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Transportation, freight rates, and economic geography

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Abstract

We investigate the role of competitive transport markets in shaping the location of economic activity and the pattern of trade. In our model, carriers supply transport services for shipping manufactured goods, and freight rates are set to clear transport markets. Each carrier must commit to the maximum capacity for a round-trip and thus faces a logistics problem as there are opportunity costs of returning empty. These costs increase the freight rates charged to firms located in regions that are net exporters of manufactured goods. Since demand for transport services depends on the spatial distribution of economic activity, the concentration of production in one region raises freight rates to serve foreign markets from there, thus working against specialization and the agglomeration of firms. Consequently, a more even spatial distribution of firms and production prevails at equilibrium when freight rates are endogenously determined than when they are assumed to be exogenous as in the literature.

Keywords: competitive transport markets; freight rates; trade; economic geography

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1 Introduction

Factor mobility and transport costs are the two key ingredients that set apart the New Economic Geography (NEG) from more traditional trade theory. While the implications of factor mobility for trade and the spatial structure of the economy have been analyzed in depth, transport costs have been a more neglected topic. Most of the recent *theoretical* research in New Trade Theory (NTT) and NEG indeed heavily relies on restrictive assumptions about transportation: transport costs are assumed to be incurred in the goods shipped ('iceberg'), they are symmetric irrespective of the shipping direction, and they are independent of the spatial organization of the economy.[1] The most restrictive assumption is, however, that transport costs for goods are treated as being *exogenenous parameters* and not prices set by the interplay of supply and demand. Although this parametric treatment is a good starting point that has allowed to break new ground in the rigorous formalization of 'old stories' about trade patterns and agglomeration in the presence of spatial frictions, it leaves a good deal of those stories unexplained. How are transport costs set by the market? How do they react to changes in supply and demand? And how do changes in supply and demand ultimately feed back on transport costs, trade patterns, and the location of industry?

The study of these questions is not merely an academic exercise. Consider, for example, the growing imbalance in manufactures trade between China and the U.S., which has become an issue for the transport sector as it creates important logistics problems associated with the 'empties'. About 60% of the containers shipped from Asia to North America in 2005 came back empty, and those "that did come back full were often transported at a steep discount for lack of demand [...] shipping companies charge an average of $1,400 to transport a 20-foot container from China to the United States. From the United States to China, the companies charge much less: $400 or $500."[2] A similar picture emerges for air freight as "airlines had become so eager to put something in their cargo holds on the inbound journey to China that rates go as low as 30 to 40 cents a kilogram, compared with $3 to $3.50 a kilogram leaving China."[3]

The foregoing figures strongly suggest that the growing imbalance in China–U.S. merchandise trade is increasingly reflected in transpacific freight rates and that those rates are becoming increasingly asymmetric. The key objective of this paper is to formalize these ideas by endogenizing transport costs through a market mechanism in a model of trade and geography. In our setting, competitive

[1] See, e.g., Krugman (1980), Helpman and Krugman (1985), Krugman (1991), Fujita *et al.* (1999), Ottaviano *et al.* (2002), Fujita and Thisse (2002), and Baldwin *et al.* (2003).

[2] The various figures and quotes are taken from the International Herald Tribune, Online Edition (by T. Fuller, January 30, 2006; `http://www.iht.com/articles/2006/01/29/business/ships.php?page=1`); and from `http://www.logisticstoday.com/displayStory.asp?sNO=8200`. Further evidence is provided by the *Review of Maritime Transport* (2007, Table 37), which reports the following ratios for container freight rates: 737$/1,643$ between the U.S. and Asia; 755$/1,549$ between Europe and Asia; and 1,032$/1,692$ between the U.S. and Europe (all values being expressed in U.S. dollars per twenty foot equivalent units, TEU).

[3] International Herald Tribune, *op. cit.*

carriers supply transport services for shipping manufactures across regions, and *freight rates* — the prices for transport services — are determined to clear transport markets. Carriers must commit to the maximum transport capacity required for a round-trip and, therefore, face a logistics problem: there is an opportunity cost associated with returning empty ('backhaul problem'), and that opportunity cost depends on the shipping direction. For instance, when a container ship returns partly empty to its harbor of origin, that ship has a very low opportunity cost of transporting additional goods in that direction. Carriers are then enticed to undercut the price set by any fully loaded ship so that there is downward pressure on freight rates in the direction of excess supply of transport services. By symmetry, there is upward pressure on freight rates in the opposite direction.

