ADBI Working Paper Series

Strategic Choice of Freight Mode and Investments in Transport Infrastructure within Production Networks

Ying Yi Tsai

No. 132
March 2009

Asian Development Bank Institute

Ying Yi Tsai is an assistant professor at the National University of Kaohsiung. He was a visiting researcher at the Asian Development Bank Institute (ADBI) from May–November 2008. This paper contains the final outcome of research work conducted during the author's tenure at ADBI.

The author wishes to thank ADBI, the members of the teams working on trade-related infrastructure investment issues, and those in the seminars who provided information, insights, and comments.

Suggested citation:

Tsai, Y. Y. 2009. Strategic Choice of Freight Mode and Investments in Transport Infrastructure within Production Networks. ADBI Working Paper 132. Tokyo: Asian Development Bank Institute. Available: http://www.adbi.org/working-paper/2009/03/13/2897.strategic.freight.mode.transport.infrastructure/

Asian Development Bank Institute
Kasumigaseki Building 8F
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

Abstract

In the context of production linkages in which downstream producers require freight services provided by transport operators, I show that the strategic choice of using an alternative transport mode does not *necessarily* induce lower access charges, relative to the standard transport mode. Additionally, I show that the nature of infrastructure investment determines the share of final goods delivery by the alternative transport mode. An immediate implication is that interactions among infrastructure investments; building transportation capacity costs; and industry-specific characteristics should be carefully assessed when planning transport infrastructure investments to enhance competitiveness in export markets.

JEL Classification: F1, L1, L2, O1, O2

Contents

1. INTRODUCTION

Countries with inadequate trade infrastructure, burdensome administrative processes, or limited competition in trade logistics services benefit less from expanding global trade. In a recent study on the role of trade facilitation in commerce expansion, Creskoff (2008: 2), citing Ikenson (2008) on the dramatic reductions in transportation time between Rwanda and South Africa, argued that “the adoption of a fully computerized customs administration and new technologies, such as web-based secure communications, cargo-tracking, mobile X-ray technology, gamma ray cavity detectors, video monitoring, electronic customs seals, specialized aircraft and vessels digital identification cards and others have the potential to substantially speed the movement of goods and facilitate trade.” An immediate implication is that progress in trade facilitation has a more significant impact on economic growth in the developing rather than developed countries.

The contribution of transport infrastructure—defined here to include land, air and sea transport—to trade, growth, and economic development is widely documented in the literature (see, for example, Gramlich 1994; Kessides 1993; Nadiri and Manuneas 1994; Bougheas, Demetriades, and Morgenroth 1999; Francois and Manchin 2007; and Brooks and Hummels forthcoming 2009). Recent studies on infrastructure have focused on the demand for infrastructure services to alleviate strains on growth (Fay and Yepes 2003); the importance of infrastructure in facilitating growing merchandise trade (Hummels forthcoming 2009); and the role played by infrastructure services in reducing trade costs, by influencing distribution margins and freight rates paid by final goods producers (Brooks and Hummels forthcoming 2009). Other significant issues related to trade and infrastructure include: the interactions between trade costs (for instance, tariffs, transportation costs, information costs, and/or communication costs) and firms’ location decisions (Fujita, Krugman, and Venables 1999); the effect of lower trade costs on production and trade patterns, particularly if stages of production differ in labor/factor intensity, and countries differ in labor/factor prices within the context of vertical industry linkages (Strauss-Khan 2005); the effects of trade cost reduction on agglomeration of vertically linked industries (Amiti 2005); how transport costs shape the spatial distribution of production (Alonso-Villar 2005); and the effects of poor transportation on production and industrial clustering (Gulyani 2001).

Much of the research on the linkages between infrastructure and economic development has come from a macroeconomic perspective, evincing a positive relationship between infrastructure investment and economic growth. Despite these insights, however, certain fundamental questions and issues remain unaddressed. For example, do infrastructure investments aimed at lowering trade costs necessarily lead to lower freight rates for transport services, particularly within the broader context of production networks (including transportation, distribution, etc.)? How does the nature of the infrastructure affect the amount of such investments? Does the high cost of lumpy, long-term infrastructure investments necessarily dampen infrastructure investment? To what extent does the degree of interconnectedness between different infrastructure investments affect the demand for infrastructure services?

This paper attempts to address these questions. To this end, I develop an analytical framework within the context of vertical linkages. In this framework, final goods producers located in the same region require transport services provided by two distinct transport operators. The transport operators engage in infrastructure investments leading to a reduction in freight rates, given the initial transport infrastructure endowment of each operator. The final goods producers compete in a market outside their home country.

My findings show that, in the context of production linkages where the final goods producer has the option to choose between a standard (e.g., land) and an alternative transport mode (e.g., air), greater investments in transport infrastructure which enable the strategic choice of using the alternative transport mode does not *necessarily* induce lower freight rates that would, in turn, facilitate trade cost reduction. My findings also show that: (i) the nature of infrastructure investment (as represented by the degree of interconnectedness) determines the alternative transport mode's share of final goods delivered by the producer; (ii) freight rates need not be reduced when service providers invest in transport infrastructure, subsequent to the producers' decision regarding the allocation of final goods delivery across transportation services; (iii) interactions among the nature of infrastructure investments, their construction costs, and industry-specific characteristics should be considered before service providers and/or the public sector commits to the provision of such infrastructure; (iv) producers' demand for transportation services should be assessed when planning transport infrastructure investments, to enhance competitiveness in export markets; and (v) there may be room for effectively reducing trade costs if governments pursue regional cooperation in transport infrastructure investment, with each government playing the leadership role in providing transport services.

In contrast to the public sector's leadership role as documented in much of the trade literature (see Spencer and Brander 1983), my analysis considers an alternative scenario that better captures the experience in Asia, where the public sector has typically acted in response to private firms' call for greater transport infrastructure provision. The assumption that the public sector responds to transport infrastructure demand, rather than pre-committing itself to such provision, is essential to the analysis and the resulting conclusions. I emphasize that private firms can act naturally in this leadership role, at least in some Asian countries, and that this reflects a more general principle in understanding the mechanics of development in Asia. Moreover, in order to capture the qualitative aspect of soft (or institutional) infrastructure resulting from cross-border legal rights and procedures, competition policy, and transportation regulatory framework, I characterize by a parameter the degree of interconnectedness between investments in physical infrastructure, while taking into account the nature of complementarity *vs*. substitutability inherent in physical infrastructure.

This paper is directly related to the literature on trade costs and transport infrastructure investment. Early contributions to the literature on trade costs were recently reviewed in Anderson and van Wincoop (2004), while studies on transport infrastructure investment are reviewed in Brooks and Hummels (forthcoming 2009). This paper is also related to the economic geography literature on the impact of trade cost reduction on firms' location decisions, as presented in Amiti (2005), Alonso-Villar (2005), and Strauss-Kahn (2005). Section 2 provides a more detailed review of contributions particularly relevant to this paper.

The rest of the paper is organized as follows: Section 2 surveys the literature on trade costs, infrastructure investment, and their relationship with economic development. Section 3 develops a simple theoretical model of strategic freight mode choice with transport infrastructure investment, in the framework of vertical industrial linkages. Section 4 summarizes the main findings, and Section 5 concludes.

2. LITERATURE REVIEW

Trade costs are broadly defined to include all costs involved in moving a good from producer to final user. Trade costs vary widely across countries and product lines. Taken together, international trade costs and local distribution costs account for a sufficiently large portion of the marginal cost of production. Using the production of Mattel's Barbie doll as an example, Feenstra (1998) showed that trade costs—including the cost of transportation, marketing, wholesaling, and retailing—can be substantial, an outcome exacerbated by growing production fragmentation. Thus, as highlighted in a recent review article by Anderson and van Wincoop (2004), it is important to have a better understanding of trade costs and the relationship between transport infrastructure, market structure, and political economy.

Given the broad scope of trade costs[1] and its relationship to subjects outside the realm of trade, I restrict attention to the strands of literature that are most relevant to the issues tackled in this paper. These include new economic geography and public and regulatory economics. Of particular interest are direct transport costs imposed by geographical location and/or natural environment. Among these are transportation infrastructure capacity and insurance against various hazards and time costs. These aspects, in contrast to others imposed by policy (tariffs, quotas and the like) have significant implications for economic development within the broader context of infrastructure capacity building, employment, choice of production location, and even freight modal choice.

