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INTERNATIONAL ASPECTS OF PUBLIC INFRASTRUCTURE INVESTMENT

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Abstract

Modelling infrastructure as an international public good in a two-country model of trade where each country's social planner behaves strategically, we show that the equilibrium levels of infrastructure are sub-optimal from a global perspective. Utilising an appropriate econometric framework and data from 14 countries over the period 1971-90, we find evidence that accords well with the main predictions of our theory. Thus, we are able to offer a plausible theoretical explanation why public capital may be under-supplied, as suggested by previous empirical literature.

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INTERNATIONAL ASPECTS OF PUBLIC INFRASTRUCTURE INVESTMENT

1. Introduction

A central question in the empirical literature on infrastructure has been whether existing stocks of public capital are sub-optimal. While the initial estimates of David Aschauer (1989a, 1989b, 1989c), which places the rate of return of public capital in the US at around 60% per annum, have been questioned by subsequent literature[1], the debate on whether there is under-investment in infrastructure is far from settled. Even though some investigators have found negligible, or even negative, effects of public capital on private productivity (e.g. Evans and Karras, 1994, Holtz-Eakin, 1994), others have found positive effects (e.g. Nadiri and Mamuneas, 1994, Lynde and Richmond, 1992 and 1993, Berndt and Hansson, 1992), which in some cases suggest that there may be an under-supply of public capital (e.g. Morrison and Schwartz, 1996, Demetriades and Mamuneas, 2000).

In this paper we provide a theoretical explanation why public infrastructure may be under-supplied by exploring the international aspects of investment in public infrastructure. Our starting point is the observation that a large component of public infrastructure investment is devoted to the extension and upgrading of transport and communications networks, which reduces transport costs and facilitates trade of goods both *within* and *across* national borders. Thus, any investment in infrastructure by the domestic economy is likely to benefit not only domestic but also foreign producers and consumers. For example, if Britain were to improve its road and rail network, this is likely to benefit French producers, as it would make it cheaper to get French goods to small towns throughout Britain. Similarly, infrastructure investments in France are likely to benefit British producers. This could hold for infrastructure investment in any country, as long as it has trade links with the rest of the world. Infrastructure, therefore, has characteristics of an international public good, which suggests that its provision may be subject to an international co-

[1] See Gramlich (1994) for an extensive review of the literature.

ordination problem.

While the link between transport costs and trade is commonplace in the trade literature[2], the idea that infrastructure might affect trade is a more recent one. The survey by Casas (1983) touches on it while Bougheas, Demetriades and Morgenroth (1999) provide a fuller analysis in a symmetric two-country model which examines the effects of infrastructure on specialisation and the volume of trade. The symmetric nature of their model, however, does not allow the authors to address co-ordination issues such as the question of how countries might share the cost of infrastructure provision, which gives rise to the possibility of under-investment. It is precisely these issues which are the focus of the current paper.

Our theoretical approach involves constructing a simple general equilibrium two country - two good model in which infrastructure investment influences domestic and international trade by reducing transport costs[3]. We assume that domestic transport costs are country specific, varying inversely with domestic infrastructure, while international transport costs are common, varying inversely with the sum of the two countries' infrastructure. For example, it is reasonable to argue that if Britain improves its motorway network, this is likely to reduce the cost of transporting goods between Britain and France as well as the cost of transporting goods within Britain. Improving British motorways is, however, unlikely to reduce the cost of transporting goods within France.

Our method of solving for the equilibrium of the model applies the concept of *voluntary-contribution* (see Laffont, 1988) for finding the infrastructure investments by the two social planners while the two goods are traded in competitive markets[4]. Specifically, we assume that the two social planners

[2] See for example the classic references by Samuelson (1954) and Mundell (1957).
[3] Clarida and Findlay (1994), and Chiu (1997) develop trade models with public investment without focusing specifically on transport infrastructure and transport costs. Bond (1997) constructs a partial equilibrium model of trade with transport costs and examines trade policy issues.
[4] Fisher and Mirman (1992), Datta (1997) and Mirman and Datta (1997) use the same approach to study dynamic externalities.

behave strategically, allocating their endowment between production and investment in infrastructure taking as given the policy of the other planner and recognising the effect of their decision on the equilibrium price mechanism. The competitive market mechanism subsequently determines the allocation of consumption between the two goods. We examine the efficiency of the equilibrium by comparing it to the case where the two social planners behave co-operatively. This solution corresponds to the outcome which would be proposed by a “global” social planner.

We subject our theoretical model to rigorous empirical testing to examine its empirical relevance. Specifically, we construct an econometric model which captures all the important elements of the theoretical model and estimate it by simultaneous methods using aggregate data. Our empirical results are consistent with the theory. Importantly, the international strategic nature of public infrastructure investment is clearly supported by the evidence, suggesting that our theoretical explanation of the possibility of under-investment is a plausible one.

