Endogenous Transport Investment, Geography, and Growth Take-Offs

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Abstract

A substantial part of the economic growth literature suggests that historically, geographic features such as decreasing trade costs have not only enhanced output, but may also be associated with rapid urbanization and 'growth take-offs'. However, this literature lacks an analytical motivation for lower transport costs, and assumes their decrease to obtain exogenously and at no cost: It thus does not explain why and when such a growth take-off may occur.

This paper addresses the issue by investigating how endogenous investment in transport infrastructure may affect growth. For that purpose, it integrates transport investment in the problem of the typical manufacturing firm in a two-region geography model.

The results imply that the relation between geography and growth depends crucially on the dispersion of economic activity: Countries with low 'economic density' may abstain from transport investment, and remain in isolation. For intermediate economic density, regions will invest to improve trade costs, but lose out on growth in order to sustain their transport capital. Finally, high density will incite more endogenous construction of transport infrastructure and ultimately incite firms to agglomerate

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geographically, thus boosting growth due to localized knowledge spillovers.

1 Introduction

1.1 Motivation

The onset of industrialization has intrigued economic research for decades, summarized in the question: Why was it 18th-century Britain to start the 'innovation machine' called the industrial revolution (Baumol, 2002)? And why did some countries manage to mirror this 'growth miracle' while others achieved it only much later, or failed? More generally, why, how and when do sudden take-offs in economic growth occur, and why not?

Generic innovations, such as the steam engine, are of course most frequently held responsible for initializing the transition to modern economic growth. But although the technology was soon widely available, many parts of Europe did not repeat the British miracle for at least a century. Institutional features and internal peace certainly played an important role, but these features were also present in other Northern European countries. Most of the explanations for the British 'miracle' and the following take-offs focus on low trade costs and the centralization of production, reaping economies of scale and consequently leading to a rapid increase in manufacturing production and urbanization.

The role of market integration, trade and transport thus has received considerable attention by the younger economic literature. 'International' growth theory, emanating from Grossman and Helpman (1990), investigates the role trade barriers play for growth due to localized spillovers. The 'big push' literature stresses the role of foresighted development of transport links (Murphy et al., 1989). The regional development literature as such has studied the impact of transport infrastructure on welfare and growth (Nijkamp and Poot, 1998), albeit mostly abstaining from analytical models. Finally, the New Economic Geography (NEG) literature has studied the reasons for agglomeration (Krugman, 1991), and advanced to its impact on welfare and growth (cf. Fujita et al., 1999, Martin and Ottaviano, 2001, etc.). The particular contribution of the latter strand is that it explains how a marginal decrease of trade costs can trigger sudden 'catastrophic agglomeration' and, through knowledge externalities, a thorough change in economic productivity.

Though the impact of trade and transport on growth is thus acknowledged, nearly all papers dealing with the matter conceive it as an exogenous force: First they establish an effect of trade costs on growth, then they decrease these trade costs exogenously and examine the welfare and growth effects. A prominent NEG example is found in Baldwin et al. (2001) who motivate why decreasing trade costs fostered a European growth take-off in the 1700s, while India and China stagnated. They achieve this effect by exogenously improving the freeness of trade, and spend an entire section on reasoning why the fall of trade costs since the 1700s was exogenous to the world economy. However, the model does not explain why trade freeness should suddenly improve at a particular point in time, and moreover Baldwin et al.'s economy also does not need to allocate resources to it. Most papers on geography and welfare follow this line: trade costs are lowered exogenously, and nobody has to pay for it.

While decreasing trade costs for free may apply to the case where a policy maker may arbitrarily lower tariffs, it is hard to believe that over the course of history trade was mainly determined by tariffs. It may be argued that the historical reductions of tariffs were rather caused by the fact that more centralized governments found other, less distorting sources of revenue (Tarschys, 1988). A substantial part of the empirical literature on the matter corroborates that individual country tariffs were and are poorly related with long-term economic growth (Rodriguez and Rodrik, 1999; O'Rourke, 2000). In contrast, there is a clear relationship between physical transport links and economic development. Assessing both concepts, Keller and Shiue (2008) find that in the industrialization of 19th-century Germany, tariffs played a minor role compared to the rapid expansion of railways.

Not tariffs, but (costly) physical transport links thus appear to play a crucial role in interconnection with growth take-offs and urbanization. So far, the bulk of NEG and other theoretical models of trade and growth have assumed changes in trade costs to obtain exogenously. It is, however, hard to imagine improvements in transport infrastructure as exogenous and causal to growth in the long run. Rather it seems plausible that only advances in economic development allowed to pay for ever faster ships, better roads and port facilities and subsequently railways, tunnels, or air links. In this vein, Bose et al. (2005) empirically repudiate any causality of transport infrastructure on growth.

However, surprisingly few articles have so far a theoretical framework where the economy actually has to pay for removing its trade obstacles, i.e. endogenizing trade infrastructure in the economy: Bougheas et al. (1999) integrate a static Ricardian model, in which a social planner constructs a 'road' between two countries only if benefits exceed cost, i.e. the gains from increased trade are large enough. Murphy et al. (1989) pioneered multiple equilibria in growth economics and suggest that a centrally coordinated 'big push' into infrastructure may render long-term growth sustainable. Takahashi (2006) integrates a similar notion into an NEG model: his economy may switch from a 'traditional' to a 'modern' technology if the resulting traffic redeems investment cost. Under certain conditions, such a switch may trigger 'catastrophic agglomeration'. All these contributions rely on a central transport technology with economies of scale to traffic that comes at a discrete investment cost. Consequently, they necessitate central organization or a coordination of resources to achieve investment in transport infrastructure. The model by Kelly (1997) differs in that it decentralizes infrastructure investment and models private incentives such that regions find it worthwhile to construct binary links to their neighbours (i.e. moving from complete isolation to perfect trade freeness). In a dynamic setting, this spatial integration induces a temporary boost in economic growth.

Kelly's setup is of particular interest in view of historical conditions. In 18th-century Britain, some great infrastructure projects are notable, but most advances in fixed transport capital were due to initiatives by local authorities and merchants in order to improve water navigation and turnpike roads. The trade of goods was organized by independent shippers, in more or less open competition. Arguably, most investment in transport facilities was privately motivated and paid for, and conceivably most of these investments seems to have focused vehicles and the establishment of regular trade links. Note that even today, most investment in transport capital originates is private and decentralized. For instance, BTS (2004, p.17) asserts that fixed infrastructure makes up for less than 20% of modern US transport investment, whose major part goes into rolling stock. But private and profit incentives are also mainly responsible for the great infrastructure projects in 19th-century Europe: Up to the end of the century, most rail lines and many canals were built by private entrepreneurs. Governmental infrastructure projects seem to have been largely for military reasons and is found to have been much less instrumental in fostering growth than their private counterparts (Keller and Shiue, 2008).

In response, this paper aims to provide an integrated model of growth take-offs with agglomeration and endogenous transport infrastructure based on private transport investment. Under above-mentioned considerations, the transport technology presented will exhibit constant returns to scale statically, i.e. it dispenses of any incentives for firms/shippers to pool their resources. Instead, the following chapters will rely on the notion of 'fleet investment', whereby goods are shipped by monopolistic firms who invest to improve the efficiency of their individual transport capital stock. This notion may be interpreted as dynamic upgrading in the ships, barges and carriages that used to transport goods in the 18th century.

1.2 Paper Outline

In view of the discussion above, I propose a model that tries to combine the following three features:

- Endogenous investment in transport infrastructure that comes at a cost
- Benefits from economic integration that depend on trade costs and are static per se
- Agglomeration (fostered by economic integration) that enhances growth due to localized spillovers

For the latter two features, various NEG models exist that display endogenous growth and agglomeration benefits. In this study, I will heavily rely on Baldwin et al. (2001) – respectively their reformulation in Baldwin et al. (2003, chap.7) – who elegantly outline these two effects.

The first feature, endogenizing transport infrastructure, is hard to borrow from literature: In principle, one has the choice between global and local infrastructure investment. Here, 'global' means that one agent, be it the government, a monopolist or a social planner, chooses the resources she devotes to trade infrastructure in order to optimize welfare, toll, or taxes. While being perfectly applicable in many real-world situations, this notion has two unattractive features: First, from a global perspective, trade infrastructure decisions may hardly be perceived as being completely centralized in a single entity. Although governments play an important role in the transport sector, there is always a viewpoint that reduces their investment choice to local rather than global considerations. Second, when advancing beyond the two-region case, 'global' transport capital does not offer any additional insights on how a particular geography may affect development: The 'global' agent will attempt to equalize the shadow prices of trade barriers, and nothing more.

'Local' trade capital, in contrast, does not suffer from the mentioned downsides. First, it resembles more closely the localized and selfish infrastructure decisions that one may identify as being more relevant to historic economic growth. Second, it promises more interesting behaviour in an environment with richer spatial structure, i.e. in a model generalized to $N > 2$ regions. Localizing endogenous transport investment may fall prone to various difficulties, however. For instance, one could imagine local monopolies that hold concessions for certain trade links and demand toll for improving infrastructure. In the case of $N > 2$ regions, however, this approach immediately runs into the problem that these monopolists may play strategic games against each other. While such games represent a fascinating topic in itself, such an approach would too far exceed the scope and purpose of this paper. The interested reader may be referred to the 'code-sharing' literature, which analyzes similar problems in the context of airline alliances (compare, for instance, Brueckner, 2001).