Direct transport costs include freight charges, as well as insurance that is customarily added to the freight charge. While measuring the transport costs for their studies, Limao and Venables (2001) obtained quotes from shipping firms for a standard container shipped from Baltimore to various destinations in the world, and found that trade costs were hugely dependent on infrastructure. Infrastructure was measured as an average of the density of the road network, the paved road network, the rail network, and the number of telephone main lines per person. They reported that infrastructure deterioration from the median to the 75th percentile of destinations raised transport costs by 12%. Further, they showed that the median landlocked country had transport costs that were 55% higher than the median coastal economy. Hence, infrastructure variables have explanatory power in predicting trade volume. Hummels (2001), on the other hand, obtained indices of ocean shipping and air freight rates from trade journals and revealed a wide dispersion in freight rates across commodities and countries in 1994. In his findings, all-commodities trade-weighted average transport cost (derived from national customs data) ranged from 3.8% of the f.o.b. price for the United States, to 13.3% for Paraguay. Using data from the World Bank's Doing Business Database, Martinez-Zarzoso and Marquez-Ramos (2008) estimated an augmented gravity equation[2] for 13 exporters and 167 importers and showed that trade flows increased by lowering transport costs and reducing the number of days required to trade. They also suggested that multilateral initiatives, such as those in the WTO, can help encourage countries to assess and improve their trade facilitation needs and priorities.

Other theoretical studies on trade costs have emphasized the impact of trade costs on the firm's choice of geographical location. For instance, Venables (1996) investigated the equilibrium locations of vertically linked industries within the framework of imperfect competition, and showed that a reduction in transport costs caused agglomeration and divergence of economic structure and income. However, Venables also revealed that further reductions could undermine the agglomeration and bring convergence. Amiti (2005) developed a model based on the new economic geography literature to analyze the effects of trade liberalization on the location of vertically-linked manufacturing firms with different factor intensities. The study demonstrated that lower trade costs can lead to an agglomeration of all upstream and downstream firms in one country, despite different factor intensities. Also in line with the new economic geography literature, Strauss-Kahn (2005) considered asymmetric countries and multiple factors of production to examine the effect of a trade cost reduction on firms' location decisions and trade patterns. The study showed that: (i) asymmetric factor prices across countries can result in a unique agglomeration equilibrium for a broad range of trade costs; and (ii) at low trade costs, a firm's location will depend on production costs, resulting in vertical specialization. Alonso-Villar (2005) revisited the effects of transport costs on the location decisions of upstream and downstream industries, when transport costs in each sector are analyzed separately. The analysis suggested that regional convergence is more the consequence of improvements in

[1] Anderson and van Wincoop (2004:691-2) provide a detailed account of trade costs consisting of transportation costs (both freight costs and time costs), policy barriers (tariffs and non-tariff barriers), information costs, contract enforcement costs, costs associated with the use of different currencies, legal and regulatory costs, and local distribution costs (wholesale and retail).

[2] Using OLS, PPML, and the Harvey Model.

transportation between upstream and downstream firms, than those between firms and consumers; it therefore provided an alternative explanation to differences in location choice, as highlighted in Krugman (1991) and Venables (1996).

Bougheas, Demetriades, and Morgenroth (1999) examined the role of infrastructure in a bilateral trade model with transport costs, and studied the welfare implications by accounting for the benefits and the costs of infrastructure. Transport costs were assumed to depend inversely on the level of infrastructure. It was shown that, depending on geography and endowment, equilibria with or without infrastructure can be obtained. Jacoby (2000) argued that roads are a particularly important form of rural infrastructure, providing cheap access to markets for agricultural output as well as modern inputs. He also argued that road building would be desirable on distributional grounds, given limited policy instruments for reaching the rural poor in remote areas. Using data from Nepal, Jacoby developed a method for estimating household-level benefits from road projects and showed that providing extensive road access to markets would confer substantial benefits on average, much of these going to poor households.

3. THE MODEL

In the context of a regional economy, I considered a three-stage game of transport infrastructure investment with a strategic choice of freight mode, within the setting of production linkages. The players are two representative downstream producers 1 and 2, and transport service providers *i* and *j*. To deliver their outputs to the international market, producers locating within the region require infrastructure services provided by transport operators. Each operator has infrastructure capacity for transport services in both modes *L* and *A*. For analytical simplicity, I assume that each transport operator invests in only one mode of physical transport infrastructure, and that the two operators do not invest in the same mode of transportation.

The rules of the game were as follows: in the first stage, the downstream producer allocates his delivery of final goods over transport services *L* and *A*. In the second stage, the transport service provider decides both the amount of infrastructure investment in a particular mode of transportation, and the freight rates for using the transport services. And finally, in the third stage, the downstream producers set their outputs and engage in Cournot competition in the product market (outside the region). The payoff to the producers is their profits net of transport costs and (equal) production costs. The payoff to the operators is the revenue from freight rates net of infrastructure investment costs.

In order to bring out the essence of trade-cost-reducing infrastructure investment, I adopted an infrastructure investment function exhibiting diminishing returns. This captures the idea that the extent to which trade costs can be reduced becomes smaller, the more infrastructure investment is undertaken. More specifically, given any primary freight rate reflecting infrastructure capacity endowment in both transport sectors *L* and *A*, (where $e_L > 0$ and $e_A > 0$), the effective ‘transport investment production function’ is given by $f(I_i)$, with $f'(I_i) > 0$ and $f''(I_i) \le 0$. Hence, subsequent to the producer’s investment in transport infrastructure, the *ex post* transportation rate is given by

$$w_i = e_i - f(I_i) - \theta f(I_j), \qquad (1)$$

An important interpretation of Equation (1) can be provided as follows: the level of primary rates in each transportation mode, e_i, reflects the disparity of infrastructure endowment within the region between transport sectors *L* and *A*, respectively. Each transport service provider invests in infrastructure, aiming to reduce transport fares and subsequently lower trade costs for the final goods producer.

The parameter $\theta \in (-1,1)$, a form of spillovers between the two infrastructure investments, can be explained in standard terms by the attributes of either substitutes $(-1 < \theta < 0)$ or complements $(0 < \theta < 1)$. Hence, a positive value of θ implies that the services generated by investment in one transport sector results in a level of connectedness (to services offered by the other transport sector) that is sufficiently high for spillovers to occur. This also implies an output of infrastructure. In contrast, a negative θ suggests substitutability.

The same parameter may also reflect interactions between hard and soft infrastructure. If I take a qualitative aspect emphasizing the soft infrastructure element (as a result of cross-border legal rights and procedures, competition policy, and the transportation regulatory framework for participating in the international market),[3] the parameter θ can alternatively be viewed as a ‘soft infrastructure’ representation of the extent to which investments in physical transport infrastructures interact with each other, while facilitating final goods delivery to the market through transport cost-reducing investment that lowers freight rates in the alternative transport mode.

Moreover, I assumed that transport service providers’ investment is not specific to a particular downstream producer, but rather benefits all producers using the services. To simplify the exposition, I present the argument with a specific example of quadratic total investment cost, as implied in Equation (1), to capture the notion of diminishing returns. More precisely, by undertaking a total infrastructure investment $\beta_i I_i^2 / 2$, where $\beta_i > 1/2$ is a parameter measuring the cost of investment, each services provider *i*, *j* (where *i*, *j* = *L*, *A*, and $i \neq j$) is able to reduce its freight rates by the amount of $\hat{I}_i$, where

$$\hat{I}_i = I_i + \theta I_j,^4 \qquad (2)$$

Notice I assumed that (i) the producers have identical technologies for deciding freight modes, but may make different choices due to differing locations, geography to shipping destination, etc.; (ii) the externalities resulting from investments in the two transport sectors, as represented by a constant, $\theta \in (-1, 1)$, are symmetric between both sectors; and (iii) for every unit of final goods delivered to the international market, the transport costs (or freight rates) for using the *L* and *A* services are given by w_L and w_A, respectively.

To illustrate the effect of modal choice, producer 1 is assumed to use a single transport mode (*L*) while producer 2 allocates his shipment of output (y_2) across transport modes *L* and *A,* such that γy_2 is shipped by *A* and y_2 is shipped by *L*.[5] Note that I did not assume any cost advantages per unit distance as necessarily resulting from the provision of a new alternative transportation mode. In fact, transport alternatives could probably, *but not necessarily,* enhance the competitiveness of a producer’s exports. For example, given two land-locked countries exporting similar but differentiated products, the entrance of air shipping in one country can be expected to enhance its competitiveness in export markets; however, this may still fail to outweigh the importance of other factors. That is, the choice of an alternative freight mode in addition to the original ones could raise a downstream producer’s costs per unit distance, without any offsetting reduction in variable production costs.