The paper is organised as follows. Section 2 puts forward the theoretical model, provides the equilibrium and examines its efficiency aspects. Section 3 formulates the econometric model, describes the data used for estimation and presents the empirical results. Finally, section 4 summarises and concludes.

2. Theoretical Model and Predictions

There are two countries: the “home” country (H) and the “foreign” country (F); the latter can be thought of as representing the rest of the world. Each country produces only one good. H produces good h and F produces f. The agents of each country derive utility from consumption of both goods, hence there is trade. Each country is endowed with a capital good. Let z_H and z_F denote the endowment of H and F, respectively. Each unit of the capital good can produce one unit of the domestic good.

The endowments can also be used for the development of infrastructure which reduces transport costs which, in turn, influence domestic and international trade. Following Samuelson's "iceberg" model (see Samuelson, 1954), we assume that only a fraction of the goods shipped arrive at their final destination. Let g denote the fraction of exports consumed. We further assume that the consumption of domestically produced goods is also subject to transport costs[5]. Let g_H and g_F denote the corresponding fractions. Notice that while domestic transport costs are country specific, international transport costs are common. Transport costs are endogenous and depend on the quality of public infrastructure. Without continuous improvement through additional investment, the existing stock of public infrastructure, i.e. road networks, telecommunications etc. will deteriorate and consequently transport costs will be high. Let z_{HG} and z_{FG} denote the investment in infrastructure of H and F, respectively. Then, the transport cost technologies are given by:

(1) $g_H = g_H(z_{HG})$

(2) $g_F = g_F(z_{FG})$

(3) $g = g(z_{HG} + z_{FG})$

where $0 < g_H, g_F, g < 1$, $z_{HG} \leq z_H$, $z_{FG} \leq z_F$ and all the functions are strictly increasing and concave. Notice that any investment in infrastructure will affect both domestic and international transport costs. Furthermore, the two investments are perfect substitutes in the international technology. Perfect substitutability is only assumed for simplicity. As long as there is some substitutability the equilibrium level of infrastructure will, generally, be sub-optimal.

In this model there is a two-level decision making in each country. The allocation of the capital good between production and infrastructure

[5] Martin and Rogers (1995) in a model of industrial location also consider both types of transport costs.

investment is decided by a social planner. Afterwards, a competitive market decides the allocation of consumption between the two goods. We capture the trading process with a price taking, utility maximising, representative agent who takes the social planner's decision as given. Market clearing determines the equilibrium prices which depend on the decisions of both social planners. While agents behave competitively, the two social planners behave strategically. Each planner makes a decision, taking into account the equilibrium price mechanism, given the other social planner's decision.

Let c_{ij} $\left(i = H, F; j = h, f\right)$ denote the consumption of the representative agent in country i of good j. Preferences in each country are specified as follows:

(4) $U_i\left(c_{ih}, c_{if}\right) \equiv \theta_{ih} \log c_{ih} + \theta_{if} \log c_{if}\ , \qquad i = H, F$

With the above functional form we can get closed form solutions without imposing any further restrictions on the infrastructure technologies[6]. However, the analysis of Nash-Cournot equilibria in public goods games by Cornes and Sandler (1996) suggests that our results are robust to more general specifications. Our method of solution is as follows. The first step is to solve each representative agent's maximisation problem. Each agent takes prices, p_h and p_f, and his income, $y_i = z_i - z_{iG}$, as given. Notice that the income levels depend on the social planner's decision. The solution of these problems will express consumption allocations as a function of relative prices $\left(p \equiv p_f / p_h\right)$ and income. Using these solutions together with the two market clearing conditions we can express the relative price as a function of the two income levels. The next step is to substitute the above solutions in the preference functions and derive the indirect utility functions for each agent. Each social planner maximises the corresponding indirect utility function by choosing his country's investment in infrastructure and taking the other planner's decision as given. The solution of these problems will yield the two

[6] See also the discussion in the following section.

reaction functions which will determine the equilibrium investments in infrastructure by the two social planners.

The following program describes the utility maximisation problem of the representative agent of country H:

Max $q_{Hh} \log c_{Hh} + q_{Hf} \log c_{Hf}$,

subject to: $p_h \frac{c_{Hh}}{g_H} + p_f \frac{c_{Hf}}{g} = p_h y_H$

The solution is given by:

(5) $c_{Hh} = \frac{q_{Hh}}{q_{Hh} + q_{Hf}} g_H y_H$ and $c_{Hf} = \frac{q_{Hf}}{q_{Hh} + q_{Hf}} \frac{g}{p} y_H$

Because of the logarithmic specification the demand for each good is proportional to income (net of any infrastructure investment). The proportionality factor depends on how strong preferences are for the home good relative to the foreign good and on relative prices which depend on transport costs. The equilibrium allocations must also satisfy the corresponding solution for country *F* and the following feasibility constraints:

(6) $z_H - z_{HG} \geq \frac{c_{Hh}}{g_H} + \frac{c_{Fh}}{g}$

(7) $z_F - z_{FG} \geq \frac{c_{Ff}}{g_F} + \frac{c_{Hf}}{g}$

The left-hand side of each expression is equal to the production of the domestic good which is also equal to income. The right hand side shows the allocation of production between domestic consumption and exports. The equilibrium relative price (terms of trade) is given by:

$$(8) \quad p = \frac{c_{Fh} / g}{c_{Hf} / g} = \frac{\theta_{Hf}\left(\theta_{Ff} + \theta_{Fh}\right)}{\theta_{Fh}\left(\theta_{Hh} + \theta_{Hf}\right)} \frac{z_H - z_{HG}}{z_F - z_{FG}}$$

Because of the logarithmic preferences the amount that each country spends on each good is proportional to its income. In addition, because international transport costs are common, they do not enter directly into the equilibrium condition. However, transport costs, both domestic and international, affect indirectly the equilibrium price because they affect the allocations of the two social planners which determine the levels of income.

Using (5), (8), and the preferences of the representative agent of H, we can derive the corresponding indirect utility function. The social planner of H maximises this utility by choosing investment in infrastructure, z_{HG}, taking as given the investment of country F, z_{FG}:

$$V\left(z_{HG}; z_H, z_F, z_{FG}\right) \equiv Max \;\; \theta_{Hh} \log g_H\left(z_{HG}\right) + \theta_{Hh} \log\left(z_H - z_{HG}\right)$$
$$+ \theta_{Hf} \log g\left(z_{HG} + z_{FG}\right) + \theta_{Hf} \log\left(z_F - z_{FG}\right) + \text{constant}$$

The solution of the above problem yields the following reaction function:

$$(9) \quad \theta_{Hh} \frac{1}{z_H - z_{HG}} = \theta_{Hh} \frac{g'_H\left(z_{HG}\right)}{g_H\left(z_{HG}\right)} + \theta_{Hf} \frac{g'\left(z_{HG} + z_{FG}\right)}{g\left(z_{HG} + z_{FG}\right)}$$

where primes denote the first derivatives. By multiplying both sides of the above equality by z_{HG} we find that the optimal policy requires that the ratio of the investment in infrastructure to production should be higher the more responsive the transport cost functions are to the former. By totally differentiating (10) we can show that the reaction function has a negative slope with an absolute value less than one. In addition, a higher endowment entails higher domestic investment in infrastructure for any level of investment by the other country.

The social planner of F faces a similar optimisation problem which yields a corresponding reaction function. The following conditions hold at the unique Cournot-Nash equilibrium, found by the intersection of the two reaction functions.

(10) $\dfrac{dz_{iG}}{dz_i} > 0$ and $\dfrac{dz_{iG}}{dz_j} < 0$; $i, g = H, F \quad i \neq j$.

Investment in infrastructure in both countries is increasing in their own endowment but decreasing in the other country's endowment. It is useful to compare this aspect of the non-co-operative solution to the co-operative outcome.

In the co-operative case, we choose the investment levels in the two countries, (z_{HG}, z_{FG}), and the levels of consumption, $(c_{Hh}, c_{Hf}, c_{Ff}, c_{Fh})$, to maximise the sum of utilities subject to the two feasibility constraints. This solution is Pareto optimal and corresponds to the case where the utilities are equally weighted. Formally the optimization problem is the following:

Max $q_{Hh} \log c_{Hh} + q_{Hf} \log c_{Hf} + q_{Ff} \log c_{Ff} + q_{Fh} \log c_{Fh}$

subject to (6) and (7).

The solution of this problem yields the following two conditions:

(11) $\dfrac{q_{Hh} + q_{Fh}}{z_H - z_{HG}} = q_{Hh} \dfrac{g'_H(z_{HG})}{g_H(z_{HG})} + (q_{Hf} + q_{Fh}) \dfrac{g'(z_{HG} + z_{FG})}{g(z_{HG} + z_{FG})}$

(12) $$\frac{\theta_{Ff}+\theta_{Hf}}{z_F-z_{FG}}=\theta_{Ff}\,\frac{g'_F\left(z_{FG}\right)}{g_F\left(z_{FG}\right)}+\left(\theta_{Hf}+\theta_{Fh}\right)\frac{g'\left(z_{HG}+z_{FG}\right)}{g\left(z_{HG}+z_{FG}\right)}$$

Equations (11) and (12) jointly determine the co-operative solution for investment in infrastructure by the two countries. Next, we compare these solutions with the reaction function, (9). Without loss of generality, we impose the following restriction:

Assumption 1: $\theta_{Hh}+\theta_{Hf}=\theta_{Ff}+\theta_{Fh}=1$ (Monotonic Transformation).

Given the logarithmic specification and the above restriction θ_{ij} represents the fraction of its net income $\left(z_i-z_{iG}\right)$ that country i spends on the good produced by country j.

Since the solutions for the two countries are symmetric, we concentrate on (11) and (9), the solution for the home country. The difference is the term θ_{Fh} which appears in the numerator of the left-hand side and the numerator of the second term of the right-hand side of the co-operative solution. Let us examine these terms more closely.