This simple market mechanism has two consequences. First, freight rate asymmetries widen with increasing imbalances in trade flows, as observed in reality. Second, since imbalances in trade flows are closely linked to the spatial clustering of economic activity, freight rates tend to increase in economic core regions (that produce a lot of manufactures), thus creating a cost wedge for shipping across different markets. Many models of trade and geography show that firms have incentives to save on either production costs or transport costs by locating in markets with either lower wages or larger demand. Yet, the foregoing cost-savings argument must be qualified in the presence of endogenous freight rates since the region specializing in manufacturing — being a net exporter of manufactures — also tends to have higher freight rates. The latter reduce firms' incentives to locate in that region by raising 'delivered' production costs, thereby working against specialization and the clustering of economic activity.

To formally explore the links between trade, geography, and freight rate asymmetries, we incorporate a competitive transport sector into the model developped by Ottaviano *et al.* (2002). That model allows us to deal with both trade ('footloose capital model') and geography ('core-periphery model') in a simple way. Carriers supply a homogeneous transport service under constant returns, which manufacturing firms use to ship their output across regions. Transport costs are assumed to be linear, which fits with the empirical findings by Hummels and Skiba (2004) who reject add-valorem transport costs of the iceberg-type. Our assumption of competitive transport markets is mostly relevant for high density routes that are also the routes where trade imbalances are larger (e.g., China–U.S.–Europe). It may be less relevant for low density peripheral routes that are monopolized by a few carriers with inferior shipping technologies, higher freight rates, and stronger price discrimination across cargo types.[4] Although the assumption of perfect competition in the transport sector simplifies the analysis, it is not essential to our qualitative results. Indeed, the basic logistics problem created by trade imbalances between locations also arises in transport markets characterized by imperfectly competitive structures. As a case in point,

[4]The empirical findings seem mixed. Whereas Clyde and Reitzes (1995) find no relationship between freight rates and carriers' market concentration on shipping routes, Hummels *et al.* (2009) find that freight markups are slightly increasing with market concentration (Skiba, 2007, finds that freight rates fall with overall trade volumes). Francois and Wooton (2001) argue that ocean shipping is organized by shipping conferences that are suspected to sustain collusion. Yet, Stopford (2009) finds that the concentration of ownership is rather low in the container liner fleet as compared to other industries, and Sjostrom (1989) finds no significantly higher markups. Larger markups are, however, found for the air transportation sector (e.g., Micco and Serebrisky, 2006).

a monopolistic carrier would also set higher freight rates for goods originating from locations that have larger outbound export volumes.

Previewing our key results, we first show that the existence of a competitive transport sector significantly dampens the so-called Home Market Effect (HME) that is typically emphasized in the NTT and NEG literatures. In particular, when the physical cost of transporting goods becomes sufficiently small in the footloose capital (FC) model, exogenous freight rates lead to full agglomeration of firms in the larger region, whereas endogenous freight rates yield dispersion of firms with no home market bias. Endogenous freight rates respond to trade imbalances and thus reduce the extent of specialization and clustering of economic activity. This result continues to hold when (i) transportation includes exogenous loading/handling costs that are not affected by the backhaul problem, and (ii) in more complex version of the model where all goods incur trade costs. Second, we show that in the core-periphery (CP) model, endogenous freight rates lead to multiple and different types of stable spatial equilibria. In particular, whereas only full agglomeration is a stable equilibrium under exogenous freight rates when the physical cost of transporting goods is low, both full agglomeration and full dispersion may simultaneously be stable equilibria under endogenous freight rates.

The remainder of the paper is organized as follows. Section 2 selectively surveys the related literature. Section 3 develops the basic model and describes the structure of the transport sector. Section 4 investigates the footloose capital model and shows that endogenous freight rates are a strong dispersion force. We provide several robustness checks and show that our qualitative results hold true even when we relax various critical assumptions. Section 5 then extends the discussion to the core-periphery model and characterizes the spatial equilibria. Finally, Section 6 concludes.

2 Related literature

The presence of trade costs in classical trade theory can be traced back at least to Samuelson (1954) and Mundell (1957). These authors discussed the role of transportation in trade under the convenient assumption of 'iceberg costs', i.e., costs that are directly incurred in terms of the goods shipped across locales. This modeling strategy turned out to be so convenient — allowing for trade frictions while obviating the need for a separate transport sector — that it has been widely followed in most of classical trade theory, NTT, and NEG. Consequently, the theoretical literature in those fields has, in general, devoted rather little attention to the modeling of a separate transport sector. However, several early trade theorists have considered that sector in more detail. Falvey (1976), Cassing (1978a), and Casas and Choi (1985), among others, all model a separate transport sector in full-fledged general equilibrium Heckscher-Ohlin-Samuelson models. Their key objectives are to investigate how the presence of that sector affects relative prices across countries, alters trade volumes and modifies the potential gains from trade. See Casas (1983) and Botazzi and Ottaviano (1996) for overviews of these results.