---

[3] The author thanks Toru Tatara for bringing up this aspect.

[4] A similar formulation is widely documented in the literature on industrial organization; see, for example, D’Aspremont and Jacquemin (1988) and Besanko and Perry (1993).

[5] The qualitative aspect of the results obtained in the analysis remains valid under an alternative specification of γy_2 by *L* and $(1-\gamma) y_2$ by *A* . See Vickers (1987) and Miller and Pazgal (2001) for a justification of this characterization. Chin and Grossman (1988) tackle the issues of trade-related intellectual property protection using the same approach of strategic choice in R&D investment .

I denoted by $P(Y)$ the inverse demand facing the two downstream final good producers 1 and 2. More specifically, I assumed that the price $P(Y)$ received for the final good is related to the total quantity *Y* of goods sold through the linear function

$$P(Y) = a - Y \,, \tag{3}$$

where $Y = y_1 + y_2$ and y_1, y_2 denote the output produced by firms 1 and 2, respectively.

I assumed that the game form is common knowledge between the producers and the service providers. The solution concept of sub-game perfect equilibrium (SPE) was employed to analyze this market game. Hence, I used the method of backward induction to obtain the results. I began my analysis by deriving the equilibrium output levels at the market stage. I then derived the equilibrium freight rates and the amount of infrastructure investment by the service providers at the second stage. Finally, I solved for the choice of freight mode by the final producer. The objective was to investigate the extent to which the producer's strategic choice of transportation mode affects both freight rates and infrastructure investment, as well the producers' output decision.

4. MAIN RESULTS

The principal results of this model can be expressed in a set of lemmas and propositions, as follows. Proofs are relegated to the appendices.

4.1 Equilibrium in the Product Market

In the final stage of the output game, firms 1 and 2 determine the level of output by solving for the following problems:

$$\max_{y_1 \geq 0} P(Y) y_1 - w_L y_1 \,. \tag{4.1}$$

$$\max_{y_2 \geq 0} P(Y) y_2 - w_L y_2 - \gamma w_A y_2 \,. \tag{4.2}$$

Lemma 1 shows that the outputs in the Cournot-Nash equilibrium depend on the freight rates $w_i > 0$, set by the transport service providers, and the freight model choice determined by the final goods producer (as captured by the share of final outputs delivery between the freight modes, $\gamma > 0$).

<u>Lemma 1</u>. For any $\gamma > 0$, w_L, and w_A, the Cournot-Nash output equilibrium at the output stage, denoted by $\{y_1^*, y_2^*\}$, is (i) $y_1^* = (a - w_L)/2$ and $y_2^* = 0$ for any γ, w_L and w_A, such that $(a - w_L)/2\gamma \leq w_A$; (ii) $y_2^* = (a - w_L - \gamma w_A)/2$ and $y_1^* = 0$ for any γ, w_L and w_A such that $(a + \gamma w_A) < w_L$; and (iii) $y_1^* = (a - w_L + \gamma w_A)/3$ and $y_2^* = (a - w_L - 2\gamma w_A)/3$ for any γ, w_L, and w_A such that $(a + \gamma w_A) > w_L$ and $(a - 2\gamma w_A) > w_L$.

Proof. See Appendix A.

An immediate result following from Lemma 1 suggests a greater market output for the firm that uses fewer transport service options.

<u>Lemma 2</u>. For any $\gamma > 0$, w_L, and w_A, the Cournot-Nash equilibrium output is such that $y_1^* > y_2^*$.

Intuitively, a firm incurs less transportation costs when it decides the freight mode than when it does not. Lower transportation costs correspond to greater potential profitability. Due to the strategic interdependence of outputs in oligopoly, a greater output (or market share) is induced as a result of lower transportation costs. It should be noted that the qualitative aspect of this result (namely, that the output in the Cournot-Nash equilibrium rises with lower transport costs) remains valid even if the analysis is conducted within an alternative setting, where firm 1's output is delivered to the market through the initial transport infrastructure endowment, while firm 2's output is delivered using the new investment as well. That is, owing to the service provider's investment, firm 2 has the strategic option of employing flexibility in its modal choice.

4.2 Decisions on Infrastructure Investment and Freight Rates

Given (y_1^*, y_2^*), each transport service provider *i*, *j* = {*L*, A}, and $i \neq j$, decides both the freight rates charges, w_L and w_A, and the amounts of infrastructure investment, I_L and I_A, for the following problems

$$\max_{w_L, I_L} w_L\big(D_L(y_1, y_2; \gamma) + D_A(y_2)\big) - (\beta_L/2) I_L^2, \tag{5.1}$$

$$\max_{w_A, I_A} w_A\big(D_L(y_1, y_2) + \gamma\, D_A(y_2)\big) - (\beta_A/2) I_A^2, \tag{5.2}$$

where

$$D_L(y_1(w_L, w_A), y_2(w_L, w_A)) \equiv y_1^* + y_2^* = [2(a - w_L) - \gamma\, w_A]/3, \text{ and}$$

$$D_A(y_2(w_L, w_A)) \equiv y_2^* = (a - w_L - 2\gamma\, w_A)/3$$

represent the demand for transport services *L* and *A* , respectively.

Equation (6) and (7) below represent the best freight rates response function of the transport service providers *L* and *A*, respectively. It is evident that both equations are obtained from the first-order conditions to Equations (5.1) and (5.2) with respect to w_L and w_A, i.e.,

$$\frac{\partial \pi_L}{\partial w_L} \equiv \frac{[2(a - w_L) - \gamma w_A]}{3} - \frac{2}{3} w_L, \tag{6}$$

$$\frac{\partial \pi_A}{\partial w_A} = \frac{\gamma[(a - w_L) - 2\gamma w_A]}{3} - \frac{2}{3}\gamma^2 w_A. \tag{7}$$

Using Equations (1), (2), (6) and (7), it is evident that the freight rates of both services *L* and *A* are given by

$$w_L(w_A, \gamma) = e_L - I_L - \theta I_A, \tag{8}$$

and

$$w_A(w_L, \gamma) = e_A - I_A - \theta I_L. \tag{9}$$

It follows immediately that the slope of the best freight rates response function depends critically on the degree of connectedness between infrastructure investments, i.e.,

$$\frac{\partial w_L}{\partial I_L} = \frac{\partial w_A}{\partial I_A} = -1, \quad \text{and} \quad \frac{\partial w_L}{\partial I_A} = \frac{\partial w_A}{\partial I_L} = -\theta. \tag{10}$$

Intuitively, the freight rates in the Cournot-Nash SPE will be such that, at the margin, any further reduction in freight rates would require an equal (and offsetting) increase in investment in the same transport mode's infrastructure. The balance between marginal changes in the freight rates for one mode and investment in the other mode is also determined by the degree of complementarity or substitutability between the two modes, as manifested in externalities.

Using the results in Lemma 1 and Equations (8) through (10), it is easy to verify that the amounts of infrastructure investment in the Cournot-Nash SPE, denoted by (I_L^*, I_A^*), must satisfy the following best investment response functions

$$\frac{\partial \pi_L}{\partial I_L} \equiv \frac{\gamma\theta}{3} w_L - \beta_L I_L = 0, \tag{11}$$

$$\frac{\partial \pi_A}{\partial I_A} \equiv \frac{\gamma\theta}{3} w_A - \beta_A I_A = 0. \tag{12}$$

Proof. Differentiating Equations (5.1) and (5.2) with respect to I_L and I_A, respectively, I have

$$\frac{\partial \pi_L}{\partial I_L} \equiv \left(\frac{\partial w_L}{\partial I_L}(D_L + D_A) + w_L \left[\frac{\partial D_L}{\partial w_L}\frac{\partial w_L}{\partial I_L} + \frac{\partial D_L}{\partial w_A}\frac{\partial w_A}{\partial I_L} + \frac{\partial D_A}{\partial w_L}\frac{\partial w_L}{\partial I_L} + \frac{\partial D_A}{\partial w_A}\frac{\partial w_A}{\partial I_L} \right] \right) - \beta_L I_L = 0.$$

$$\frac{\partial \pi_A}{\partial I_A} \equiv \left(\frac{\partial w_A}{\partial I_A}\gamma D_A + w_A \gamma \left[\frac{\partial D_A}{\partial w_L}\frac{\partial w_L}{\partial I_L} + \frac{\partial D_A}{\partial w_A}\frac{\partial w_A}{\partial I_L} \right] \right) - \beta_A I_A = 0$$

Using Equation (10) and rewriting Equations (11) and (12), the best investment response functions are now expressed as function of w_L, w_A, γ, θ, β_L and β_A, namely,

$$\frac{\partial \pi_L}{\partial I_L} = \frac{-2a + w_L(4+\gamma\theta) + w_A\gamma}{3} - \beta_L I_L, \text{ and}$$

$$\frac{\partial \pi_A}{\partial I_A} = \frac{-\gamma[a - w_L - (4\gamma + \theta)w_A]}{3} - \beta_A I_A .$$

It is evident, from Equation (6), that $2(a - 2w_L) - \gamma w_A = 0$. Hence, I have established the result that $\frac{\partial \pi_L}{\partial I_L} \equiv \frac{\gamma\theta}{3} w_L - \beta_L I_L = 0$. Further, from Equation (7), it is clear that $(a - w_L)\gamma - 4w_A\gamma^2 = 0$. Hence, I have $\frac{\partial \pi_A}{\partial I_A} \equiv \frac{\gamma\theta}{3} w_A - \beta_A I_A = 0$.