The left-hand side captures the marginal cost of infrastructure investment. An increase in infrastructure investment by one unit reduces the amount available for consumption by one unit. The social planner of H takes into account that home consumption is only reduced by a fraction θ_{Hh}, while for the global optimum we need to take into account the corresponding reduction in the utility of the foreign country's representative agent. The term θ_{Fh} appears in the co-operative solution because it represents the fraction of its income that the foreign country spends on the home good. Therefore, the social planner of H underestimates the marginal cost of infrastructure investment, which leads to *over-investment*.

The second term of the right-hand side captures the marginal benefits of infrastructure investment from the reduction in the international transport cost function. While the social planner of H takes into account only the benefits for country H, the global social planner also considers the benefits for country F. This effect leads to *under-investment*.

Let $*$ denote the non-co-operative solutions. After subtracting (9) from (11), we arrive at the following result:

Proposition 1:

If $$\theta_{Fh}\left\{\frac{g'\left(z_{HG}^{*}+z_{FG}^{*}\right)}{g\left(z_{HG}^{*}+z_{FG}^{*}\right)}-\frac{1}{z_H-z_{HG}^{*}}\right\}>0$$

then there will be under-investment in infrastructure.

It is useful to examine the extent to which under-investment is likely using the above result. The first term in the parenthesis represents the difference between the marginal national benefits from the marginal global benefits of infrastructure investment. It captures the spill-out benefits of infrastructure investment and the stronger it is, the more likely that there will be under-investment. The second term captures the global cost of infrastructure investment and is probably overstated by the preference specification. Under logarithmic preferences the fraction of income that each country spends on each good is constant, as a result of which the terms of trade are equal to the ratio of incomes (for symmetric preferences)[7]. As one country increases its infrastructure investment, thus reducing its net income, it improves its terms of trade. While this reduces the amount of its own good available for trade, it does not affect the amount that it imports from abroad. This reflects the absence of price substitution, which is a peculiarity of the logarithmic utility function. The logarithmic specification was adopted because it allows for a closed-form solution. Under more plausible specifications, a change in the

[7] By symmetric preferences we mean that $\theta_{Hh}=\theta_{Ff}$ and $\theta_{Hf}=\theta_{Fh}$.

terms of trade will also induce a substitution effect which would weaken the strength of the second term[8].

3. Econometric Model and Results

In order to test the predictions of our theory we construct a simple econometric model that focuses on the long run effects of public investment. The model is specified in per capita terms, since the theoretical results are derived in the context of a representative agent model. Also, in order to move from a two-country model to the realities of a multi-country setting, we adopt the convention that the ‘foreign country’ represents all the trading partners of the domestic economy. ‘Foreign country’ income and infrastructure are then defined in a way that takes into account the influence of geographical factors and/or existing trade patterns.

Our specification allows us to test some of the main predictions of our model, for example that increases in foreign income reduce domestic infrastructure investment, which is the result of the strategic interaction between international policy-makers. The model is specified in log-linear form and consists of two equations, which respectively determine per capita infrastructure investment and transport costs for each country.

The infrastructure equation relates the logarithm of per capita infrastructure investment of country i (zg_i) to the following variables:

(i) country i’s endowment, which we measure by the logarithm of its real per capita GDP (y_i),

(ii) the cost of investment (CI_i), which we proxy with the long term interest rate and

(iii) the logarithm of the sum of real per capita GDP’s of country i ’s trading partners.

[8] In a recent paper, Bond (1997), develops a partial equilibrium model which effectively eliminates the effect of infrastructure investments on the output of the two goods. Under the same conditions, our model clearly suggests that there will be under-investment in infrastructure.

As a proxy for infrastructure investment we use public investment in constant 1985 US dollars.

The income of a trading partner that is far away from the home country, or with which it trades relatively little, is likely to have a smaller effect on the home country's investment decisions than that of a partner that is close, or with which it trades more intensively. In order to take into account these multi-country factors, we construct distance and trade adjusted measures of 'foreign income', defined as the logarithm of the weighted sum of foreign incomes, with appropriately defined weights. For the distance adjusted measure (dpy_j) each foreign country's real per capita GDP is scaled by the corresponding distance from the home country. For the trade adjusted measure ($dpty_j$), each foreign country's real per capita GDP is additionally scaled using a corresponding trade weight[9].