For this study, I chose another approach instead: Instead of modelling a transport sector that has the incentive to build up capital, I do shift transport expenditure to the monopolistically competitive manufacturing firms in the Baldwin et al. (2001) model. Each of those firms acts like a monopolist, and due to their atomistic size, neither of them has any incentive to deviate from monopoly pricing. In order to introduce infrastructure, imagine that each manufacturing firm ships its exports to other regions via its own fleet of vehicles. Now, the firm may invest in constructing intangible capital to improve its fleet's characteristics and thus lower the marginal cost for transporting goods. Equivalently, this notion may be thought of as the effort a firm has to spend on 'opening up' an export market - which is in a sense similar to the entrance cost on export markets introduced by Melitz (2003). In this manner, investment in transport capital – which I will label as 'fleet investment' henceforth – stays clear of strategic interference.

Consequently, the remainder of this paper is structured around integrating fleet investment in the Baldwin et al. (2001) model: In section 2, the model assumptions of Baldwin et al. (2001) will be reiterated, then fleet investment will be introduced into the programme of the manufacturing firm and, finally, the model will be solved for its short-run equilibrium. Section 3 solves for the long-run equilibrium and firm location, and section 4 analyzes the effects on welfare and growth. Finally, section 5 will conclude the paper.

2 The Model

As has been outlined above, the following sections attempt to integrate the notion of 'fleet investment' into an NEG model. The NEG model of choice was introduced by Baldwin et al. (2001), who provide a framework of 'catastrophic' agglomeration-enhanced growth due to localized knowledge spillovers. Notation throughout this study will closely follow the notation in Baldwin et al. (2003) in order to ease comparison with this class of NEG models.

2.1 Model Set-up

Akin to Baldwin et al. (2001), consider an economy comprising two regions with identical consumers and three sectors: manufacturing (M), agriculture (A), and an innovation sector (I). While the former sector is modelled as monopolistically competitive, the A and I sector are assumed to be perfectly competitive. There are two immobile production factors (labour L and capital K), and one tacit 'production factor', namely transport capital particular to each manufacturing firm.

With respect to labour endowment, preferences and technology, both regions are symmetric and, following tradition, will be referred to as 'North' and 'South'. The expositions in this section will focus only on Northern agents, with the corresponding Southern expressions (denoted by $*$) to be derived by symmetry.

The two regions may trade in agricultural goods at no cost, while trade in manufacturing goods is subject to transport costs of the iceberg type. More specifically, of any τ goods shipped from the North to the South, only one unit arrives in the South; thus a fraction of $1 - \frac{1}{\tau}$ of the shipped goods 'melts' away in transport. Similarly, exports from the South to the North are subject to an iceberg cost parameter τ^*.

The model's consumers optimize according to the following, time-separable utility function:

$$U = \int_0^{\infty} e^{-\rho t} C_A^{(1-\mu)} C_M^{\mu} \, dt \qquad \text{where} \quad C_M = \left(\int_0^{n^w} c_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

Here, C_A refers to consumption of the agricultural good, C_M to consumption of a composite manufacturing good, which is defined as CES over the mass of goods n^w existing in the 'global' economy. By the structure of (1), the parameter $\mu \in (0, 1)$ will denote the share of manufacturing in consumption, while $\sigma > 1$ denotes the elasticity of substitution among manufacturing goods. The consumer's demand function at every point in time is straightforward to obtain, viz.

$$C_A = \frac{(1-\mu)w_L}{p_A} \qquad c_i = \frac{\mu \, w_L \, p_i^{-\sigma}}{\int_0^{n^w} p_j^{1-\sigma} dj}$$

where w_L denotes consumer income. Since each consumer is assumed to inelastically supply one unit of labour to a friction-less labour market, w_L is equivalent to the wage of the respective consumer. Due to the simplicity of (1), the corresponding instantaneous indirect utility function is proportional to real wage:

$$V(p_A, p_i) \propto \quad \omega \equiv \frac{w_L}{\mathcal{P}} \qquad \text{where} \quad \mathcal{P} = P_A^{1-\mu} P_M^{\frac{\mu}{1-\sigma}} \quad \text{and} \quad P_M = \int_0^{n^w} p_i^{1-\sigma} di \tag{2}$$

The CES structure entails the convenient property that price elasticity of demand equals σ for each manufacturing product.

The agricultural sector is perfectly competitive, with a constant marginal cost of $a_A w_L$, where the (inverse) productivity parameter a_A is assumed to be symmetric across regions.

In addition to the agricultural and the manufacturing sector (to follow below), each region's economy also comprises a perfectly competitive 'innovation' sector akin to Baldwin et al. (2001), which employs an amount of labour L_I to produce a_I units of capital. As in Baldwin et al. (2003), each manufacturing firm requires one unit of capital for operation. It is assumed here that capital may only be employed in the region where it was constructed; Therefore the mass of capital equals the mass of firms in each region $K = n$ and $K^* = n^*$ (with $K + K^* \equiv K^w$ and $n + n^* \equiv n^w$). Due to the particular nature of capital assumed, its owners face a depreciation rate δ in form of a constant 'death' probability; i.e. at each period, a particular unit of capital evaporates with probability δ. According to the law of large numbers, the capital 'vanishing' in the north over one time period thus equals δK.

2.2 The Manufacturing Firm

The manufacturing sector is assumed as standard Dixit and Stiglitz (1977) monopolistically competitive, where each firm produces one good variety subject to increasing returns to scale,

while it is a price taker on the factor markets. The firm employs one unit of capital in order to produce x_i units of its variety, with marginal cost only involving labour.
The specific cost function for both Northern and Southern firms assumed here is $F + a_M w_L x_i$, with a_M representing an (inverse) labour productivity factor and F a fixed-cost term solely accruing to capital owners. The revenue function relevant for the typical Northern firm is the sum of revenue in the Northern ($R_i(p_i)$) and in the Southern ($R_i^*(p_i^*)$) market:

$$R_i(p_i) \equiv \frac{\mu\, E\, p_i^{1-\sigma}}{P_M} \qquad R_i^*(p_i^*) \equiv \frac{\mu\, E^*\, p_i^{*1-\sigma}}{P_M^*}$$

where E and E^* denote aggregate Northern and Southern consumption expenditure, respectively (a fraction μ of which is reserved for manufacturing goods).
Since each firm is atomistic, it rationally ignores its actions' impact on the price level of manufacturing goods $P_M = \int_0^{n^w} p_j^{1-\sigma} dj$ and $P_M^* = \int_0^{n^w} p_j^{*1-\sigma} dj$. Moreover, this assumption rules out any direct strategic interaction between firms. Thus on each market, the firm acts like a monopolist confronted with a downward-sloping demand of elasticity σ.
By standard monopoly pricing, the firm chooses output such that its ex-factory price ('mill price') is set to a constant mark-up over marginal cost $p = \frac{\sigma}{\sigma-1} a_M w_L$. This directly implies that operating profits are equal to a constant fraction $\frac{1}{\sigma}$ of revenue.
In the Southern market, however, the price to be paid to import one unit of the Northern good will equal $p_i^* = \tau p_i$ due to iceberg losses. Note that this formulation is entirely equivalent to the firm optimizing domestic and export output separately, with the marginal cost term for exported units augmented by the term τ - as in the following problem:

$$\max_{p_i, p_i^*} \quad \int_0^\infty e^{-rt} \left(p_i x_i(p_i) + p_i^* x_i^*(p_i^*) - F - w_L a_M (x_i(p_i) + x_i^*(p_i^*)\tau) \right) dt$$

Here, p_i and p_i^* denote product i's price in the Northern and Southern market, respectively, while $p_i x_i(p_i)$ and $p_i^* x_i^*(p_i^*)$ capture demand as expressed in dependence of price.
From the mark-up pricing rule, instantaneous operating profit thus emerges as:

$$\pi_i = p_i^{1-\sigma} \frac{\mu}{\sigma} \left(\frac{E}{P_M} + \phi \frac{E^*}{P_M^*} \right) = \frac{1}{\sigma} \left(R_i(p_i) + \phi R_i^*(p_i) \right) \quad \text{where} \quad p_i = \frac{\sigma}{\sigma - 1} w_L a_M \ , \ \phi \equiv \tau^{1-\sigma} \tag{3}$$

According to (3), operating profits are affected by real income in North and South, the firm's marginal cost and a given parameter $\phi \in (0, 1]$ capturing freeness of trade: $\phi \to 0$ corresponds to prohibitive trade costs, while $\phi = 1$ symbolizes no trade costs at all (cf. Baldwin et al. 2001).

2.3 The Manufacturing Firm and Fleet Investment

So far, the firm's problem follows the standard layout, as in Baldwin et al. (2001) and familiar to the NEG literature since Krugman (1991). Now suppose the firm has the option to decrease the iceberg costs it is facing by devoting part of its labour force to constructing transport infrastructure.

This feature may be interpreted as if each firm exports by its own fleet of vehicles and may improve its fleet's characteristics such that less of its goods 'melt' during shipment. Equivalently, fleet investment may be thought of as the effort spent on lobbying etc. to better penetrate an export market.