It follows immediately, from Equations (11) and (12), that the equilibrium freight rates are given by

$$w_L^* = \frac{3}{\gamma\theta}\beta_L I_L^* , \tag{13}$$

$$w_A^* = \frac{3}{\gamma\theta}\beta_A I_A^* \tag{14}$$

The rates therefore depend on the equilibrium levels of infrastructure investment; the extent of complementarity/substitutability between the transport modes; and the final goods' producers' allocation decisions across transport modes. Note that the greater the flexibility in modal choice (as reflected by γ), or the greater the complementarity between the alternative transport modes, the lower the equilibrium freight rates.

4.2.1 Equilibrium Infrastructure Investments

Using Equations (5.1) and (5.2), the infrastructure investments I_L and I_A implied by $D_L = y_1^* + y_2^* = \frac{(2a - 4w_L + \gamma w_A)}{3}$, and $D_A = \gamma y_2^* = \frac{\gamma(a - w_L - 4\gamma w_A)}{3}$ can be obtained by solving for

$$2a - 4(e_L - I_L - \theta I_A) - \gamma(e_A - I_A - \theta I_L) = 0 \text{, and}$$

$$a - (e_L - I_L - \theta I_A) - 4\gamma(e_A - I_A - \theta I_L) = 0 .$$

Rearranging, I have

$$(4 + \gamma\theta)I_L + (4\theta + \gamma))\, I_A = \gamma e_A + 4e_L - 2a . \tag{15}$$

$$(1 + 4\gamma\theta)I_L + (\theta + 4\gamma)\, I_A = 4\gamma e_A + e_L - a . \tag{16}$$

Solving (15) and (16) for (I_L^*, I_A^*), I have

$$I_L^* \equiv \frac{1}{\Delta}\begin{vmatrix} \gamma e_A + 4e_L - 2a & 4\theta + \gamma \\ 4\gamma e_A + \gamma e_L - a & \theta + 4\gamma \end{vmatrix} = \frac{[(15e_L - 7a) - 15e_A\theta]\gamma + 2a\theta}{\Delta}, \tag{17}$$

$$I_A^* = \frac{1}{\Delta}\begin{vmatrix} 4 + \gamma\theta & \gamma e_A + 4e_L - 2a \\ 1 + 4\gamma\theta & 4\gamma e_A + e_L - a \end{vmatrix} = \frac{[15e_A - (15e_L - 7a)\theta]\gamma - 2a}{\Delta}, \tag{18}$$

where $\Delta = \begin{vmatrix} 4 + \gamma\theta & 4\theta + \gamma \\ 1 + 4\gamma\theta & \theta + 4\gamma \end{vmatrix} = 15\gamma(1 - \theta^2) > 0$.

Proposition 1 characterizes the amounts of infrastructure investment in the Cournot-Nash SPE. Of interest, I explore the properties of the equilibrium infrastructure investments.

Proposition 1 *For any* $a > 0$, $e_A > 0$, $e_L > 0$, *and* $\gamma \in (0,1)$,

(a) if $\theta \in (\tilde{\theta}, 1)$, $\gamma \in (0, \underline{\gamma}_1)$, $e_L > 7a/15$, *and* $e_A > (e_L - 7a/15)$, *there exists* $\tilde{\gamma} \in (0,1)$ *such that* $I_A^* \geq I_L^*$ *for any* $\gamma \in [\tilde{\gamma}, \underline{\gamma}_1)$, *and* $I_A^* < I_L^*$ *for any* $\gamma \in [0, \tilde{\gamma})$, *where* $\underline{\theta} = (15e_L - 7a)/15e_A$, $\underline{\gamma}_1 = 2a\theta/[15e_A\theta - (15e_L - 7a)]$, *and* $\tilde{\gamma} = 2a/15[e_A - (e_L - 7a/15)]$.

(b) if $\theta \in (\breve{\theta}, \hat{\theta}) < 0$, $\gamma \in (\breve{\gamma}_1, 1]$, $e_L > 7a/15$, *and* $e_A > (e_L - 7a/15)$, *there exists* $\tilde{\gamma}$ *such that* $I_A^* \geq I_L^*$ *for any* $\gamma \in [\tilde{\gamma}, 1]$, *and* $I_A^* < I_L^*$ *for any* $\gamma \in (\breve{\gamma}_1, \tilde{\gamma})$, *where* $\breve{\theta} = (7a - 15e_L)/15e_A$, $\hat{\theta} = 15e_A/(7a - 15e_L)$, and $\breve{\gamma}_1 = 2a\theta/[15e_A\theta + (15e_L - 7a)]$.

Proof. See Appendix B.

When the downstream producer's choice of freight mode influences the infrastructure investment decisions of the transport service providers, it makes intuitive sense that a higher investment in the alternative transport infrastructure emerges as a result of a greater demand for the alternative freight mode (compared to the standard transport mode). Nonetheless, depending on the threshold level of freight modal choices, the infrastructure investment of one service provider may be greater than the other (i.e., depending on the value of γ I may have either $I_A > I_L$ or $I_A < I_L$).

Interestingly, the nature of infrastructure investment has a decisive impact on the critical value for the freight modal choice. A closer examination of the conditions for infrastructure investments in equilibrium shows that a greater share of the alternative freight mode is desirable for infrastructure substitutes than it is for infrastructure complements. A key lesson from this result is that the utilization of alternative transport services to facilitate the delivery of final goods can be enhanced by strengthening soft infrastructure; this would mitigate the distinct features of substitutes *vs.* complements in physical infrastructure, or enhance the complementary of alternative transport modes.

4.2.2 Equilibrium Freight Rates

Substituting the results of equilibrium infrastructure investments contained in Equations (17) and (18) into Equations (13) and (14), the freight rates, in the SPE, are now given by

$$w_L^* = \frac{\beta_L}{5\theta(1-\theta^2)} \frac{[(15e_L - 7a) - 15e_A\theta]\gamma + 2a\theta}{\gamma^2}, \tag{19}$$

$$w_A^* = \frac{\beta_A}{5\theta(1-\theta^2)} \frac{[15e_A - (15e_L - 7a)\theta]\gamma - 2a}{\gamma^2}. \tag{20}$$

Proposition 2 below characterizes the properties of the freight rates in the SPE.

<u>Proposition 2.</u> *For any* $a > 0$, $\beta_A > 0$, $\beta_L > 0$, $e_L > 7a/15$, *and* $e_A > (e_L - 7a/15)$,

(a) if $\theta \in (\tilde{\theta}, 1)$, *there exists* $\gamma^E \in (\tilde{\gamma}, \underline{\gamma}_1)$ *such that* $w_A^* \geq w_L^*$ *for any* $\gamma^E \leq \gamma < \underline{\gamma}_1$ *if* $\beta_A < \beta_L$, *and for any* $\tilde{\gamma} \leq \gamma < \underline{\gamma}_1$ *if* $\beta_A > \beta_L$, *and that* $w_A^* < w_L^*$ *for any* $\tilde{\gamma} \leq \gamma < \gamma^E$ *if* $\beta_A < \beta_L$ *and for any* $\gamma^E \leq \gamma < \tilde{\gamma}$ *if* $\beta_A > \beta_L$, *where* $\tilde{\theta} = (15e_L - 7a)/(15e_A - 2a)$ *and*
$\gamma^E = 2a(\beta_A + \beta_L\theta)/[15e_A(\beta_A + \beta_L\theta) - (15e_L - 7a)(\beta_L + \beta_A\theta)]$.

