\frac{1}{\alpha} \left(\frac{(1-\alpha)x_{hfm}}{L_h} \right)^{\frac{1}{\alpha}} M_{hf}^{\frac{1}{\alpha}-1} Q_{fh} \right] * \left[\frac{D_f \gamma G_h^{\gamma-1}}{a_h \sigma} \right].$$

$$\text{Rearranging, } \frac{\partial w_h}{\partial M_{hf}} \frac{\partial M_{hf}}{\partial G_h} = \frac{\gamma}{\alpha} \left(\frac{(1-\alpha)x_{hfm}D_f}{\alpha\sigma L_h} \right)^{\frac{1}{\alpha}} N_f^{\frac{1-\phi}{\phi}} q G_h^{\gamma/\alpha-1}.$$

Since, $\gamma, \alpha, (1-\alpha) > 0$, $\frac{\partial w_h}{\partial M_{hf}} \frac{\partial M_{hf}}{\partial G_h} > 0$.

(ii) Given w_h^* (as above) and the equilibrium number of import varieties of the producer good

from country f , $N_{fh}^* = \left[\frac{\alpha c_f x_{hfm} G_h^\eta}{\phi-1} g(x_{hfm}, M_{hf})^{\frac{1-\alpha}{\alpha}} \right]^{\frac{1-\phi}{\phi}}$. The impact on wages from

improvements in importing technology, $\frac{\partial w_h}{\partial N_{fh}} \frac{\partial N_{fh}}{\partial G_h}$, is then derived in the same way as in (i).

$$\frac{\partial w_h}{\partial N_{fh}} \frac{\partial N_{fh}}{\partial G_h} = \Phi G_h^\Omega, \text{ where } \Phi \equiv N_f^{\frac{1-\phi}{\phi}} q \left(\frac{\gamma\phi(1-\alpha)}{\alpha} + \eta\phi \right) \left(\frac{c}{\phi-1} \right)^{\frac{1-\phi}{\phi}} \left(\frac{(1-\alpha)x_{hfm}D_f}{\alpha\sigma L_h} \right)^{\frac{1}{\alpha} + \frac{(1-\alpha)(1-\phi)}{\alpha\phi}}, \text{ and}$$

$$\Omega \equiv \frac{1-\phi}{\phi} \left(\eta + \frac{\gamma(1-\alpha)}{\alpha} \right) - 1 + \frac{\gamma}{\alpha}$$

Since $\gamma, \alpha, (1-\alpha), \gamma, \eta, \phi > 0, \Phi > 0$.

Proof of Proposition 2:

Welfare gains from exporting:

$$\frac{\partial^2 w_h}{\partial G_h^2} \Big|_{\bar{N}} = \frac{\gamma}{\alpha} \left(\frac{\gamma}{\alpha} - 1 \right) \left(\frac{(1-\alpha)x_{hfm}M_{hf}}{L_h} \right)^{\frac{1}{\alpha}} N_f^{\frac{1}{1-\phi}} q G_h^{\gamma/\alpha-2} \text{ is a function of } (x_{hfm} * M_h).$$

Welfare gains from importing:

$$\frac{\partial^2 w_h}{\partial G_h^2} \Big|_{\bar{M}} = \Phi \Omega G_h^{\Omega-1}, \text{ where } \Phi \text{ is an increasing function of } N, \text{ and can be shown to be a function of } (z_{hfm} * N_{hf}) \text{ by replacing with } z_{hfm}^*, \text{ as well as } (x_{hfm} * M_h).$$