The way in which 'fleet investment' is modelled into the manufacturing firm is the continuous equivalent of Bester and Petrakis (2004), who investigate a monopolist's dynamic choice of a capital stock affecting labour productivity.

Suppose each firm initially faces transport costs of $\underline{\phi} \in (0,1)$. Furthermore, suppose the firm may invest into transport capital K_i^T in order to improve its trade costs via the strictly increasing and twice differentiable function $\phi(K_i^T) : [0, \infty) \to [\underline{\phi}, 1)$. As $\phi(K_i^T)$ is bounded above by 1, a sensible specification of $\phi(K_i^T)$ requires that zero capital implies 'initial' trade costs, while increasing transport capital drives iceberg costs closer to zero:

$$\phi(0) = \underline{\phi} \quad \text{and} \quad \lim_{K_i^T \to \infty} \phi(K_i^T) = 1 \tag{4}$$

Let K_i^T follow a standard law of motion:

$$\dot{K}_i^T = \overline{Q}_i - \overline{\delta}_T K_i^T \tag{5}$$

Here $\overline{Q}_i$ denotes investment into transport capital, while $\overline{\delta}_T$ denotes its depreciation rate. The firm may choose $\overline{Q}_i$ subject to adjustment costs $C(Q_i, K_i^T)w_L$, with $\partial^2 C()/(\partial Q_i)^2 \geq 0$ and $\partial^2 C()/(\partial K_i)^2 \geq 0$. Including the additional option of fleet investment, the firm's problem is thus represented as follows:

$$\begin{aligned} \max_{p_{i,t}, p^*_{i,t}, Q_{i,t}} \quad & \int_0^\infty e^{-rt} (x_i(p_{i,t})p_{i,t} + x_i^*(p^*_{i,t}, \phi(K_{i,t}^T))p^*_{i,t} - F - C(Q_{i,t}, K_{i,t}^T)w_L - \\ & - w_L a_M \left(x_i(p_{i,t}) + \tau x_i^*(p^*_{i,t}, \phi(K_{i,t}^T)) \right) dt \\ s.t. \quad & \dot{K}_i^T = \overline{Q}_i - \overline{\delta}_T K_i^T \end{aligned} \tag{6}$$

Since under no uncertainty, simultaneous optimization is equivalent to sequential optimization, (6) may be reformulated by taking into account the optimal pricing rule from (3):

$$\max_{Q_i} \quad \int_0^\infty e^{-rt} \left(\pi_i(\phi_i(K_i^T)) - C(Q_i, K_i^T)w_L \right) dt \quad s.t. \quad \dot{K}_i^T = \overline{Q}_i - \overline{\delta}_T K_i^T \tag{7}$$

Here, the concavity of both the objective function and the costate equation ensures the sufficiency of the first-order conditions for attaining an optimum.[1]
For the sake of analytically tractable solutions, let adjustment costs be quadratic in the (improper) transport investment rate, with a_T representing an (inverse) productivity parameter:

$$C(Q_i, K_i^T)w_L = a_T \left(\frac{\overline{Q}_i}{K_i^T + 1} \right)^2$$

Moreover, the bijective relationship between K_i^T and ϕ_i allows for expressing (7) directly in terms of ϕ_i: For that purpose, choose a specific specification for $\phi(K_i^T)$ that conforms to the requirements in (4):

$$\phi_i = \frac{K_i^T + \underline{\phi}}{K_i^T + 1} \quad \Leftrightarrow \quad K_i^T = \frac{\phi_i - \underline{\phi}}{1 - \phi_i} \tag{8}$$

Finally, redefine $Q_i \equiv \frac{\overline{Q}_i}{K_i^T+1}$ and $\delta_T = \frac{\bar{\delta}_T}{(1-\underline{\phi})}$. Thus, the firm's investment problem can be represented as follows:

$$\max_{Q_i} \quad \int_0^\infty e^{-rt} \left(\pi_i(\phi_i) - w_L a_T Q_i^2 \right) dt \quad s.t. \quad \dot{\phi}_i = (1 - \phi_i) \left(Q_i - \delta_T(\phi_i - \underline{\phi}) \right) \tag{9}$$

The corresponding first order conditions are (with λ denoting ϕ_i's shadow price):

$$2w_L a_T Q = \lambda(1 - \phi_i)$$
$$\lambda\rho - \dot{\lambda} = \frac{\partial \pi(\phi_i)}{\partial \phi_i} + \lambda \left(-\frac{\dot{\phi}_i}{1 - \phi_i} - (1 - \phi_i)\delta_T \right)$$

which gives rise to a dynamic system characterized by equation (10)and ϕ_i's law of motion as in (9):

$$\dot{Q}_i = (\rho + \delta_T(1 - \phi_i))\, Q_i - \frac{\partial \pi(\phi_i)}{\partial \phi_i} \frac{(1 - \phi_i)}{2a_T w_L} \tag{10}$$

Note that since the firm rationally ignores the impact of its choice on the price level, we have $\frac{\partial \pi(\phi_i)}{\partial \phi_i} = p_i^{1-\sigma} \frac{\mu}{\sigma} \frac{E^*}{\int_0^{n^w} p_j^{*1-\sigma} dj}$ being constant with respect to ϕ_i.
In order to obtain the firm's investment steady state, nullify ϕ's law of motion and equation (10) for the loci:

$$Q_i(\phi_i)|_{\dot{\phi}_i=0} = \delta_T \left(\phi_i - \underline{\phi} \right) \qquad Q_i(\phi_i)|_{\dot{Q}_i=0} = \frac{\partial \pi(\phi_i)}{\partial \phi_i} \frac{(1 - \phi_i)}{2a_T w_L \left(\rho + \delta_T(1 - \phi_i) \right)} \tag{11}$$

[1] Note that $\pi_i(\phi_i)$ is linear in ϕ_i, and that the conditions spelt out in (4) stipulate that $\partial^2 \phi_i(K_i^T)/(\partial K_i^T)^2 < 0$.

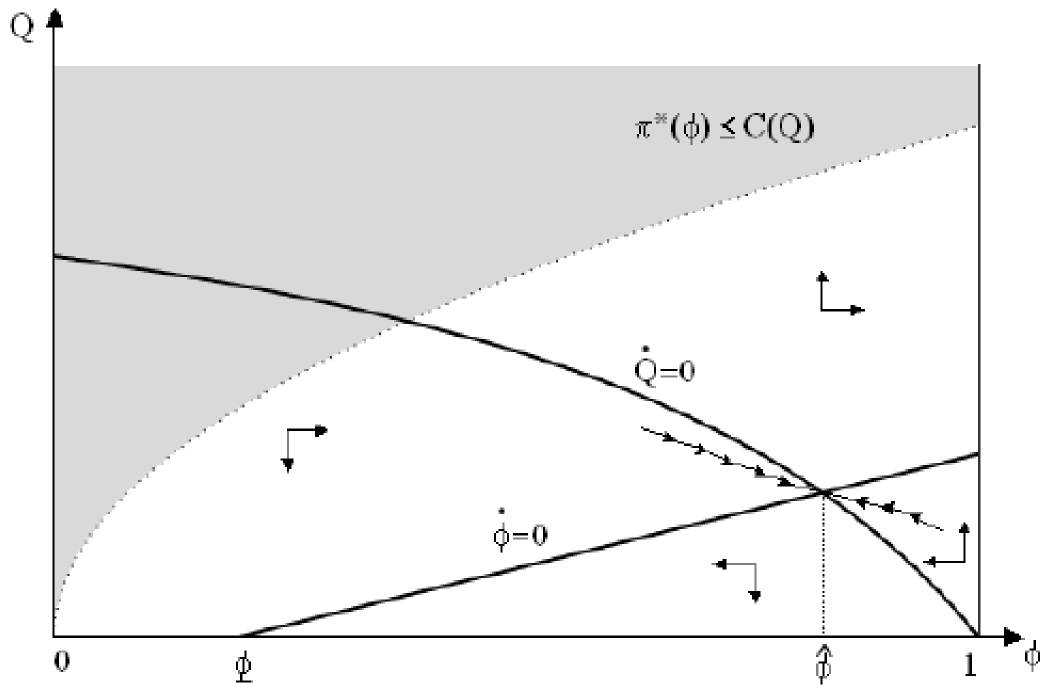
Figure 1 displays the loci for $\dot{\phi}_i = 0$ and $\dot{Q}_i = 0$: Note that the ϕ_i-locus is linear and increasing in ϕ, whereas the Q_i-locus is decreasing in ϕ, with $Q_i(0)|_{\dot{Q}_i=0}$ being positive, while $Q_i(1)|_{\dot{Q}_i=0} = 0$. Since $\delta_T > 0$, $\underline{\phi} \in (0,1)$ and $\phi \in [0,1]$, both loci thus have to intersect for some $(\hat{\phi}_i, \hat{Q}_i)$.

The dynamics in the firm's transport infrastructure system are straightforward to obtain and imply that the steady state in $\hat{\phi}_i$ is saddle-point stable. Starting from $\underline{\phi}$, the corresponding saddle path is associated with initially large investment effort Q_i, which subsequently decreases to $\hat{Q}_i$ as ϕ_i rises over time.