Thus, we estimate two infrastructure investment equations, which are defined as follows:

(13) $$zg_i = \alpha_z + \beta_{11} y_i + \beta_{12} dpy_j + \beta_{13} CI_i + \varepsilon_Z$$

(14) $$zg_i = \alpha_z + \beta_{11} y_i + \beta_{12} dpty_j + \beta_{13} CI_i + \varepsilon_Z$$

The transport-costs equation is derived from the transport cost technology utilised in our theoretical model, which suggests an inverse relationship between (i) domestic transport costs and domestic infrastructure and (ii) international transport costs and the sum of domestic and foreign infrastructure. Since it is difficult to obtain internationally comparable data on *domestic* transport costs, we restrict our analysis to modelling the effects of *international* transport costs. Thus, our transport costs equation specifies that the logarithm of average transport costs for imports into country i (tc_i) be (inversely) related to both the logarithm of domestic per capita infrastructure investment (zg_i) and the logarithm of the sum of all foreign per capita

[9] Details of variable construction and data sources can be found in the appendix.

infrastructure investment. As with the definition of 'foreign income' in the infrastructure investment equation, we take into account the influence of geographical factors and trade patterns in the definition of the sum of foreign infrastructure. Specifically, we define a foreign infrastructure variable which scales each of the foreign countries' infrastructure investments using distance ($dpzg_j$) and another one which scales it with both distance and a trade weight ($dptzg_j$). Additionally, we allow transport costs to be influenced independently by the remoteness of country i from its trading partners (R_i). This variable is expected to have a positive effect. However, as the influence of remoteness may to a large extent be indirectly captured by the definition of relevant foreign infrastructure, its direct influence may not be large.

We thus obtain the following two transport-costs equations:

(15) $tc_i = \alpha_T + \beta_{24} zg_i + \beta_{25} dpzg_j + \beta_{26} R_i + \varepsilon_T$

(16) $tc_i = \alpha_T + \beta_{24} zg_i + \beta_{25} dptzg_j + \beta_{26} R_i + \varepsilon_T$

Transport costs are measured by the freight factor published by the IMF[10]. This variable is constructed by dividing total c.i.f. imports by total f.o.b., and is therefore a measure of average total transport costs for all imports into a country. The freight factor in 1990 for the sample of countries used here ranged from 2% for Sweden to 9% for Japan, which seem plausible.

Overall we attach particular importance on β_{12} in equations 13 and 14, which we expect to be negative, reflecting the strategic nature of domestic infrastructure investment decisions. Similarly β_{25} must be negative if foreign infrastructure exhibits spillovers, as is assumed in our theoretical model.

Our data set consists of annual observations for the period 1971 to 1990 covering 14 countries, namely Australia, Belgium/Luxembourg, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway,

[10] A similar variable was constructed by Harrigan (1993).

Sweden, the United Kingdom and the USA. The choice of countries was determined by the availability of infrastructure data. In order to capture the long run effects of public investment and to eliminate cyclical effects, we average our data over four non-overlapping periods, 1971-74, 1975-79, 1980-84, 1985-90. Given that we are using the sum of foreign incomes and average transport costs for each country we have 14 observations per period for each equation. In order to obtain a reasonable sample size for estimation all the observations are pooled yielding a sample of 56 observations.

In order to obtain benchmark results against which the results of our full model can be judged, we estimate the infrastructure investment equation excluding the sum of the foreign incomes using ordinary least squares estimation (OLS)[11]. The results from this estimation, which are shown in table 1, confirm that the income of the home country has a significant positive effect on infrastructure investment while the long run interest rate has a negative effect.

Turning to the estimation of the fully specified equations, presented in columns 2 and 3 of the same table, we observe that all the coefficients have the predicted signs and, except for the long-run interest rate, are statistically significant. Furthermore, the inclusion of the foreign infrastructure variables adds significantly to the explanatory power of the model. Notably the results confirm that domestic infrastructure investment is increasing in domestic real GDP and decreasing in foreign income, irrespective of the definition of the latter. Thus, one of the central predictions of the theoretical model appears to be strongly supported by the data.

The OLS estimates presented in Table 1 implicitly assume that domestic income is exogenous. To examine the robustness of our results to this assumption, we also estimate the infrastructure equations using instrumental variable (IV) estimation, where domestic income is instrumented by the lag of

[11] Given the heterogeneity of the sample of countries, the residuals from the estimation suffer from heteroskedasticity. We therefore apply the method proposed by White (1980), in order to correct this problem. Consequently, the standard errors reported are heteroskedasticity consistent. All estimations were carried out using TSP version 4.4.

domestic income. The results from the IV estimation are set out in table 2. The coefficients and t-statistics are very similar to those found using ordinary least squares and one can therefore conclude that endogeneity is not a problem. Thus, the result that infrastructure investment is negatively related to the sum of all trading partners' incomes is found to be robust.

For the transport cost equation, as with the infrastructure investment equations we first estimate a benchmark model where transport costs depend only on remoteness. The results are presented in table 3. As expected, remoteness significantly increases transport costs. Estimation of the fully specified equation improves the fit of the model significantly and confirms that both domestic infrastructure investment and the sum of foreign infrastructure investment reduce transport costs. However the coefficient for remoteness, has changed sign and is no longer significant. This might be due to collinearity with the foreign infrastructure variables, which were scaled by distance. We therefore estimate the two transport cost equations again, now omitting remoteness. The results indicate that there is indeed a collinearity problem since the t-statistics associated with the coefficients for the foreign infrastructure variables increase significantly. However the overall result that spillovers exist still holds.