The NTT and NEG literatures have also devoted some attention to the explicit modeling of transport costs and their impacts on trade flows, the distribution of economic activity, and regional specialization.

Takahashi (2006) discusses the consequences of both government spending on infrastructure and the choice of transport technology on the agglomeration process. Behrens and Gaigné (2006) and Behrens *et al.* (2006) endogenize transport costs by assuming the presence of transport density externalities. Although these contributions enrich the modeling of transport costs, they do not really incorporate a transport sector. There are but a few contributions that consider explicitly such a sector in the presence of spatial factor mobility and imperfect competition. Gasiorek (1997) develops a three sector model with a 'trading resource' sector that competes for production factors. He shows that the effects of trade liberalization on welfare crucially hinge on ad valorem vs specific freight rates and on the factor intensity of the trading sector. Larch (2007) traces out the implications of the internationalization of the transport sector on the volume of trade and on incomes in a NTT model. Last, Behrens *et al.* (2009) investigate how the number of carriers operating in the market changes the spatial distribution of economic activity and how deregulation in an imperfectly competitive transport sector maps into welfare changes.

While the trade literature has somewhat analyzed transport costs in general terms it has, however, not devoted much attention to the backhaul problem *per se*. Wicksell (1918, p.407) pointed out that "the increased number of ships going from England to America with full load, and bound to go back in ballast or with insufficient cargo, must increase the transport charges on goods going one way and diminish the cost of sending goods the other way." Cassing (1978b) is perhaps the only author who discusses the importance of the backhaul problem for several trade patterns and the possible lack of product tradability in a one-factor Ricardian model. Casas (1983) also briefly sketches the problem of transport as a 'joint production' (fronthaul and backhaul), but his analysis remains mostly discursive. We know of no contributions to the analysis of the backhaul problem in NTT or NEG settings with mobile factors and imperfect competition in product or transport markets.

By contrast, the backhaul problem has attracted considerable attention in the operational research, industrial organization and transportation literatures. Indeed, many classes of backhaul problems have been extensively analyzed, mostly as cases of (time constrained) vehicle routing and scheduling problems. These problems consist in finding optimal routes and schedules to minimize the distance and/or time that vehicles travel unloaded (see, e.g., Desrosiers *et al.* 1995, and Cordeau *et al.*, 1998, for surveys). Another strand of the literature has more specifically investigated the management and allocation of empty containers across multiple ports (Li *et al.*, 2007) or the allocation of empty freight cars across railway networks (Holmberg *et al.*, 1998; Joborn *et al.*, 2004). See Dejax and Crainic (1987) for an extensive review of the models dealing with empty flows and backhaul problems in freight transportation. In contrast to the economics literature, the foregoing contributions do not consider that product and transport prices are endogenously set by markets.

The transport economics literature offers a narrower set of formal discussions about the impact of backhaul problems on prices in transport and product markets. Felton (1981) analyzed the consequences of Interstate Commerce Commission rate regulation that impeded the carriers' ability to adjust their backhaul rates to trade imbalances and that, therefore, exacerbated the problem of the 'empties'. More recently, Anderson and Renault (2008) study the backhaul problem in imperfectly competitive markets as an element of the larger theory of price discrimination for joint production. Anderson and Wilson (2008) extend that analysis to the case of a dominant firm that faces a competitive fringe. Demriel *et al.* (2010) develop a matching model between clients and carriers to analyze how freight rates are set on both front- and backhaul trips. Imperfect information about matches and the implied search and waiting costs are shown to be important in determining freight rates.[5]

Turning finally to empirical economic studies, there is ample evidence on the links between directional trade imbalances and asymmetric freight rates. Going beyond armchair evidence (see the introduction), Márquez-Ramos *et al.* (2005) find that freight rates for goods exported from Spain are significantly lower than for goods imported to Spain. They explain this difference by the 50% capacity underutilization of containerships in the outbound leg of maritime trips. Clark *et al.* (2004) and Blonigen and Wilson (2008) show that directional trade imbalances between the U.S. and their trading partners have a significant effect on freight rates and/or import charges. Jonkeren *et al.* (2011) investigate trade imbalances across the northwestern European inland waterways and find that imbalances in regional trade flows have a substantial causal effect on transport prices. All of these studies suggest that there exist sizable freight rate asymmetries across markets, that they are linked to regional imbalances in trade flows, and that they may have important impacts on the spatial structure of the economy and, therefore, trade flows.