Solving for the steady-state values yields two solutions for $\hat{\phi}_i$ of which one is inadmissible since it would imply $\phi_i > 1$. The admissible solution is given in (12):

$$(1-\hat{\phi}_i) = -\frac{1}{2}\left(\frac{\partial\pi(\phi)/\partial\phi}{2\delta_T^2 a_T w_L} + \frac{\rho}{\delta_T} - (1-\underline{\phi})\right) + \\ + \sqrt{\frac{1}{4}\left(\frac{\partial\pi(\phi)/\partial\phi}{2\delta_T^2 a_T w_L} + \frac{\rho}{\delta_T} - (1-\underline{\phi})\right)^2 + \frac{\rho}{\delta_T}(1-\underline{\phi})} \qquad (12)$$

In addition to the optimum derived above, a further requirement should be met by transport



Parametrization chosen for this figure: $\partial\pi_i(\phi_i)/\partial\phi_i = 0.4$, $\rho = 0.1$, $\delta_T = 0.2$, $\underline{\phi} = 0.2$, $a_T = 1$

Figure 1: Phase diagram of firm fleet investment

infrastructure: The instantaneous operating profit from export should be greater than the expenses on maintaining the transport infrastructure associated with it:

$$\pi_i^*(\phi) \equiv \phi_i \frac{\partial \pi_i(\phi)}{\partial \phi} = \phi_i \frac{\mu}{\sigma} \left(\frac{\sigma}{\sigma - 1} w_L a_M \right)^{1-\sigma} \frac{E^*}{P_M^*} \geq w_L C(Q_i) = w_L a_T Q_i^2 \qquad (13)$$

While the equilibrium conditions laid out in the following sections assure that (13) is satisfied for steady state values $(\hat{Q}_i, \hat{\phi}_i)$, (cf. proposition 3 in the appendix), I assume (13) to hold as well in the short run, i.e. until the steady state is reached. Firms are thus restrained to financing their fleets from their export profits.[2] This condition can as well be represented in Figure 1: Choosing any investment rate Q_i above the dotted line violates condition (13) and is thus inadmissible. Thus, if a firm starts out $\underline{\phi}$, and the saddle path value of Q_i corresponding to $\underline{\phi}$ lies in the (shaded) inadmissible area, the firm would refrain from exercising its fleet investment option.

Though it is not analytically possible to pin down the exact parameter settings where fleet investment is at the brink of profitability according to condition (13), it is straightforward to establish sufficient conditions for feasibility or infeasibility of investment at $\underline{\phi}$. If $Q_i(\underline{\phi})|_{\dot{Q}_i=0} \leq \sqrt{\pi_i^*(\underline{\phi})/(a_T w_L)}$, then the saddle path at $\underline{\phi}$ will be in the admissible region, and the firm will embark on its investment trajectory.

Since (13) does not admit any $Q > 0$ at $\underline{\phi} = 0$ (no trade freeness at all), and $Q(\phi)|_{\dot{Q}=0}$ is decreasing with $Q(1)|_{\dot{Q}=0} = 0$, there exists a $\underline{\phi} \in [0, \hat{\phi}]$ such that condition (13) is violated for initial fleet investment. Thus, for any parameter setting, there exists a $\underline{\phi}$ such that the firm is caught in an 'isolation trap'.

2.4 Market Clearing and Spillovers

Having specified the economy's agents and their programmes, one may now turn to combining the bits in 'short-run' equilibrium. Since in the agricultural and innovation sectors marginal cost equals average cost, they operate with zero profits. Moreover, the respective firms in each region are entirely symmetric, which allows for dropping the i-index in the expressions for the manufacturing sector. Next, turn to specifying the (inverse) productivity terms a_A, a_I, a_M and a_T.

In order to allow for 'endogenous' growth, I assume the existing capital stock to exert spillovers via the innovation sector's marginal cost term a_I, akin to Baldwin et al. (2001). In

[2]Even if it is assumed that the firm may not borrow on the capital market to finance its fleet construction (which pose problems as firms are considered homogeneous in that respect), one may think of cross-financing initial fleet investment out of the operating profits originating from the domestic market. However, assuming so would not change the qualitative conclusions from the model - it would just imply an upward shift of the dotted curve in Figure 1.

particular, let (inverse) productivity of the Northern innovation sector be defined as follows:

$$a_I \equiv \frac{1}{K + \lambda K*} = \frac{1}{AK^w} \quad \text{with} \quad A \equiv s + \lambda(1-s)\ , \quad s \equiv \frac{K}{K^w}\ , \qquad \lambda \in [0,1]$$

As in Baldwin et al. (2001), the parameter λ captures 'localized' spillovers - i.e. the domestic capital stock contributes more to innovation efficiency than the one of the 'foreign' region.
For the agricultural sector, free trade ensures that $p_A = p_A{}^*$. Since labour is mobile across sectors, this entails $w_L = w_L^*$. Following Baldwin et al. (2003), choose the agricultural good as the numéraire of the national economy and normalize agricultural output such that a_A equals unity. This implies $p_A = w_L = p_A^* = w_L^* = 1$.
Akin to agriculture, one may normalize the units of manufacturing output such that $a_M = \frac{\sigma-1}{\sigma}$, which conveniently forces mill prices to equal one ($p = \frac{\sigma}{\sigma-1} a_M w_L = 1 = p^*$). By unity mill prices, homogeneity of manufacturing firms in either region, and the fact $K^w = n^w$, the price levels P_M and P_M^* from (2) simplify accordingly:

$$P_M = \int_0^{K^w} p_i^{1-\sigma} di = \int_0^{K} 1 di + \int_K^{K^w} \tau^{*\,1-\sigma} di = K + \phi^* K^* = \Delta K^w \qquad \Delta \equiv s + \phi^*(1-s)$$

$$P_M^* = \int_0^{K} \tau^{1-\sigma} di + \int_K^{K^w} 1 di = \phi K + K^* = \Delta^* K^w \qquad \Delta^* \equiv \phi s + (1-s)$$

Using the relation above as well as defining the Northern share in national consumption expenditure $s_E \equiv E/E^w$ leads to a simpler formulation of the individual firm's operating profits (recall that the manufacturing firms operating profits are revenue divided by σ):

$$\pi_i = \frac{1}{\sigma}(R(p) + R^*(p\tau)) = \frac{1}{\sigma}\left(\frac{\mu E}{\Delta K^w} + \frac{\phi \mu E^*}{\Delta^* K^w}\right) = \frac{\mu}{\sigma}\frac{E^w}{K^w} B \qquad B \equiv \frac{s_E}{\Delta} + \phi \frac{(1-s_E)}{\Delta^*}$$

$$\pi_i^* = \frac{1}{\sigma}(R(p\tau^*) + R^*(p)) = \frac{1}{\sigma}\left(\frac{\phi^* \mu E}{\Delta K^w} + \frac{\mu E^*}{\Delta^* K^w}\right) = \frac{\mu}{\sigma}\frac{E^w}{K^w} B^* \qquad B^* \equiv \phi^* \frac{s_E}{\Delta} + \frac{(1-s_E)}{\Delta^*}$$

Henceforth, I will follow Baldwin et al. (2003) and denote the term $\frac{\mu}{\sigma}$ as b.
In order for transport investment to remain viable, its productivity term a_T should equally profit from the existing amount of manufacturing capital K^w. Modelling spillovers in this way embodies that advances in national productivity should facilitate investment in transport infrastructure - e.g. a steam engine already existing in the industrial sector should lower the cost of constructing steam ships.
In particular, I will assume $a_T = 1/K^w\Delta^*$ and $a_T^* = 1/K^w\Delta$, so spillovers of manufacturing capital on transport depend on freeness of trade. However, I do specify location spillovers via integrating the Southern price level term Δ^* in Northern a_T: This feature is chosen for technical reasons since it allows for analytically tractable solutions in long-run equilibrium.

Note, though, that leaving the Δ^* term out of a_T does not fundamentally change the behaviour of fleet investment.[3]

Having specified the productivity parameters, proceed with expressing the labor market clearing equilibrium: Northern consumption expenditure E has to equal capital income plus labour income (equal to the number of workers $L = L_A + L_M + L_I = \frac{1}{2}L^w$). Aggregate capital income has to total the number of firms $K = (1-s)K^w$ times operating profits π minus fixed costs for transport capital $a_T Q^2$ minus fixed costs for capital.

$$E = \frac{L^w}{2} + (\pi - a_T Q^2)sK^w - L_I \qquad E^* = \frac{L^w}{2} + (\pi^* - a_T^* Q^{*2})(1-s)K^w - L_I^* \tag{14}$$

3 Steady State and Comparative Statics

Having laid out the fundamental instantaneous equations, proceed with specifying the general equilibrium terms in the economy's steady state. First, require that $\dot{E}$ equals zero, which by the consumer's Euler equation $\dot{E}/E = r - \rho$ forces r to equal ρ (cf. Baldwin et al. 2001, p.18).