Domestic infrastructure investment may itself be endogenous in the transport-costs equations. We address this through instrumental variable estimation, using the explanatory variables from the infrastructure equations as instruments. The results are presented in table 4. The coefficients of the infrastructure variables remain negative. However the coefficient of domestic infrastructure becomes statistically insignificant at conventional significance levels. While these findings seem to suggest that foreign infrastructure is more important in determining international transport costs, this is at best only a very tentative conclusion since the instruments can only explain around 20% of the variation in domestic infrastructure.

Overall our empirical results endorse our theoretical priors that infrastructure investment in any economy has an important international dimension.

Specifically, we find evidence which indicates that infrastructure investment is a strategic decision that can not be examined in isolation of the investment decisions of a country's trading partners. Our findings also suggest that this strategic behaviour arises from the spillovers across national boundaries created by infrastructure investments, which are an important determinant of international transport costs[12].

4. Conclusion

In a recent related paper Bougheas, Demetriades and Morgenroth (1999) examine the effect of infrastructure on specialisation and the volume of trade within a Ricardian framework. While explicitly considering the resource cost of infrastructure and modelling its influence on transport costs, the symmetric structure of that model restricts both the theoretical and the empirical analysis to countries with similar endowments. The important question of how countries would share the cost of providing international transport services is, therefore, not addressed. Thus, the current paper takes the argument several steps further. Most importantly, it addresses the question of whether the equilibrium level of infrastructure would be optimal. The answer to this question not only has significant implications for international policy co-ordination but also fills an important gap in the existing literature on infrastructure which has not, so far, provided theoretical models to explain why public infrastructure may be supplied at sub-optimal levels. Furthermore, the generalised nature of the model, particularly the relaxation of symmetry, provides better scope for empirical testing.

Our results have important policy implications, particularly for trading blocks such as the European Union. According to our model, such blocks are likely to be better off by addressing the co-ordination problem associated with the provision of trade-promoting public infrastructure. While the European Structural Funds are aimed at economic growth and recovery of regions which are underdeveloped by comparison with the Community average, they are not

[12] An independent recent study of international transport costs by Limão and Venables (1999) confirms the importance of infrastructure spillovers across countries, using several different data sets.

specifically designed to address co-ordination failures of this type[13]. Yet they are particularly well suited for this purpose since optimal provision of public capital is also likely to raise the rate of return of public capital, thereby increasing economic growth[14]. Given that the current regulations for the Funds are about to expire in 1999, future reforms, which are under way, offer the opportunity to explicitly take into account market failures[15].

The need to centralise public infrastructure provision is, in fact, widely recognised within federal systems. For example, highway construction and maintenance in Germany is the responsibility of the federal authorities. Similarly, in the US, while this is carried out by the state authorities that are legally the owners of highways, it is mostly funded by the federal government[16]. The view that whenever public goods or services have spill-out effects or externalities beyond the jurisdictions that supply them may result in under-provision is, of course, well founded in the literature on fiscal federalism and has its roots in Pigou's externality theorem (Oates, 1991; Quigley, 1997). If we re-interpret our model as representing two trading federal states in a closed economy context, our under-provision result would become consistent with the predictions of this literature. The novelty of our paper remains, however, that we have shown, both theoretically and empirically, that under-provision of public infrastructure could also be the result of international co-ordination failures in an international trade framework. The policy relevance of our result cannot, therefore, be over-emphasised. While federal states customarily address spill-outs or externalities across their jurisdictions, either through a system of inter-governmental transfers or by centralising decisions regarding public goods, this is clearly very rarely the case for independent nations that trade with each other.

[13] This is Objective 1 of the Structural Funds. Other objectives are aimed at the creation of employment and re-structuring of labour markets.
[14] Goybet and Bertoldi (1994) argue along similar lines. The theoretical relationship between infrastructure and economic growth is explored in Bougheas, Demetriades and Mamuneas (2000).
[15] See Begg (1998) for an up to date account of the reform of the European Structural Funds and the related Agenda 2000 proposals.
[16] We are grateful to an anonymous referee for this clarification.

Table 1. OLS Results of Infrastructure Investment

Dependent variable zg_i			
	(1)	*(2)*	*(3)*
Constant	*1.03*	*1.52*	*0.1*
	(0.39)	*(0.6)*	*(0.004)*
y_i	*0.76*	*0.56*	0.68
	(2.67)	*(2.03)*	(2.44)
dpy_j		-0.17	
		(4.28)	
$dpty_j$			-0.14
			(5.24)
CI_i	-0.06	-0.05	-0.05
	(2.02)	(1.73)	(1.86)
Adj. R^2	0.10	0.21	0.20
S.E. of regression	0.44	0.41	0.41
F-test (0 slopes)	4.12	5.92	5.65
No. of observations	56	56	56

t-statistics derived from heteroskedasticity robust standard errors in parenthesis. In the case of all F-tests the H_0 hypothesis of zero slopes is rejected. zg_i denotes infrastructure investment in the home country, y_i denotes home income, dpy_j and $dpty_j$ are weighted measures of the sum of foreign income and CI_i denotes the long run interest rate.