(b) if $\theta \in (-1, 0)$, *there exists* $\gamma^e \in (\breve{\gamma}_1, 1]$ *such that* $w_A^* \geq w_L^*$ *for any* $\breve{\gamma}_1 < \gamma \leq \gamma^e$, *and* $w_A^* < w_L^*$ *for any* $\gamma^e < \gamma \leq 1$, *where*
$\gamma^e = 2a(\beta_A - \beta_L\theta)/[15e_A(\beta_A - \beta_L\theta) + (15e_L - 7a)(\beta_L - \beta_A\theta)]$.

Proof. See Appendix C.

Intuitively, when the infrastructure investment cost of one transportation mode is higher than that of the other, the degree of interconnectedness (alternatively, the extent to which one transport service is linked to the other) determines both the freight rates set by the service providers and the level of utilization chosen by the service users (that is, the final goods producers). A higher (lower) interconnectedness level corresponds to a greater (smaller) complementary between the transport services. Although a high unit marginal cost of infrastructure investment suggests high freight rates, the degree of infrastructure complementary mitigates the direct negative impact of investment cost on a service provider's profit, by engendering a higher level of utilization for the services. In the extreme, when the infrastructure services approximate perfect complements, namely, $\theta \to 1$, the final goods producer has to use the alternative transport services to a sufficiently great extent (as captured by $\underline{\gamma}_1$, the level of γ necessary to maintain a competitive equilibrium). This suggests that freight rates rise as a result of increases in transport service demand, and that the impact of the investment cost on freight rates is weakened. For infrastructure substitutes, a similar argument suggests that high freight rates can be sustained only when the alternative transportation service is not used to a sufficiently high level (as captured by γ^e).

4.3 Equilibrium choice of the Mode of Transportation

At the first stage, the producer utilizing the alternative transportation service decides the level of γ, i.e.,

$$\max_{\gamma>0} \pi_2 = (a - y_1^* - y_2^* - w_L^* - \gamma w_A^*) y_2^*. \tag{21}$$

Using the results contained in Lemma B-1 and Lemma B-2 (see Appendix B), it is evident that for any $a > 0$, $e_L > 7a/15$, and $e_A > (e_L - 7a/15)$, if $\theta \in (\tilde{\theta}, 1)$, the SPE outcome is given by choosing $\gamma \in [0,1]$ to solve for

$$\max_{0\le\gamma\le1} \pi_2^* = \frac{(a - w_L^* - 2\gamma w_A^*)^2}{9}. \tag{22}$$

It is easy to show that, for any $a > 0$, $\beta_A > 0$, $\beta_L > 0$, $e_L > 7a/15$, $e_A > (e_L - 7a/15)$ and $\theta \in (-1, 1)$,

$$\frac{\partial^2 \pi_2^*}{\partial \gamma^2} > 0 \text{ if and only if } Z < 0, \tag{23}$$

where $Z = \dfrac{\partial^2 w_L^*}{\partial \gamma^2} + 4\dfrac{\partial w_A^*}{\partial \gamma} + 2\gamma \dfrac{\partial^2 w_A^*}{\partial \gamma^2}$.

A closer examination of the inequality (23) suggests that firm 2's profit is strictly convex in γ if $Z < 0$,[6] for any $a > 0$, $\beta_A > 0$, $\beta_L > 0$, $e_L > 7a/15$, $e_A > (e_L - 7a/15)$, $\gamma \in [0,1]$ and $\theta \in (-1, 1)$.

Proposition 3. *For any* $a > 0$, $\beta_A > 0$, $\beta_L > 0$, $e_L > 7a/15$, $e_A > (e_L - 7a/15)$,

(a) if $\theta \in (\tilde{\theta}, 1)$ *and* $\beta_A < \beta_L$, *then the SPE outcome of* γ^* *is given by*

$$\gamma^* = \begin{cases} \underline{\gamma}_1, & \text{if } \beta_A/\beta_L < \rho(\theta) \\ \gamma^E, & \text{if } \beta_A/\beta_L > \rho(\theta) \end{cases}.$$

(b) if $\theta \in (\breve{\theta}, \hat{\theta})$ *and* $\beta_A < \beta_L$, *then the SPE outcome of* γ^* *is given by*

$$\gamma^* = \breve{\gamma}_1$$

Proof. See Appendix D.

[6] This result is analogous to results in the theory of perfect competition, where a firm's profit function is convex in prices. That is, although profit is a concave function of the choice variable of output, the maximized value may, in fact, be convex in a parameter (Varian, 1992:41).

This implies that the interactions between the degree of infrastructure interconnectedness and the relative cost of transport infrastructure investment influence the choice of freight mode. In the extreme case of perfect complements (i.e., $\theta = 1$), a lower cost of investment in transport infrastructure *A* (than in *L)* is needed to ensure its utilization by the producer. More generally, complementarity between transport modes works to the advantage of the customer for transport services, as investment in one mode enhances the productivity and/or lowers the cost of the other. Similarly, if investment in the alternative mode reduces the efficiency of the original, customers may require a greater level of infrastructure investment across the two transport modes, to achieve the same level of service.

5. CONCLUSION

In this analysis, I investigated the freight modal choice problem of a final goods producer in the context of vertical production linkages. I developed an analytical framework in which downstream final goods producers within a region require transport services provided by two distinct upstream transport operators. In order to capture in the simplest manner the qualitative aspect of soft (or institutional) infrastructure resulting from cross-border legal rights and procedures, competition policy, and transportation regulatory framework, I characterized by a parameter the degree of interconnectedness between the investments in physical infrastructure, while taking into account the nature of complementarity *vs*. substitutability inherent in the physical infrastructure. More specifically, this parameter is symmetric across transport modes for each service provider; i.e., an identical parameter value highlights the role of strategic choice of transport mode in both infrastructure investment and freight rates.

The policy implications of the results provide important insights into whether or not greater transport infrastructure capacity facilitates the delivery of final goods to the end market and subsequently lowers trade costs. The results may be particularly useful when considering, for example, the value of air transport in a land-locked country. In the analysis, I demonstrated that freight rates need not be reduced when service providers invest in transport infrastructure, subsequent to the producers' decision regarding the allocation of final goods delivery across transportation services. An immediate implication is that the producers' demand for transportation services should be carefully assessed when planning transport infrastructure investments to enhance competitiveness in export markets.

If I approximate the level of interconnectedness between transportation infrastructure as the degree of substitutability/complementary in delivering a commodity (be it an intermediate or final good) to the end market, then the results suggest that interactions among the nature of infrastructure investments, their construction costs, and industry-specific characteristics should be considered before service providers and/or the public sector commits to the provision of such infrastructure.

While the service providers could be in the public sector as well, it is competitive profit maximization that drives the linkages between the goods' producers and the service providers. In contrast to the public sector's leadership role as documented in much of the trade literature (see Spencer and Brander 1983), my analysis considers an alternative scenario that better captures the experience in Asia, where the public sector has typically acted in response to private firms' call for greater transport infrastructure provision. The assumption that the public sector responds to the need for transport infrastructure, rather than pre-committing itself to such provision, is essential to the analysis and the resulting conclusions. I emphasize that private firms can act naturally in this leadership role, at least in some Asian countries, and that this reflects a more general principle in understanding the mechanics of development in Asia.

APPENDIX A

Given the freight rates w_L and w_A and the freight modal share γ, for any output of firm *j* ($y_j \geq 0$), firm *i*'s best (output) response function, $R_i(y_j)$, where *i, j* = 1, 2 and $i \neq j$, is given by:

$$y_i = R_i(y_j) = \begin{cases} (a - w_i - w_j - y_j)/2, if\ y_j < a - w_i - w_j \\ 0 \qquad\qquad\qquad , if\ y_j \geq a - w_i - w_j. \end{cases} \tag{A.1}$$

$$y_j = R_j(y_i) = \begin{cases} (a - w_i - \gamma w_j - y_i)/2,\ if\ y_i < a - w_i - \gamma w_j \\ 0 \qquad\qquad\qquad ,\ if\ y_i \geq a - w_i - \gamma w_j. \end{cases} \tag{A.2}$$

Solving Equations (A.1) and (A.2) for the output levels in the Nash Equilibrium, denoted by $\{y_1^*, y_2^*\}$, I have (i) $y_1^* = (a - w_L)/2$ and $y_2^* = 0$ for any γ, w_L and w_A, such that $(a - w_L)/2\gamma \leq w_A$; (ii) $y_2^* = (a - w_L - \gamma w_A)/2$ and $y_1^* = 0$ for any γ, w_L and w_A such that $(a + \gamma w_A) < w_L$; and (iii) $y_1^* = (a - w_L + \gamma w_A)/3$ and $y_2^* = (a - w_L - 2\gamma w_A)/3$ for any γ, w_L, and w_A such that $(a + \gamma w_A) > w_L$ and $(a - 2\gamma w_A) > w_L$.