Moreover, capital should grow at constant steady state rates $g = \frac{\dot{K}}{K}$ and $g^* = \frac{\dot{K}^*}{K^*}$. To keep this pace, the Northern and Southern innovation sectors require labour input L_I and L_I^* as follows:

$$L_I = (\delta + g)Ka_I = (\delta + g)\frac{s}{A} \qquad L_I^* = (\delta + g^*)K^* a_I^* = (\delta + g^*)\frac{1-s}{A^*} \tag{15}$$

Moreover, steady state requires the regional distribution of capital and expenditure, i.e. the Northern shares s and s_E to be constant. The time derivative of s thus implies steady state conditions similar to Baldwin et al. (2003, p.174):

$$\dot{s} = (g - g^*)\, s\, (1-s) \tag{16}$$

Therefore, steady state equilibria divide into two types: any interior equilibrium (i.e. $s \in (0,1)$) where $g = g^*$, and the 'Core-Periphery' outcome with $s \in \{0, 1\}$. By symmetry, and following NEG tradition, I will henceforth limit Core-Periphery (CP) analysis to the core-in-the-north case, viz. $s = 1$. At any interior equilibrium, both North and South dispose of a positive mass of manufacturing firms, and both regions must be wanting to sustain their share of capital. Therefore they both have to invest in order to raise their capital stock exactly at the rate g. The price of capital, respectively the value of a firm v, therefore has to

[3]Leaving out Δ^* expresses $\hat{\phi}$ as a polynomial of third order, which would complicate further analysis considerably. The derivatives with respect to parameter s, however, retain their signs in this case – which suggests that the qualitative conclusions from the model should not change.

equate its cost.[4] Since in the steady state, ϕ and ϕ^* as well as fleet investment remain fixed, the operating profit of a firm will gradually decrease by a rate of $g = g^*$, and its capital may be deprecated with a constant probability δ. Thus from any time point, future expected profit flows (net fleet investment) equal the current times $e^{(g+\delta)t}$. Finally, these future profit flows are discounted at a rate $r = \rho$, which defines the value of the firm in steady state as (cf. Baldwin et al. 2003, p.162):

$$v = \frac{\pi - a_T Q^2}{\rho + \delta + g} \qquad\qquad v^* = \frac{\pi^* - a_T^* Q^{*2}}{\rho + \delta + g} \tag{17}$$

As has been specified in the previous section, the cost of a marginal unit of Northern capital equals $a_I w_L = 1/AK^w$. This in turn implies:

$$\pi - a_T Q^2 = \frac{\rho + \delta + g}{AK^w} \qquad\qquad \pi^* - a_T^* Q^{*2} = \frac{\rho + \delta + g}{A^* K^w} \tag{18}$$

If condition (18) is not satisfied, capital will change at a rate different from g, triggering an adjustment in the number of firms until the condition is satisfied again.[5]
Equation (18) can now be employed to pin down regional expenditure E and E^* as from the market clearing equation (14):

$$E = \frac{L^w}{2} + \rho\frac{s}{A} \qquad\qquad E^* = \frac{L^w}{2} + \rho\frac{(1-s)}{A^*} \tag{19}$$

Note that in the CP steady state, operating profits and fixed cost in the South are zero, hence $E^* = \frac{1}{2}L^w$. Therefore the market clearing identity in (19) has to hold both at interior and CP equilibria.

Having expressed E and E^* in terms of model parameters, one may now proceed to solving for the steady state values of ϕ and ϕ^*: From profit optimization we know the term $\partial\pi(\phi)/\partial\phi$ from (13) equals $b\frac{E^*}{K^w \Delta^*}$, which together with the specification for a_T implies that

$$\frac{1}{2\delta_T^2 a_T}\frac{\partial \pi(\phi)}{\partial \phi} = \frac{b}{2\delta_T^2}\left(\frac{L^w}{2} + \rho\frac{(1-s)}{A^*}\right)$$

Substituting for this term in (12) denotes $\hat{\phi}$ as a function of parameters and the variable s:

$$\left(1 - \hat{\phi}(s)\right) = -\frac{\frac{b}{2\delta_T^2}E^* + \frac{\rho}{\delta_T} - (1 - \underline{\phi})}{2} + \sqrt{\left(\frac{\frac{b}{2\delta_T^2}E^* + \frac{\rho}{\delta_T} - (1 - \underline{\phi})}{2}\right)^2 + \frac{\rho}{\delta_T}(1 - \underline{\phi})} \tag{20}$$

[4] Note that this condition is equivalent to the zero-profit condition implied by free entry that is typically used in NEG models.

[5] With respect to particular way in which fleet investment was specified, a brief period of $v > a_I$ will necessarily break the homogeneity among regional firms in the short run. The newly entered firms have to initiate fleet construction starting from $\underline{\phi}$, which introduces ϕ_i terms that differ over the regional sector. Nevertheless, as the economy reaches its steady state, the ϕ_i and Q_i terms have to eventually equalize across firms.

Differentiation reveals that E^* is a decreasing function of s, thus $\hat{\phi}$ is decreasing in s as well. Moreover $\hat{\phi}$ is increasing in L^w and $\underline{\phi}$, but decreasing in ρ and δ_T. Contrasting $\hat{\phi}$ with $\hat{\phi}^*$, straightforward differentiation with respect to s reveals that $\frac{d(\hat{\phi}-\hat{\phi}^*)}{ds}$ is negative. Thus if a Northern firm is confronted with increasing s, it will take into account that lower $(1-s)$ implies lower expenditure in the South and will thus reduce fleet investment.
By taking into account the firm's steady state equations, (20) defines the firm's level of fleet investment as follows:

$$\hat{Q}^2 = (\hat{\phi} - \underline{\phi})\delta_T(\delta_T(1-\underline{\phi}) + \rho) - \frac{b}{2}\left(\frac{L^w}{2} + \rho\frac{(1-s)}{A^*}\right)(1-\hat{\phi}) \tag{21}$$

Thus for given s, a firm's expenditure on maintaining its steady state fleet $\hat{Q}^2$ is linearly decreasing in $\hat{\phi}$. Moreover, it is decreasing in $\underline{\phi}$ and ρ, but increasing in δ_T and L^w, by mechanisms easily to infer from Figure 1.
Relation (19) may as well be used to define the share of Northern expenditure at any steady state:

$$s_E^{EE} = \frac{\frac{1}{2}L^w + \rho\frac{s}{A}}{L^w + \rho\left(\frac{s}{A} + \frac{(1-s)}{A^*}\right)} \tag{22}$$

In varying form, identity (22) is a recurring feature in NEG models of the Baldwin et al. (2003) type, which these authors typically refer to as 'EE relation'. Note that the function s_E^{EE} does neither depend on ϕ nor on Q. Differentiation of s_E^{EE} with respect to s reveals that s_E^{EE} is a strictly increasing function of s.[6]
Still following Baldwin et al. (2001), a second relation between s and s_E may be developed out of equation (18): Since at all interior equilibria $v = a_I$ and $v^* = a_I^*$, equation (18) implies that operating profits net fleet investment have to be equalized between both North and South, i.e. $A(\pi - a_T Q^2) = A^*(\pi^* - a_T^* Q^{*2})$. This leads to the following equation (using the expression for E^w obtained from (19)):

$$AB = A^*B^* + \frac{\Upsilon}{\Delta\Delta^*} \quad \text{where} \quad \Upsilon = \frac{A\hat{Q}^2\Delta - A^*\hat{Q}^{*2}\Delta^*}{bL^w + b\rho\left(\frac{s}{A} + \frac{(1-s)}{A^*}\right)} \tag{23}$$

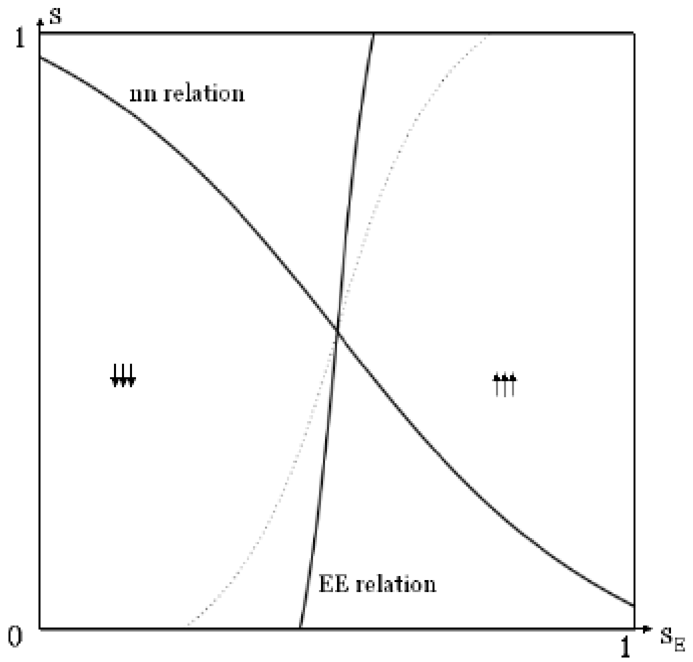
Straightforward algebra then yields the following expression:

$$s_E^{nn}(s) = \frac{\Upsilon + \Delta\left((1-\hat{\phi}\lambda) - (1+\hat{\phi})(1-\lambda)s\right)}{\left(1-\hat{\phi}\hat{\phi}^*\right)(A^*s + A(1-s))} \tag{24}$$

Note that (24) defines s_E as a function of s, since $\hat{\phi}$ and $\hat{Q}$ only depend on s (apart from parameters). In spirit, (24) is equivalent to the equation Baldwin et al. (2001) call the 'nn

[6]Actually, $\frac{ds_E^{EE}}{ds} = \frac{\rho\lambda}{E^w}\left(\frac{(1-s_E)}{A^2} - \frac{s_E}{A^{*2}}\right)$.

relation'. As it reflects $\frac{v}{a_I} = \frac{v^*}{a_I^*} = 1$, any s_E that is off this relation does not correspond to earnings equalization. Any s_E larger than s_E^{nn} for a given s implies $\frac{v}{a_I} > \frac{v^*}{a_I^*}$, which triggers more investment in the North and thus increasing s (vice versa for any pair $(s, s_E) < (s, s_E^{nn}(s))$).
All Northern capital shares s that set s_E^{nn} and s_E^{EE} equal thus correspond to an interior equilibrium: The symmetric steady state $s = s_E = \frac{1}{2}$ is one obvious solution that holds for all parameter settings. Note that in perfect symmetry, $\hat{\phi} = \hat{\phi}^*$ and hence $\hat{Q} = \hat{Q}^*$.