3 Basic model

We start by presenting the basic two-region trade and location model that extends the framework discussed by Ottaviano *et al.* (2002) and Ottaviano and Thisse (2004). In our setting, manufacturing firms first choose their location; transport firms then offer transport services to maximize profits and freight rates are determined to clear the transport market; last, manufacturing firms maximize profits and product markets clear. We solve the model backwards starting with the product market for a given spatial distribution of firms and freight rates. We then characterize the equilibrium freight rates, taking the spatial distribution of firms as still given (short run). Finally, in Section 4, we derive the spatial equilibrium distribution of manufacturing firms, the pattern of specialization and, in Section 5, the spatial distribution of population (long run).

3.1 Preferences, technology and product prices

Consider a world with two regions and three sectors: a 'traditional' competitive sector, a monopolistically competitive 'manufacturing' sector, and a transport sector. Variables associated with the two regions will be subscripted by $i = H, F$ ('home' and 'foreign'). We assume that there is a mass L of

[5] Rietveld and Roson (2002) consider the backhaul problem in the context of public transportation. We do not survey that abundant literature in more detail here.

workers/consumers, a share θ_H of which is located in region H. In what follows we also assume, without loss of generality, that region H is larger ($1/2 \leq \theta_H < 1$). All consumers have identical quasi-linear preferences over a homogeneous good produced by the traditional sector, and a unit mass of varieties of a horizontally differentiated good produced by the manufacturing sector.[6] The subutility over the varieties $v \in [0,1]$ of the manufactured good is quadratic. Preferences in region i are as follows:

$$U_i \equiv \alpha \int_0^1 q_i(v)\mathrm{d}v - \frac{\beta-\gamma}{2}\int_0^1 [q_i(v)]^2 \mathrm{d}v - \frac{\gamma}{2}\left[\int_0^1 q_i(v)\mathrm{d}v\right]^2 + q_i^0, \tag{1}$$

where $q_i(v)$ denotes the consumption of variety v; where q_i^0 stands for the consumption of the homogeneous good; and where $\alpha > 0$, $\beta > \gamma \geq 0$ are preference parameters.

Each consumer is endowed with $\overline{q}^0 > 0$ units of labor that can be supplied to any sector. Labor is perfectly mobile across sectors, so that there is a single wage rate w_i in each region. Production in the traditional sector takes place under constant returns to scale and one unit of labor produces a unit of the homogenous good. We assume that the output of that sector can be costlessly traded between regions, which makes sure that its price is equalized across markets and equals marginal cost. We choose it as the numéraire ($p_i^0 = p_j^0 = w_i = w_j \equiv 1$). Each agent maximizes her utility (1) subject to her budget constraint

$$\int_0^1 p_i(v)q_i(v)\mathrm{d}v + q_i^0 \leq \overline{q}^0 + e_i, \tag{2}$$

where $p_i(v)$ stands for the consumer price of variety v in region i; and where e_i denotes her earnings expressed in terms of the numéraire. The latter will include elements such as the capital rents in the footloose capital model (Section 4), or entrepreneurial profits in the footloose entrepreneur model (Section 5). Maximizing (1) subject to (2) yields the following individual demands:[7]

$$q_i(v) = a - (b+c)p_i(v) + c\int_0^1 p_i(v)\mathrm{d}v,$$

where a, b and c are positive coefficients given by $a \equiv \alpha/\beta$, $b \equiv 1/\beta$ and $c \equiv \gamma/[(\beta-\gamma)\beta]$.

We assume that manufacturing firms are symmetric and differ only by their location and by the particular variety they produce. This allows us to alleviate notation by suppressing the variety index v. Let p_{ij} stand for the consumer price of a variety produced in i and sold in j, and let n_H and n_F denote the distribution of manufacturing firms across the two regions. Aggregate demand for a variety produced in i and consumed in j is then given by $Q_{ij} \equiv \theta_j L q_{ij} = \theta_j L[a - (b+c)p_{ij} + c\,P_j]$, where $P_j \equiv n_j p_{jj} + n_i p_{ij}$ denotes the average consumer price in market $j = H, F$.

[6]As shown in Section 3.4 below, our key qualitative results do neither depend on quasi-linearity nor on the presence of a costlessly tradable numéraire good.