APPENDIX B

To prove Proposition 1, I establish some preliminary results, which are organized in Lemmata A-1 and A-2 as follows:

Lemma B-1. *For any* $a > 0$, $e_A > 0$, $e_L > 0$, $\theta > 0$ *and* $\gamma > 0$,

(a) $I_L^* > 0$ *and* $I_A^* > 0$ *if* $\theta \in (\underline{\theta}, 1)$, $\gamma \in (\underline{\gamma}_2, \underline{\gamma}_1)$, $e_L > 7a/15$, *and* $e_A > (e_L - 7a/15)$,

(b) $I_A^* \geq I_L^*$ *if* $\gamma \geq \tilde{\gamma}$ *and* $I_A^* < I_L^*$ *if* $\gamma < \tilde{\gamma}$, *given* $\theta \in (\underline{\theta}, 1)$, $e_L > 7a/15$, *and* $e_A > (e_L - 7a/15)$,

(c) $1 > \underline{\gamma}_1 > \tilde{\gamma}$ *if* $\theta \in (\tilde{\theta}, 1)$ *and* $e_L > 7a/15$ *where*
$\tilde{\theta} \equiv (15e_L - 7a)/(15e_A - 2a) < \theta$, $\underline{\theta} = (15e_L - 7a)/15e_A$,
$\underline{\gamma_1} = 2a\theta/[15e_A\theta - (15e_L - 7a)]$, *and* $\tilde{\gamma} \equiv 2a/[15e_A - (15e_L - 7a)]$.

Proofs. (1) Using Equations (17) and (18), it is clear, for any $a > 0$, $e_A > 0$, $e_L > 0$, $\theta > 0$ and $\gamma > 0$, that (a) $I_L^* > 0$ if $\theta > (15e_L - 7a)/15e_A \equiv \underline{\theta}$ and $\gamma < 2a\theta/[15e_A\theta - (15e_L - 7a)] \equiv \underline{\gamma_1}$, and that (b) $I_A^* > 0$ if $\overline{\theta} \equiv 15e_A/(15e_L - 7a) > \theta$ and $\gamma > 2a/[15e_A - (15e_L - 7a)\theta] \equiv \underline{\gamma_2}$. This implies that $I_L^* > 0$ and $I_A^* > 0$ if and only if $\theta \in (\underline{\theta}, \overline{\theta})$ and $\gamma \in (\underline{\gamma}_2, \underline{\gamma}_1)$. A straightforward computation shows that $\underline{\theta} < \overline{\theta}$ if $e_L > 7a/15$ and $e_A > (e_L - 7a/15)$ (which implies that $\overline{\theta} > 1$), and that $\underline{\gamma}_1 > \underline{\gamma}_2$ if $e_L > 7a/15$ and $\theta \in (0,1)$ since $\underline{\gamma}_1 - \underline{\gamma}_2 = (15e_L - 7a)(1 - \theta^2) > 0$. Hence, I have established the result that, for any $a > 0$, $e_L > 7a/15$, and $e_A > (e_L - 7a/15)$, $I_L^* > 0$ and $I_A^* > 0$ if $\theta \in (\underline{\theta}, 1)$ and $\gamma \in (\underline{\gamma}_2, \underline{\gamma}_1)$. This proves Part (a) of Lemma A-1.

(2) A simple calculation of the difference between I_L^* and I_A^* shows that, for any $e_L > 7a/15$ and $e_A > (e_L - 7a/15)$, there exists an $\gamma = \tilde{\gamma} \equiv 2a/15[e_A - (e_L - 7a/15)]$ at which $I_A^* = I_L^*$, such that $I_A^* > I_L^*$ if $\gamma > \tilde{\gamma}$, and $I_A^* < I_L^*$ if $\gamma < \tilde{\gamma}$. This proves Part (b) in Lemma A-1.

(3) A closer examination for the values of $\underline{\gamma}_1$ and $\tilde{\gamma}$ suggests that, for any $e_L > 7a/15$ and $\underline{\theta} < \theta < 1$, (a) $\underline{\gamma}_1 > \tilde{\gamma}$ since $\underline{\gamma}_1 - \tilde{\gamma} = (15e_L - 7a)(1 - \theta)$; and (b) $\underline{\gamma}_1 < 1$ if $\tilde{\theta} \equiv (15e_L - 7a)/(15e_A - 2a) < \theta$. In fact, for any $e_L > 7a/15$, if $(15e_L - 7a) < (15e_A - 2a)$ then $(e_L - 7a/15) < e_A$. This implies that, for any $e_L > 7a/15$, $\tilde{\theta} < 1$. It follows immediately that $0 < \underline{\theta} < \tilde{\theta} < 1 < \overline{\theta}$. Hence, I have established that $1 > \underline{\gamma}_1 > \tilde{\gamma}$ for any $\tilde{\theta} < \theta < 1$. This proves Part (c) in Lemma A-1. I have now completed the proofs of Lemma A-1 to Proposition 1(a).

Lemma B-2. *For any* $a>0$, $e_A>0$, $e_L>0$, $-1<\theta<0$ *and* $\gamma>0$,

(a) $I_L^*>0$ *and* $I_A^*>0$ if $\theta\in(\breve{\theta},\widehat{\theta})$, $\gamma>\breve{\gamma}_2$, $e_L>7a/15$, *and* $e_A>(e_L-7a/15)$,

(b) $I_A^*\geq I_L^*$ *if* $\gamma\geq\tilde{\gamma}$ *and* $I_A^*<I_L^*$ *if* $\gamma<\tilde{\gamma}$, *given* $\theta\in(\breve{\theta},\widehat{\theta})$, $e_L>7a/15$, *and* $e_A>(e_L-7a/15)$, *and*

(c) $1>\tilde{\gamma}>\breve{\gamma}_1$ *if* $e_L>7a/15$ *and* $e_A>(e_L-7a/15)$, *where* $\breve{\theta}=(7a-15e_L)/15e_A, \widehat{\theta}=15e_A/(7a-15e_L)$, and $\breve{\gamma}_1=2a\theta/[15e_A\theta+(15e_L-7a)]$.

Proofs. (a) If $\theta\in(-1,0)$, then the numerator in Equations (17) and (18) is now given by $[15(e_L-7a)+15\theta e_A]\gamma-2a\theta$ and $[15e_A+(15e_L-7a)\theta]\gamma-2a$, respectively. It is evident that (a) $I_L^*>0$ if $\gamma>2a\theta/[(15e_L-7a)+15\theta e_A]\equiv\breve{\gamma}_1$ and $\theta>\breve{\theta}\equiv(7a-15e_L)/15e_A$, and that (b) $I_A^*>0$ if $\gamma>2a/[15e_A+(15e_L-7a)\theta]\equiv\breve{\gamma}_2$ and $\theta<\widehat{\theta}\equiv15e_A/(7a-15e_L)$. This implies that, for any $\theta\in(-1,0)$, $I_L^*>0$ and $I_A^*>0$ if and only if $\theta\in(\breve{\theta},\widehat{\theta})$ and $\gamma>\max\{\breve{\gamma}_1,\breve{\gamma}_2\}$. A straightforward computation shows that $\breve{\theta}<\widehat{\theta}$ if $e_L>7a/15$ and $e_A>(e_L-7a/15)$, and that $\breve{\gamma}_1<\breve{\gamma}_2$ if $e_L>7a/15$ and $\theta\in(-1,0)$. Hence, I have established the result that, for any $a>0$, $e_L>7a/15$, and $e_A>(e_L-7a/15)$, $I_L^*>0$ and $I_A^*>0$ if $\theta\in(\breve{\theta},\widehat{\theta})$ and $\gamma>\breve{\gamma}_2$. This proves Part (a) of Lemma A-2.

(2) A simple calculation of the difference between I_L^* and I_A^* shows that, for any $\theta\in(-1,0)$, $e_L>7a/15$ and $e_A>(e_L-7a/15)$, there exists an $\gamma=\tilde{\gamma}\equiv2a/15[e_A-(e_L-7a/15)]$ at which $I_A^*=I_L^*$, such that $I_A^*>I_L^*$ if $\gamma>\tilde{\gamma}$, and $I_A^*<I_L^*$ if $\gamma<\tilde{\gamma}$. This proves Part (b) in Lemma A-2.