Parametrization chosen for this figure: $L^w = 0.7$, $\rho = 0.1$, $\delta_T = 0.3$, $\lambda = 0.4$, $b = 0.3$

Figure 2: Phase diagram of equilibrium relations

Figure 2 exemplifies s_E^{EE} and s_E^{nn} for a given parameter setting: Intersections of the *nn* and *EE* relations represent interior equilibria. Since the *nn* relation only holds for the latter, the CP equilibria are found where the *EE* relation intersects the boundaries $s = 0$ and $s = 1$. The larger the $\hat{\phi}$ implied by the parameters L^w, ρ, $\underline{\phi}$ and δ_T, the more the *nn* relation will tilt anti-clockwise.[7] The symmetric equilibrium at $s = s_E = \frac{1}{2}$ changes its stability according to this tilt: As long as the *nn* relation in Figure 2 is 'flatter' with respect to the *EE* relation (i.e. $\frac{ds_E^{EE}}{ds}|_{s=s_E=\frac{1}{2}} < \frac{ds_E^{nn}}{ds}|_{s=s_E=\frac{1}{2}}$), then this equilibrium is stable; Hence small perturbations will incite the system to return to the symmetric steady state. As soon as

[7]... since $\frac{d^2 s_E^{nn}}{d\hat{\phi} ds} \geq 0$

$\frac{ds_E^{EE}}{ds}|_{s=s_E=\frac{1}{2}} > \frac{ds_E^{nn}}{ds}|_{s=s_E=\frac{1}{2}}$, however, the system will diverge from symmetry.
Similarly , the Core-Periphery (CP) equilibria become stable as soon as $s_E^{nn}(1) < s_E^{EE}(1)$, which may always be achieved for parameter settings such that $\hat{\phi}|_{s=s_E=\frac{1}{2}}$ is large enough. This feature is exactly the same as with most NEG models: There ϕ is treated as a parameter, and raising it enough exogenously destabilizes the symmetric outcome as some ϕ_S and induces the CP equilibrium to become stable at some ϕ_B (cf. Baldwin et al. (2001) for a more detailed discussion). As for the model presented so far, the rationale for this behaviour stems from the fact that for sufficiently low trade costs, firms find it advantageous to agglomerate in one region in order to benefit from low capital cost due to maximum technology spillovers.
As is the case with most NEG models, the steady state values of ϕ for breaking symmetry $\hat{\phi}_B$ and for sustaining a CP equilibrium $\hat{\phi}_S$ are in general not equal. Moreover, for a limited range of $\hat{\phi}_S$, stable interior equilibria may emerge that are asymmetric. Unfortunately, deriving these asymmetric equilibria from equalizing the *EE* and *nn* relations (equations (22) and (24)) does not yield a closed form solution for s in dependence of parameters. For the sake of brevity, I will thus forego this discussion and simply note that under certain parameter settings there exist $\hat{\phi}$ such that the symmetric equilibrium becomes unstable and the CP outcome stable.
One may now contrast the 'nn' relation with the one that arises if firms do not find it worthwhile to invest in transport infrastructure,: In this case $\hat{\phi} = \hat{\phi}^* = \underline{\phi}$ and $\hat{Q} = \hat{Q}^* = 0$, hence the 'nn' relation reduces to

$$s_E^{nn}|_{\hat{\phi}=\hat{\phi}^*=\underline{\phi}} = \frac{\Delta\left((1-\underline{\phi}\lambda) - (1+\underline{\phi})(1-\lambda)s\right)}{\left(1-\underline{\phi}^2\right)\left(A^*s + A(1-s)\right)} \tag{25}$$

Equation (25) is represented by the dotted line in Figure 2. Moreover it is identical to the *nn* relation established by Baldwin et al. (2001). Following the discussion in their article, one infers that there exist levels of $\underline{\phi}$ such that the symmetric equilibrium is stable, respectively unstable, under equation (25). For our purpose, the interesting case occurs when $s_E^{nn}|_{\hat{\phi}=\hat{\phi}^*=\underline{\phi}}$ implies a stable symmetric equilibrium. Note that the differentiation of equations (24) and (25) with respect to s, respectively, reveals that the slope of (24) is less than (or equal to) the slope of(25), irrespectively of parameter choice. Therefore, if the national economy starts out at $\underline{\phi}$, and manufacturing firms find it worthwhile to construct their fleets, then the *nn* relation will rotate anti-clockwise. Furthermore, this difference in slopes depends crucially on L^w: The larger the parameter, the larger the consumption potential to reap by fleet construction and thus the farther (24) rotates anti-clockwise with respect to (25).

4 Welfare and Growth Effects

The model outlined so far may now be employed to analyse the impact of fleet investment on welfare[8] ω and the steady state growth rate g. For that purpose, consider the following scenario: Suppose the national economy starts out at the 'isolated' equilibrium, a symmetric and stable steady state, with trade freeness $\phi = \phi^* = \underline{\phi}$. Then firms obtain the opportunity of fleet construction which may or may not raise $\phi = \phi^* > \underline{\phi}$. Depending on parameter settings, the new symmetric steady state may then remain stable or become unstable, triggering an eventual convergence to the Core-Periphery (CP) outcome.

In order to analyze welfare, consider first the real wage of the typical Northern consumer, which is equal to:

$$\omega = \left(\int_0^{K^w} p_i^{1-\sigma} di \right)^{\frac{\mu}{\sigma-1}} = (K^w \Delta)^{\frac{\mu}{\sigma-1}}$$

Differentiating this expression with respect to time and holding s and s_E fixed yields

$$\frac{\dot{\omega}}{\omega} = \frac{\mu}{\sigma - 1} \left(\frac{\dot{K}^w}{K^w} + \frac{\dot{\Delta}}{\Delta} \right)$$

where in steady state, the growth rate of the 'global' capital stock K^w is fixed at a rate g.
In any steady state, $\dot{\hat{\phi}}^* = 0$ implies $\dot{\Delta} = 0$ and thus long-term growth does not depend on ϕ^* directly. As long as firms are still improving their fleets, however, $\frac{\dot{\Delta}}{\Delta}$ is positive, while the effect on $\frac{\dot{K}^w}{K^w}$ is more complicated:

The symmetric case where $s = s_E = \frac{1}{2}$ implies $\Delta = \frac{1+\phi^*}{2}$ and $Q = Q^*$. Moreover, operating profits have to equal bE^w since μE^w is the global expenditure on consumption goods. Therefore in the symmetric case, the annuity return on capital is $bE^w - 2Q^2/(1 + \phi^*)$. When firms initiate fleet construction, Q jumps from 0 to its saddle path value at $\underline{\phi}$, so the return on capital falls, which in turn induces less new capital respectively firms to appear.[9] After this initial period, however, Q will decline while ϕ will rise until both have reached their steady state, which entails an improving return on capital. So K^w will instantaneously recede when firms start to invest and slowly rise subsequently together with Δ. As long as firms will not have reached their steady state fleet, K will thus rise at a rate larger than the steady state growth rate g. So allowing for fleet investment will lead to an initial fall in real wages that is followed by higher-than-usual growth.

Continue by examining the steady state growth rate g. From $v = a_I$ and the fact that aggregate profits in the North are bBE^w, we obtain

$$g = A \left(bBE^w - \frac{\hat{Q}^2}{\Delta^*} \right) - \rho - \delta$$

[8] Recall that from equation (1), utility is proportional to real wage ω.

[9] Remember that firms will exit at a rate that is at most equal to δ.

Thus the long-run growth rate of capital depends on ϕ via the terms B and $\hat{Q}^2/\Delta^*$. In the symmetric case, B equals unity, and therefore any steady state $\hat{Q} > 0$ represents a drag on capital growth. This reflects the reasoning that improving transport infrastructure must come at a cost, and that its maintenance requires resources. Consequently, the drag on growth exerted by transport infrastructure is the larger the higher is the 'maintenance cost parameter' δ_T (With $\delta_T = 0$, growth after having reached the steady state would be equal to growth at $\underline{\phi}$).

These conclusions, though, are limited to the scenario where the economy remains at symmetry, even after having reached $\hat{\phi} > \underline{\phi}$. However, if parameters are such that $\hat{\phi}|_{s=s_E=\frac{1}{2}}$ is large enough, the corresponding nn relation may even render the CP outcome stable, as is shown in Figure 2.