Table 2. IV Results of Infrastructure Investment (instrumenting yi)

Dependent variable zg_i			
	(4)	*(5)*	*(6)*
Constant	*-0.54*	*1.95*	*0.40*
	(0.24)	*(0.94)*	*(0.19)*
y_i	*0.71*	*0.51*	0.64
	(2.94)	*(2.27)*	(2.79)
dpy_j		-0.17	
		(4.52)	
$dpty_j$			-0.14
			(5.53)
CI_i	-0.06	-0.05	0.06
	(2.09)	(1.80)	(1.94)
Instruments	ly_i	ly_i	ly_i
Adj. R^2	0.10	0.21	0.20
S.E of regression	0.44	0.41	0.41
F- test (0 slopes)	3.66	5.72	5.39
No. of observations	56	56	56

t-statistics derived from heteroskedasticity robust standard errors in parenthesis. In the case of all F-tests the H_0 hypothesis of zero slopes is rejected. ly_i is the lag of y_i. zg_i denotes infrastructure investment in the home country, y_i denotes home income, dpy_j and $dpty_j$ are weighted measures of the sum of foreign income and CI_i denotes the long run interest rate.

Table 3. OLS Results Transport Cost equation

Dependent variable tc_i					
	(7)	*(8)*	*(9)*	*(10)*	*(11)*
Constant	*-6.63*	*-2.28*	*-0.56*	*-1.69*	*-2.21*
	(7.15)	*(0.62)*	*(0.33)*	*(2.92)*	*(4.82)*
R_i	*0.42*	-0.43	-0.21		
	(3.8)	(1.06)	(0.96)		
zg_i		-0.20	-0.18	-0.19	-0.20
		(2.12)	(2.22)	(2.0)	(2.54)
$dpzg_j$		-0.48		-0.27	
		(2.40)		(4.46)	
$dptzg_j$			-0.37		-0.29
			(3.83)		(6.62)
Adj. R^2	0.17	0.23	0.36	0.23	0.36
S.E of regression	0.41	0.40	0.36	0.40	0.36
F- test (0 slopes)	12.99	6.66	11.43	9.50	16.59
No. of observations	56	56	56	56	66

t-statistics derived from heteroskedasticity robust standard errors in parenthesis. In the case of all F-tests the H_0 hypothesis of zero slopes is rejected. tc_i denotes our measure of transport cost, R_i denotes remoteness of the home country, zg_i denotes home country infrastructure investment , $dpzg_j$ and $dptzg_j$ are weighted measures of foreign infrastructure investment.

Table 4. IV Results Transport Cost equation (instrumenting *zgi*)

Dependent variable				
	(12)	*(13)*	*(14)*	*(15)*
Constant	*5.71*	*0.41*	*1.32*	*-0.38*
	(1.13)	*(0.23)*	*(0.57)*	*(0.25)*
R_i	-0.57	-0.15		
	(1.26)	(0.65)		
zg_i	-0.58	-0.45	-0.7	-0.53
	(1.78)	(1.52)	(1.79)	(1.91)
$dpzg_j$	-0.62		-0.37	
	(2.41)		(3.66)	
$dptzg_j$		-0.39		-0.34
		(4.01)		(5.04)
Instruments	y_i, dpy_j, CI_i	y_i, $dpty_j$, CI_i	y_i, dpy_j, CI_i	y_i, $dpty_j$, CI_i
Adj. R^2	0.17	0.31	0.15	0.30
S.E of regression	0.43	0.38	0.45	0.39
F- test (0 slopes)	5.66	10.13	7.61	14.23
No. of observations	56	56	56	56

t-statistics derived from heteroskedasticity robust standard errors in parenthesis. In the case of all F-tests the H_0 hypothesis of zero slopes is rejected. tc_i denotes our measure of transport cost, R_i denotes remoteness of the home country, zg_i denotes home country infrastructure investment , $dpzg_j$ and $dptzg_j$ are weighted measures of foreign infrastructure investment.

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Appendix: Data Description and Sources

(POP_i, POP_j) Population of the home country and foreign country j was taken from *Penn World Tables (Mark 6)*.

(ZG_i, ZG_j) Infrastructure investment at home and in foreign country j in constant 1985 US dollars is measured by public investment which was obtained from the *OECD Sectoral Database*.

(Y_i, Y_j) GDP in the home country and in foreign country j in constant 1985 US dollars was taken from *Penn World Tables (Mark 6)*.

(tc_i) Transport Costs were constructed using the CIF/FOB factor from *IMF International Financial Statistics Yearbooks* minus one, which expresses the transport costs as a percentage of the value of the goods traded.

tc_i *= (CIF/FOB)-1*

(D_{ij}) Distance, as measured by the great circle distance between major cities, was obtained from Jon Haveman's international trade data, which can be downloaded from the Purdue University Internet site:

http://intrepid.mgmt.purdue.edu/Jon/Data/TradeData.html#Gravity.