(3) A closer examination for the values of $\tilde{\gamma}$ and $\breve{\gamma}_2$ suggests that (a) $\tilde{\gamma}>\breve{\gamma}_2$ if $e_L>7a/15$ and $-1<\theta<0$ since $\tilde{\gamma}-\breve{\gamma}_2=(15e_L-7a)(1+\theta)>0$, and (b) $\tilde{\gamma}<1$ for any $a>3(e_L-e_A)$ since $1-\tilde{\gamma}=a-3((e_L-e_A)>0$ if $a>3(e_L-e_A)$. Note that for any $a>0$ and $e_L>7a/15$, $a>3(e_L-e_A)$ holds true for any $e_A>(e_L-7a/15)$. This suggests that $\tilde{\gamma}<1$ for any $e_A>(e_L-7a/15)$. This proves Part (c) in Lemma A-2. I have now completed the proofs of Lemma A-2 to Proposition 1(b).

APPENDIX C

(a) For any $\theta \in (\tilde{\theta}, 1)$, $\tilde{\gamma} < \gamma < \underline{\gamma}_1$, $e_L > 7a/15$, *and* $e_A > (e_L - 7a/15)$, it is clear, using Equations (19) and (20), that there exists $\gamma^E \in (\tilde{\gamma}, \underline{\gamma}_1)$ such that $w_A^* \geq w_L^*$ for any $\gamma^E \leq \gamma < \underline{\gamma}_1$, and $w_A^* < w_L^*$ for any $\tilde{\gamma} \leq \gamma < \gamma^E$, where $\underline{\gamma_1} = 2a\theta/[15e_A\theta - (15e_L - 7a)]$, and $\gamma^E = 2a(\beta_A + \theta\beta_L)/[15(\beta_A + \theta\beta_L)e_A - (15e_L - 7a)(\beta_A\theta + \beta_L)]$. (b) Further, a comparison between $\tilde{\gamma}$ and γ^E shows, for any $e_L > 7a/15$, $\theta \in (\tilde{\theta}, 1)$, and $0 < \gamma < \underline{\gamma}_1$, that $\tilde{\gamma} < \gamma^E$ if $\beta_A < \beta_L$, and that $\tilde{\gamma} > \gamma^E$ if $\beta_A > \beta_L$ since $\tilde{\gamma} - \gamma^E = (15e_L - 7a)(\beta_A - \beta_L)(1-\theta)$. Hence, I have established that (i) $w_A^* \geq w_L^*$ for $\gamma^E \leq \gamma < \underline{\gamma}_1$ if $\beta_A < \beta_L$, and $\tilde{\gamma} \leq \gamma < \underline{\gamma}_1$ if $\beta_A > \beta_L$, and that (ii) $w_A^* < w_L^*$ for $\tilde{\gamma} \leq \gamma < \gamma^E$ if $\beta_A < \beta_L$ and $\gamma^E \leq \gamma < \tilde{\gamma}$ if $\beta_A > \beta_L$. This proves Corollary 1(a).

(b) Now, for any $\theta \in (-1, 0)$, taking into account the θ term in the denominator, the numerator in Equation (19) and (20) is written as $2a\theta - [15(e_L - 7a) + 15e_A\theta)]\gamma$ and $2a - [15e_A + (15e_L - 7a)\theta]\gamma$, respectively. It is evident that $w_L^* > 0$ if $\gamma < \breve{\gamma}_1$ and $\theta > \breve{\theta}$ and $w_A^* > 0$ if $\gamma < \breve{\gamma}_2$ and $\theta < \hat{\theta}$. A closer examination of the parameters shows that $\breve{\gamma}_2 - \breve{\gamma}_1 = (15e_L - 7a)(1-\theta^2) > 0$ and $\hat{\theta} - \breve{\theta} = [15e_A - (15e_L - 7a)][15e_A + (15e_L - 7a)] > 0$. Hence, I have established the result that $w_L^* > 0$ and $w_A^* > 0$ if $\gamma < (\breve{\gamma}_1, 1)$ and $\theta \in (\breve{\theta}, \hat{\theta})$ for any $e_L > 7a/15$ and $\theta \in (-1, 0)$.

Moreover, it is straightforward to show that, for any $\gamma < (\breve{\gamma}_1, 1)$ and $\theta \in (\breve{\theta}, \hat{\theta})$, there exists $\gamma^e \in (\breve{\gamma}_1, 1)$ such that $w_A^* \geq w_L^*$ for any $\gamma \geq \gamma^e$, and $w_A^* < w_L^*$ for any $\gamma < \gamma^e$, where $\gamma^e = 2a(\beta_A - \beta_L\theta)/[15e_A(\beta_A - \beta_L\theta) + (15e_L - 7a)(\beta_L - \beta_A\theta)]$.

Further, a simple comparison between the values of $\breve{\gamma}_1$, $\tilde{\gamma}$ and γ^e shows that, for any $e_L > 7a/15$, $\theta \in (\breve{\theta}, \hat{\theta})$, and $\gamma \in (\breve{\gamma}_1, 1)$: (i) $\tilde{\gamma} > \gamma^e$ since $\tilde{\gamma} - \gamma^e = (15e_L - 7a)(\beta_A + \beta_L)(1-\theta) > 0$; (ii) $\tilde{\gamma} > \breve{\gamma}_1$ since $\tilde{\gamma} - \breve{\gamma}_1 = (15e_L - 7a)(1+\theta) > 0$, and (iii) $\breve{\gamma}_1 < \gamma^e$ since $\gamma^e - \breve{\gamma}_1 = (15e_L - 7a)[\beta_A(1+\theta^2) - 2\theta\beta_L] > 0$. Hence, I have established the result that $\tilde{\gamma} > \gamma^e > \breve{\gamma}_1$. This proves Corollary 1(b).

APPENDIX D

Using Equation (22), it is straightforward to show the first-order-condition is given by

$$\frac{\partial \pi^*_2}{\partial \gamma} = \frac{2}{9}(a - w^*_L - 2\gamma\, w^*_A)\left(-\frac{\partial w^*_L}{\partial \gamma} - 2w^*_A - 2\gamma \frac{\partial w^*_A}{\partial \gamma}\right), \qquad \text{(A.3)}$$

and the second-order-condition suggests

$$\frac{\partial^2 \pi^*_2}{\partial \gamma^2} = \frac{2}{9}\left\{\left(-\frac{\partial w^*_L}{\partial \gamma} - 2w^*_A - 2\gamma \frac{\partial w^*_A}{\partial \gamma}\right)^2 + (a - w^*_L - 2\gamma\, w^*_A)\left(-\frac{\partial^2 w^*_L}{\partial \gamma^2} - 4\frac{\partial w^*_A}{\partial \gamma} - 2\gamma \frac{\partial^2 w^*_A}{\partial \gamma^2}\right)\right\} .$$

(A.4)

Denote by *Z* the third term in the curly bracket, that is,

$$Z = -\left(\frac{\partial^2 w^*_L}{\partial \gamma^2} + 4\frac{\partial w^*_A}{\partial \gamma} + 2\gamma \frac{\partial^2 w^*_A}{\partial \gamma^2}\right).$$

Using the results contained in Equations (19) and (20), I have $Z < 0$ if

$$\beta_L(2a\theta + [(15e_L - 7a) - 15e_A\theta]\gamma) < 4a(\beta_A\gamma - \beta_L\theta) . \qquad \text{(A.5)}$$

It is evident, from Equation (22), that $\pi^*_2(\gamma) < \pi^*_2(\underline{\gamma}_1)$ for any $\gamma > \underline{\gamma}_1$. Hence, I evaluate Equation (22) at $\gamma = \underline{\gamma}_1$, it is straightforward to show that the inequality holds if

$$\frac{\beta_A}{\beta_L} < \frac{15e_A\theta - (15e_L - 7a)}{2a} \equiv \sigma(\theta) = \frac{\theta}{\underline{\gamma}_1} . \qquad \text{(A.6)}$$

A closer examination of the inequality (A.5) shows, for any $a > 0$, $\beta_A > 0$, $\beta_L > 0$, $e_L > 7a/15$, $e_A > (e_L - 7a/15)$, $\gamma \in [\tilde{\gamma}, \underline{\gamma}_1)$ and $\theta \in (\tilde{\theta}, 1)$, that firm 2's profit is strictly convex in γ if $\dfrac{\beta_A}{\beta_L} < \tilde{\theta}$.