If fleet investment is thus large enough to break symmetry, the economy will be propelled to the CP equilibrium. At the core-in-the-North outcome, the entire 'global' fleet will belong to Northern firms, as the Southern manufacturing base has vanished. Since Southern expenditure is strictly decreasing in the Northern capital share s, Northern firms will decrease their steady state fleet and investment, i.e. both $\hat{\phi}$ and $\hat{Q}$ will be lower with respect to symmetric equilibrium.

As the Core-in-the-North case may arise ultimately, one may wonder how its steady-state growth rate g_{CP} relates to the one of the symmetric case g_{sym} and growth in isolation $g_{\underline{\phi}}$, respectively. Using the identity for E^w from (19), the following expressions can be established:

$$g_{\underline{\phi}} = bL^w \frac{1+\lambda}{2} - (1-b)\rho - \delta$$

$$g_{sym} = bL^w \frac{1+\lambda}{2} - (1-b)\rho - \delta - \hat{Q}^2_{sym} \frac{1+\lambda}{1+\hat{\phi}_{sym}}$$

$$g_{CP} = bL^w - (1-b)\rho - \delta - \frac{\hat{Q}^2_{CP}}{\hat{\phi}_{CP}}$$

$$g_{CP} - g_{\underline{\phi}} = bL^w \frac{1-\lambda}{2} - \frac{\hat{Q}^2_{CP}}{\hat{\phi}_{CP}} \tag{26}$$

$$g_{CP} - g_{sym} = bL^w \frac{1-\lambda}{2} + \hat{Q}^2_{sym} \frac{1+\lambda}{1+\hat{\phi}_{sym}} - \frac{\hat{Q}^2_{CP}}{\hat{\phi}_{CP}} \tag{27}$$

First, it is obvious that the cost of fleet maintenance after breaking isolation represents a 'drag' on growth as $g_{sym} \leq g_{\underline{\phi}}$. For growth in the CP case, however, the picture is less clear: The former term in equations (26) and (27) represents the positive impact of agglomeration, which optimizes spillovers due to geographical vicinity: The more marked the localization of spillovers (i.e. the lower λ), the more pronounced will be the advantage of g_{CP} over g_{sym}. The terms involving $\hat{Q}$, in contrast, represent the cost of fleet maintenance. As for (27), it can be shown that in any stable CP steady state, $g_{CP} \geq g_{sym}$ (cf. Proposition 5 in

the appendix), thus agglomeration will only persist if it offers a growth advantage over the symmetric steady state.
As far as equation (26) is concerned, note that the term $\frac{\hat{Q}^2_{CP}}{\hat{\phi}_{CP}}$ is non-negative, but considerably smaller than $\delta^2_T \hat{\phi}_{CP}$.[10] So the sign of (26) depends crucially on how revenue in the South $\frac{bL^w}{2}$ relates to λ. Only relatively small values of bL^w and quite large ones for λ will induce $g_{CP} < g_{\underline{\phi}}$. The parameter intervals allowing for such a case are further restrained by the fact that $bL^w = 0$ implies $\hat{Q}_{CP} = 0$, and larger values of λ render breaking isolation less likely. Numerical simulation shows that there exist parameter combinations such that $g_{CP} < g_{\underline{\phi}}$, but these are quite hard to find. Proposition 6 in the appendix shows that $\lambda > \frac{2}{3}$ is necessary in order to attain $g_{CP} < g_{\underline{\phi}}$, and in numerical simulation it requires even values of λ that are considerably larger than $\frac{2}{3}$. Further numerical evidence shows that the vast majority of parameter settings stipulate $g_{CP} > g_{\underline{\phi}}$.

The discussion so far shows that the behaviour of the 'global' economy depends crucially on the labour force L^w in relation to parameters ($\underline{\phi}$ in particular). Thus the terms that matter for discussion reflect the ratio between population and geography, i.e. population density. Starting out at an initial state stable steady state with trade freeness parameter $\underline{\phi}$, one may therefore identify different scenarios with respect to population density $L^w/\underline{\phi}$:

- If L^w is too low with respect to the other parameters (particularly $\underline{\phi}$), then firms are not willing to fund fleet construction, and the economy is captured in an 'isolation trap': The consumers in the economy are then too dispersed to render investment in infrastructure worthwhile. The economy thus stays at the initial symmetric and stable steady state (call it 'isolation' equilibrium) we assumed as our starting point.

- If L^w takes on intermediate values with respect to the previous setting, then firms will initiate fleet construction, pushing the economy towards more trade openness. For still low values of L^w with respect to the other parameters, however, this new symmetric steady state will still be stable. Though there are benefits from lower trade costs, real wage growth lowers with respect to the isolation equilibrium, since resources have to be diverted from innovation to maintain transport infrastructure.

- Finally, if L^w takes on values large enough that it not only requires a CP outcome, but also renders expenditure on fleet investment less than $(1 - \lambda)$ times operating profits from exports to the South, then the new steady state growth rate exceeds growth from the isolation case.

[10]This follows directly from the steady state value for Q: $\hat{Q} = \delta_T(p\hat{h}i - \underline{\phi})$.

5 Conclusion

By applying comparative statics on steady states, the model presented above has achieved the primary purpose of this paper: it shows that endogenizing transport infrastructure has an impact on growth and welfare, and this effect may be ambiguous. Several features arise from relating population to geography: If population is sparse and geography disadvantageous (low population density), no firm will be interested in sacrificing resources in order to improve trade. The economy may be seen as being caught in an 'isolation trap'. If population density reaches a certain threshold, firms embark on improving their trade costs by investing in transport capital. The economy may then find a new equilibrium with lower trade costs - however this new equilibrium also suffers from a lower growth rate of real wages, since it requires devoting resources away from innovation towards infrastructure maintenance.

If population density is large enough, the mentioned new equilibrium will incite the economy's manufacturing firms to agglomerate in one region, which (for most parameter settings) enhances the growth rate with respect to the non-agglomerated steady state. Finally, for a sufficiently high level of population density, the agglomeration benefits will raise the the new growth rate above the level it sustained in isolation. These features reflect that transport infrastructure comes at a cost: The more disadvantageous is geography, the more any region has to divert labour force from innovation towards improving its trade relations.

The just mentioned effects stem from the notion of 'fleet investment', which offers two advantages apart from representing a more realistic model of historic transport capital. First, the model is relieved from assigning profits that may arise in a different formulation of transport capital. Second, fleet investment lends itself to generalizing this model to several regions, which may still pertain the concept of localized and selfish considerations in constructing transport capital (and without falling prone to complicated strategic considerations). Finally, I tried to introduce fleet investment in such a way that it may be easily employed in other New Economic Geography models, such as the classics by Krugman (1991) and Fujita et al. (1999).

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Appendix

The following inequalities are intended to underpin the conclusions from section 4. Although not explicitly stated below, the inequalities are based on the parameter restrictions $\rho, \underline{\phi}, \delta_T, \lambda, b \in [0,1]$ and $L^w \geq 0$, a space over which differentiability of the terms below is assumed where necessary.

LEMMA 1. *Inequality* (A-1) *holds under all circumstances:*

$$\frac{\hat{Q}_{CP}^2}{\hat{\phi}_{CP}} \leq \frac{\hat{Q}_{sym}^2}{\hat{\phi}_{sym}} \tag{A-1}$$

Proof. This follows directly from the fact that $\hat{\phi}_{sym} \geq \hat{\phi}_{CP} \geq \underline{\phi}$ and $Q_i \equiv \delta_T(\hat{\phi}_i - \underline{\phi})$. □

LEMMA 2. *In steady state,* $\hat{\phi} - \underline{\phi} \leq \frac{bE^*}{2d_T^2}$ *holds for all parameter settings.*

Proof. Recall that

$$\hat{\phi} - \underline{\phi} = 1 - \underline{\phi} + \frac{1}{2}\Xi - \sqrt{\frac{1}{4}\Xi^2 + \frac{\rho}{\delta_t}(1-\underline{\phi})} \quad \text{where} \quad \Xi \equiv \frac{bE^*}{2\delta_T} + \frac{\rho}{\delta_T} - (1-\underline{\phi})$$

The parameter restrictions require that $0 \leq \hat{\phi} - \underline{\phi} \leq 1 - \underline{\phi}$ and $\Xi \geq -1$. Moreover $\frac{bE^*}{2\delta_T^2} = 0$ implies $\hat{\phi} = \underline{\phi}$.

The first derivative of $\hat{\phi} - \underline{\phi}$ with respect to the parameters $\frac{bE^*}{2\delta_T}$ is straightforward to obtain:

$$\frac{d(\hat{\phi} - \underline{\phi})}{d(bE^*/2\delta_T^2)} = \frac{1}{2}\left(1 - \frac{\Xi}{2\sqrt{\frac{1}{4}\Xi^2 + \frac{\rho}{\delta_T}(1-\underline{\phi})}}\right)$$

Since $\Xi \geq -1$, we have $-1 \leq \frac{\Xi}{2\sqrt{\frac{1}{4}\Xi^2 + \frac{\rho}{\delta_T}(1-\underline{\phi})}} \leq 1$ and thus $0 \leq \frac{d(\hat{\phi}-\underline{\phi})}{d(bE^*/2\delta_T^2)} \leq 1$.[11]

$\hat{\phi} - \underline{\phi}$ therefore never exceeds $\frac{bE^*}{2\delta_T^2}$.