(R_i) Remoteness is defined as:

$$R_i = \frac{1}{n}\sum D_{ij}$$

where n is the number of trading partners and D_{ij} is the distance between country i and trading partner j. Wei (1996) constructs a similar variable.

(TW_{ij}) Trade weight is the share of the home country's trade with the foreign country (where trade is total imports from all 13 trading partners) and was derived using trade data from the *IMF Directions of Trade Database*.

(CI_i) Cost of investment is proxied by the long-run real interest rate which was constructed by subtracting the change in the public investment deflator, which is taken from the *OECD Sectoral Database*, from the long run government bond yield which was taken from the *IMF International Financial Statistics (IFS)* data base. For Japan the public investment deflator was not available and instead we use the GDP deflator. The government bond yields for the various countries are not available for the same length of maturity of the bond. However, the shortest length of maturity is ten years.

(dpy_j) Sum of foreign per capita GDP scaled by distance.

$$dpy_j = \sum\left(\frac{Y_j}{POP_j}\right)/D_{ij}$$

($dpty_j$) Sum of trade weighted foreign per capita GDP scaled by distance

$$dpty_j = \sum \left(\frac{TW_{ij} * Y_j}{POP_j} \right) / D_{ij}$$

($dpzg_j$) Sum of foreign per capita public investment scaled by distance

$$dpzg_j = \sum \left(\frac{ZG_j}{POP_j} \right) / D_{ij}$$

($dptz_j$) Sum of foreign trade weighted public investment scaled by distance

$$dptz_j = \sum \left(\frac{TW_{ij} * ZG_j}{POP_j} \right) / D_{ij}$$

Appendix (not intended for publication)

For simplicity we set $q_{ij} = 1$ for $i = H, F$; $j = h, f$.

The slope of the reaction function.

Let $A \equiv \dfrac{1}{\left(z_H - z_{HG}\right)^2} > 0$

$$B \equiv \frac{1}{\left(z_F - z_{FG}\right)^2} > 0$$

$$C \equiv \frac{g_H'' g_H - \left(g_F'\right)^2}{\left(g_F\right)^2} < 0$$

$$D \equiv \frac{g_F'' g_F - \left(g_F'\right)^2}{\left(g_F\right)^2} < 0$$

$$E \equiv \frac{g'' g - \left(g_F'\right)^2}{\left(g\right)^2} < 0$$

By totally differentiating (9), the home country's reaction function, we get:

$$-Adz_H + Adz_{HG} = Cdz_{HG} + Edz_{HG} + Edz_{FG}$$

The slope is given by:

$$\frac{¶ \, z_{HG}}{¶ \, z_{FG}} = \frac{-E}{C + E - A} \quad \text{and} \quad 0 < \left| \frac{E}{C + E - A} \right| < 1$$

Derivation of the co-operative solution

Let l_1 and l_2 denote the Lagrangean multipliers which correspond to the constraints (7) and (8), respectively. Then the first order conditions of this optimization problem are:

(A1) $\frac{q_{Hh}}{c_{Hh}} = \frac{l_1}{g_H}$

(A2) $\frac{q_{Hf}}{c_{Hf}} = \frac{l_2}{g}$

(A3) $\frac{q_{Ff}}{c_{Ff}} = \frac{l_2}{g_F}$

(A4) $\frac{q_{Fh}}{c_{Fh}} = \frac{l_1}{g}$

(A5) $-l_1 + l_1 c_{Hh} \frac{g'_H}{g_H^2} + l_1 c_{Fh} \frac{g'}{g^2} + l_2 c_{Hf} \frac{g'}{g^2} = 0$

(A6) $-l_2 + l_2 c_{Ff} \frac{g'_F}{g_F^2} + l_2 c_{Hf} \frac{g'}{g^2} + l_1 c_{Fh} \frac{g'}{g^2} = 0$

Using (6), (A1) and (A4), we get:

(A7) $c_{Hh} = \frac{q_{Hh}}{q_{Hh} + q_{Fh}} g_H \left(z_H - z_{HG}\right)$ and $c_{Fh} = \frac{q_{Fh}}{q_{Hh} + q_{Fh}} g\left(z_H - z_{HG}\right)$

Using (7), (A2), and (A3), we get:

(A8) $c_{Ff} = \frac{q_{Ff}}{q_{Ff} + q_{Hf}} g_F \left(z_F - z_{FG}\right)$ and $c_{Hf} = \frac{q_{Hf}}{q_{Ff} + q_{Hf}} g\left(z_F - z_{FG}\right)$

From (A2) and (A4), we get:

(A9) $\frac{l_2}{l_1} = \frac{q_{Hf}}{q_{Fh}} \frac{c_{Fh}}{c_{Hf}}$

Substituting (A7) and (A9) in A(5) yields equation (11). Equation (12) is obtained from A(8), A(9) and A(6).