Hence, for any $\dfrac{\beta_A}{\beta_L} < \tilde{\theta}$, evaluating $\pi^*_2(\gamma)$ at both end points of $\tilde{\gamma}$ and $\underline{\gamma}_1$, and comparing $\pi^*_2(\tilde{\gamma})$ to $\pi^*_2(\underline{\gamma}_1)$. A straightforward calculation shows that $\pi^*_2(\underline{\gamma}_1) > \pi^*_2(\tilde{\gamma})$ if

$$\frac{\beta_A}{\beta_L} < \frac{[15e_A - (15e_L - 7a)]\theta}{4a} \equiv \rho(\theta) = \frac{\theta}{2\tilde{\gamma}}. \qquad \text{(A.7)}$$

Using Equations (A.6) and (A.7), it is easy to verify that $\frac{\theta}{2\tilde{\gamma}} < \frac{\theta}{\underline{\gamma}_1}$ for any $\theta \in (\tilde{\theta}, 1)$. This implies that the SPE outcome of the γ, denoted by γ^*, chosen by firm 2 is $\underline{\gamma}_1$ if $\frac{\beta_A}{\beta_L} < \frac{\theta}{2\tilde{\gamma}}$, and γ^E otherwise, since firm 2's profit is continuous and strictly convex in γ and there exists $\gamma^E \in (\tilde{\gamma}, \underline{\gamma}_1)$. Hence, I have established the results of Proposition 3(a).

Similarly, for any $a > 0$, $e_L > 7a/15$ and $e_A > (e_L - 7a/15)$, if $-1 < \theta < 0$, where $\theta \in (\breve{\theta}, \hat{\theta})$, then $\frac{\partial^2 \pi_2^*}{\partial \gamma^2} > 0$ if and only if

$$\beta_L(2a\theta - \gamma[15e_A\theta + (15e_L - 7a)] + 4a[\beta_A + \beta_L\theta] < 0. \qquad \text{(A.8)}$$

Again, evaluating Equation (22) at $\gamma = \breve{\gamma}_1$, it is straightforward to show that the inequality holds if

$$\frac{\beta_A}{\beta_L} < \frac{(15e_L - 7a) + 15e_A\theta}{2a} = \frac{\theta}{\breve{\gamma}_1}. \qquad \text{(A.9)}$$

A closer examination of the inequality (A.9) shows, for any $a > 0$, $\beta_A > 0$, $\beta_L > 0$, $e_L > 7a/15$, $e_A > (e_L - 7a/15)$, $\gamma \in (\breve{\gamma}_1, 1)$ and $\theta \in (\breve{\theta}, \hat{\theta})$, that firm 2's profit is strictly convex in γ if $\frac{\beta_A}{\beta_L} < \breve{\theta}$.

Hence, for any $\frac{\beta_A}{\beta_L} < \breve{\theta}$, evaluating $\pi_2^*(\gamma)$ at both end points of $\breve{\gamma}_1$ and 1, and comparing $\pi_2^*(\breve{\gamma}_1)$ to $\pi_2^*(1)$. A straightforward calculation shows that $\pi_2^*(\breve{\gamma}_1) > \pi_2^*(1)$ for any

$$\frac{\beta_A}{\beta_L} < \frac{\theta}{2}. \qquad \text{(A.10)}$$

Using Equations (A.9) and (A.10), it is easy to verify that $\frac{\theta}{2} < \frac{\theta}{\breve{\gamma}_1}$ for any $\theta \in (\breve{\theta}, \hat{\theta})$. This implies that the SPE outcome of the γ, denoted by γ^*, chosen by firm 2 is $\breve{\gamma}_1$ for any $\theta \in (\breve{\theta}, \hat{\theta})$. Hence, I have established the results of Proposition 3(b). This completes the proof to Proposition 3.

REFERENCES

Alonso-Villar, O. 2005. The Effects of Transport Costs Revisited. *Journal of Economic Geography* 5: 589–604.

Amiti, M. 2005. Location of Vertically Linked Industries: Agglomeration Versus Comparative Advantage. *European Economic Review* 49: 809–832.

Anderson, J.E., and E. van Wincoop. 2004. Trade costs. *Journal of Economic Literature* XLII: 691–751.

Besanko, D. and M.K. Perry. 1993. Equilibrium Incentives for Exclusive Dealing in a Differentiated Products Oligopoly. *Rand Journal of Economics* 24: 646–667.

Bougheas, S., P. Demetriades, and E. Morgenroth. 1999. Infrastructure, Transport Costs and Trade. *Journal of International Economics* 47: 169–189.

Brooks, D.H., and D. Hummels, eds. (Forthcoming 2009). *Infrastructure's Role in Lowering Asia's Trade Costs: Building for Trade*. Cheltenham, United Kingdom and Northampton, Massachusetts: Edward Elgar Publishing.

Chin, J. C., and G.M. Grossman. 1988. Intellectual Property Rights and North–South Trade. NBER Working Paper Series No. 2769. Cambridge, Massachusetts: National Bureau of Economic Research, November.

Creskoff, S. 2008. Trade Facilitation: An Often Overlooked Engine of Trade Expansion. *Global Trade and Customs Journal* 3: 2.

D'Aspremont C., and A. Jacquemin. 1988. Cooperative and Noncooperative R&D in Duopoly with Spillovers. *American Economic Review* 78: 1133–1137.

Fay, M., and T. Yepes. 2003. Investing in Infrastructure: What is needed from 2000 to 2010. World Bank Policy Research Working Paper No. 3102. Washington DC: World Bank

Feenstra, R. 1998. Integration of Trade and Disintegration of Production in the Global Economy. *Journal of Economic Perspectives* Fall: 31–50.

Francois, J.F., and M. Manchin. 2007. Institutions, Infrastructure and Trade. Centro Studi Luca d'Agliano Development Studies Working Paper No. 224. Available: http://ssrn.com/abstract=964209.

Fujita, M., P. Krugman, and A. Venables. 1999. *The Spatial Economy: Cities, Regions and International Trade*. Cambridge, Massachusetts: MIT Press.

Gramlich, E. 1994 Infrastructure Investment: A Review Essay. *Journal of Economic Literature* 32: 1176–1196.

Gulyani, S. 2001. Effects of Poor Transportation on Lean Production and Industrial Clustering: Evidence from the Indian Auto Industry. *World Development* 29: 1157–1177.

Hummels, D. 2001. Time as a Trade Barrier. GTAP Working Papers 1152, Center for Global Trade Analysis. Purdue University.

Hummels, D. (Forthcoming 2009) Trends in Asian Trade: Implications for Transport Infrastructure and Trade Costs. *In Infrastructure's Role in Lowering Asia's Trade Costs: Building for Trade*, edited by D.H. Brooks and D. Hummels. Cheltenham, United Kingdom and Northampton, Massachusetts: Edward Elgar Publishing.

Ikenson, D. 2008. While Doha Sleeps: Securing Economic Growth Through Trade Facilitation. Trade Policy Analysis No. 37. Cato Institute.

Jacoby, H. G. 2000. Access to Markets and the Benefits of Rural Roads. *The Economic Journal* 110: 713–737.

Kessides, C. 1993. The Contributions of Infrastructure to Economic Development: A Review of Experience and Policy Implications. World Bank Discussion Papers. Washington, DC: World Bank

Krugman, P. 1991. Increasing Returns and Economic Geography. *Journal of Political Economy* 99: 483–499.

Limao, N., and A.J. Venables. 2001. Infrastructure, Geographical Disadvantage, Transport Costs and Trade. *World Bank Economic Review* 15: 451–479.

Martinez-Zarzoso, I., and L. Marquez-Ramos. 2008. The Effects of Trade Facilitation on Sectoral Trade. *The B.E. Journal of Economic Analysis & Policy* 8: Article 42.

Miller, N. H., and A. I. Pazgal. 2001. The Equivalence of Price and Quantity Competition with Delegation. *Rand Journal of Economics* 32: 284–301.

Nadiri, M., and T. Mamuneas. 1994. The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of U.S. Manufacturing Industries. *The Review of Economics and Statistics* 76: 22–37.

Spencer, B. J., and J.A. Brander. 1983. International R&D Rivalry and Industrial Strategy. *Review of Economic Studies* 50: 707–722.

Strauss-Khan, V. 2005. Firm's Location Decision Across Asymmetric Countries and Employment Inequality. *European Economic Review* 49: 299–320.

Varian, H. R. 1992. *Microeconomic Analysis*, New York: W.W. Norton.

Venables, A. J. 1996. Equilibrium Locations of Vertically Linked Industries. *International Economic Review* 37: 341–359.

Vickers, J. 1987. Delegation and the Theory of the Firm. *The Economic Journal* 95: 138–147.