Note that in case of a Core-Periphery steady state, this condition boils down to:

$$\hat{\phi}_{CP} - \underline{\phi} \leq \frac{bL^w}{4\delta_T^2}$$

□

[11] $\hat{\phi} - \underline{\phi}$ is actually a concave function of $\frac{bE^*}{2\delta_T^2}$, as $\frac{d^2(\hat{\phi}-\underline{\phi})}{(d(bE^*/2\delta_T^2))^2} < 0$.

Proposition 3. *In steady state, profits from exports always exceed the cost for fleet maintenance:*

$$a_T \hat{Q}^2 \leq \frac{bE^*}{K^w \Delta^*} \hat{\phi} \qquad \Leftrightarrow \qquad \hat{Q}^2 \leq bE^* \hat{\phi}$$

Proof. This follows directly from Lemma 2:

$$\hat{Q}^2 = \delta_T^2 (\hat{\phi} - \underline{\phi})^2 \leq \delta_T^2 (\hat{\phi} - \underline{\phi}) \hat{\phi} \leq \frac{bE^*}{2} \hat{\phi} \leq bE^* \hat{\phi}$$

□

Lemma 4. *If growth in the symmetric steady state g_{sym} exceeds growth in the corresponding core-periphery steady state g_{CP}, then the parameter λ must be larger than $\hat{\phi}_{sym}$ (the symmetric steady state trade freeness).*

Proof. Suppose that $g_{sym} > g_{CP}$, i.e.

$$\begin{aligned} g_{CP} - g_{sym} &= \frac{bL^w}{2}(1-\lambda) + \frac{\hat{Q}_{sym}^2}{1+\hat{\phi}_{sym}}(1+\lambda) - \frac{\hat{Q}_{CP}^2}{\hat{\phi}_{CP}} < 0 \\ \Leftrightarrow \quad & \frac{bL^w}{2} - \frac{\hat{Q}_{CP}^2}{\hat{\phi}_{CP}} + \frac{\hat{Q}_{sym}^2}{1+\hat{\phi}_{sym}} < \lambda \left(\frac{bL^w}{2} - \frac{\hat{Q}_{sym}^2}{1+\hat{\phi}_{sym}} \right) \end{aligned}$$

Now suppose that $\lambda < \hat{\phi}_{sym}$, thus

$$\begin{aligned} & \frac{bL^w}{2} - \frac{\hat{Q}_{CP}^2}{\hat{\phi}_{CP}} + \frac{\hat{Q}_{sym}^2}{1+\hat{\phi}_{sym}} < \phi_{sym} \left(\frac{bL^w}{2} - \frac{\hat{Q}_{sym}^2}{1+\hat{\phi}_{sym}} \right) \\ \Leftrightarrow \quad & (1-\phi_{sym}) \frac{bL^w}{2} + \hat{Q}_{sym}^2 < \frac{\hat{Q}_{CP}^2}{\hat{\phi}_{CP}} \end{aligned}$$

Since $\frac{\hat{Q}_{CP}^2}{\hat{\phi}_{CP}} \leq \frac{\hat{Q}_{sym}^2}{\hat{\phi}_{sym}}$, this implies

$$\hat{\phi}_{sym}(1-\hat{\phi}_{sym}) \frac{bL^w}{2} < (1-\hat{\phi}_{sym}) \hat{Q}_{sym}^2$$

which violates Proposition 3. Therefore $g_{sym} > g_{CP}$ implies $\lambda > \hat{\phi}_{sym}$. □

Proposition 5. *In any stable Core-Periphery steady state, growth g_{CP} exceeds the growth rate from the corresponding symmetric steady state g_{sym}.*

Proof. According to the discussion on page 16, a stable Core-Periphery (CP) steady state is characterized by $s_E^{nn} < s_E^{EE}$, respectively (from equations (22) and (24)) by the inequality

$$\hat{Q}_{CP}^2 - \hat{\phi}_{CP}\lambda\hat{Q}_{CP}^* + (\lambda - \hat{\phi})b(L^w + \rho) < (1 - \hat{\phi}\hat{\phi}^*)b(\frac{L^w}{2} + \rho)$$

Taking $s_E^{nn} - s_E^{EE}$ as a function of the parameter ρ reveals that $\frac{\partial(s_E^{nn} - s_E^{EE})}{\partial\rho} > 0$. Therefore $s_E^{nn} - s_E^{EE} < 0$ for some $\rho > 0$ implies that for $\rho = 0$ we have evenly $s_E^{nn} - s_E^{EE}|_{\rho=0} < 0$. Note that $\rho = 0$ implies $\hat{\phi} = \hat{\phi}^*$ and $\hat{Q} = \hat{Q}^*$ (cf. equation (20)). Hence CP stability implies:

$$(1 - \hat{\phi}_{CP}\lambda)\hat{Q}_{CP}^2 < (1 - \hat{\phi}_{CP}^2 + 2\hat{\phi}_{CP} - 2\lambda)\frac{bL^w}{2} \tag{A-2}$$

Now suppose that $g_{sym} > g_{CP}$:

$$\begin{aligned} g_{CP} - g_{sym} < 0 \Leftrightarrow \quad & \frac{bL^w}{2}(1-\lambda) + \frac{\hat{Q}_{sym}^2}{1+\hat{\phi}_{sym}}(1+\lambda) - \frac{\hat{Q}_{CP}^2}{\hat{\phi}_{CP}} < 0 \\ \Leftrightarrow \quad & \frac{bL^w}{2}(1-\lambda)\hat{\phi}_{CP}(1+\hat{\phi}_{CP}) < \hat{Q}_{CP}^2(1+\hat{\phi}_{sym}) - \hat{Q}_{sym}^2\hat{\phi}_{CP}(1+\lambda) \quad \text{(A-3)} \end{aligned}$$

Now note that[12]

$$\hat{Q}_{CP}^2(1 + \phi_{sym}) - \hat{Q}_{sym}^2(1+\lambda)\hat{\phi}_{CP} \leq \hat{Q}_{CP}^2 - \lambda\hat{\phi}_{CP}\hat{Q}_{CP}^2$$

One may thus combine the left-hand side of (A-3) and the right-hand side of (A-2) such that

$$\frac{bL^w}{2}(1-\lambda)\hat{\phi}_{CP}(1+\hat{\phi}_{sym}) < \frac{bL^w}{2}(1 - \hat{\phi}_{CP}^2 - 2\lambda + 2\hat{\phi}_{CP}) \tag{A-4}$$

an expression whose left-hand side is non-negative. For the right-hand side, however, note that due to Lemma 4, the case $g_{sym} > g_{CP}$ requires $\lambda > \hat{\phi}_{sym} \geq \hat{\phi}_{CP}$. Hence under a stable CP steady state, $g_{sym} > g_{CP}$ leads to a contradiction in inequality (A-4). □

Proposition 6. *Core-Periphery growth is smaller than growth in isolation $g_{CP} < g_{\underline{\phi}}$ only if $\lambda > \frac{2}{3}$ (Provided the export profitability condition* (13) *holds).*

Proof. Note that $g_{\underline{\phi}} > g_{CP}$ implies

$$\frac{bL^w}{2\delta_T^2}(1-\lambda) < \frac{(\hat{\phi}_{CP} - \underline{\phi})^2}{\hat{\phi}_{CP}} \tag{A-5}$$

[12]Proof: Suppose that $\hat{Q}_{sym}^2(1+\lambda)\hat{\phi}_{CP} < (\hat{\phi}_{sym} + \lambda\hat{\phi}_{CP})\hat{Q}_{CP}^2$. By $\hat{\phi}_{sym} \geq \hat{\phi}_{CP}$, this implies $\hat{Q}_{sym}^2(1+\lambda)\hat{\phi}_{CP} < (1+\lambda)\hat{\phi}_{sym}\hat{Q}_{CP}^2$, which violates the condition stipulated by Lemma 1.

Lemma 2 requires that $\frac{(\hat{\phi}_{CP}-\underline{\phi})^2}{\hat{\phi}_{CP}} < (1-\frac{\underline{\phi}}{\hat{\phi}_{CP}})\frac{bL^w}{4\delta_T^2}$, thus $g_{CP} < g_{\underline{\phi}}$ stipulates that

$$\frac{\hat{\phi}_{CP}+\underline{\phi}}{2\hat{\phi}_{CP}} < \lambda \tag{A-6}$$

From the export profitability condition we have that

$$\hat{Q}_{CP}^2 \leq \frac{bL^w}{2}\underline{\phi}$$

which implies in combination with (A-5) that $(1-\lambda) < \frac{\underline{\phi}}{\hat{\phi}_{CP}}$, respectively

$$\frac{\hat{\phi}_{CP}-\underline{\phi}}{\hat{\phi}_{CP}} \leq \lambda \tag{A-7}$$

Both inequalities (A-6) and (A-7) need to hold simultaneously. As the LHS of (A-6) is decreasing and the LHS of (A-7) is increasing over $\hat{\phi}_{CP} \in [\underline{\phi}, 1]$, λ must be larger than the $\hat{\phi}_{CP}$ at the intersection of the two terms. Therefore $\lambda > \frac{2}{3}$ is a necessary condition for $g_{CP} < g_{\underline{\phi}}$. □