[7]As in Ottaviano *et al.* (2002), we assume that the labor endowment $\overline{q}^0$ is large enough for agents to consume the numéraire good in equilibrium, i.e., $q_i^0 > 0$. In that case, all income effects are embedded in the demand for the costlessly tradeable numéraire good and the distribution of firms' profits to shareholders and the location where these profits are generated are immaterial.

As with the traditional sector, workers can be employed at unit productivity in the transport sector. For simplicity, we assume that transportation is a homogeneous service and that it takes the same amount of labor to ship each variety of the manufactured good. However, *transport services are differentiated with regard to the shipping direction*. Put otherwise, transport services from H to F and from F to H are different goods. Carriers offer services in each direction at unit freight rates t_{HF} (from H to F) and t_{FH} (from F to H) that are determined within competitive transport markets.[8] Since our focus is to analyze how freight rates affect regional specialization as well as trade patterns and the spatial distribution of economic activity, we abstract from internal trade costs by assuming that transporting the good within each region is costless ($t_{HH} = t_{FF} = 0$). Because we assume that the transport market is perfectly competitive and that transportation is a homogeneous service in each direction, freight rates are independent of the chosen carrier.[9]

Production of each variety of the manufactured good requires a constant variable labor input, and a fixed input f of another factor. Without loss of generality, we normalize the variable input requirement to zero.[10] The profit of a manufacturing firm established in region i is then given by

$$\Pi_i = p_{ii}Q_{ii} + (p_{ij} - t_{ij})Q_{ij} - fr_i, \qquad i \neq j, \tag{3}$$

where r_i stands for the returns to the fixed production factor. Note that (3) consists in the operating profits from local sales, the operating profits from exports ('distant sales'), minus the total payment fr_i to the firm's fixed production factor. This fixed factor, and its price, can be either capital and capital rentals in the footloose entrepreneur model (Section 4), or entrepreneurs' (skilled workers) earnings (time) in the core-periphery model (Section 5). We need not make a distinction between these interpretations for now, but we will come back to this point a bit later as it has implications for the spatial structure of economic activity and the agglomeration process.

Since each manufacturing firm is negligible to the market, it has no impact on the average price P_i, on the firm distribution (n_H, n_F), and on the freight rates t_{HF} and t_{FH}. Maximizing profits (3) with respect to prices yields a linear system of four first-order conditions. It is readily verified that the profit maximizing product prices and outputs in market i are given by

$$p_{ii}(P_i) = \frac{1}{2}\frac{a + cP_i}{b + c} \quad \text{and} \quad p_{ji}(P_i) = p_{ii}(P_i) + \frac{1}{2}t_{ji}, \quad i \neq j$$
$$q_{ii} = (b + c)\, p_{ii} \quad \text{and} \quad q_{ji} = (b + c)\,(p_{ji} - t_{ji})\,, \quad i \neq j,$$

[8]We assume that manufacturing firms outsource transportation. This assumption seems reasonable to us since, according to figures from the Bureau of Transport Statistic, \$192 billion of the \$313 billion of transportation services in the U.S. in 1992 were generated by for-hire transportation. Although the in-house figure of \$121 billion is substantial, it turns out that the manufacturing sector uses the largest share of for-hire transport services (about 80%).

[9]Adding product differentiation to the transport sector (in terms of, e.g., shipping frequencies, extra services on certain routes, specialized handling,...), though relevant from an empirical point of view, is unlikely to materially change our main results. In Section 3.2, we discuss in more depth the assumption of a competitive transport sector.

[10]Introducing a constant marginal labor requirement m into the model is equivalent to rescaling the demand intercept $a/(b + c)$ to $a/(b + c) - m$ (see Ottaviano *et al.*, 2002). As the choice of the parameters a, b and c is free, we can set $m = 0$ without loss of generality.

which depend on the average prices P_H and P_F, themselves functions of the product prices. Solving for the fixed point, we readily obtain the equilibrium prices as follows:

$$p_{ii}^* = \frac{1}{2}\frac{2a + cn_j t_{ji}}{2b + c} \quad \text{and} \quad p_{ji}^* = p_{ii}^* + \frac{t_{ji}}{2}, \quad i \neq j. \tag{4}$$

If we assume that $t_{HF} = t_{FH} = \tau$, expressions (4) are identical to those in Ottaviano *et al.* (2002). The fundamental difference between their model and ours is that we consider that freight rates are: (i) determined by supply and demand in a competitive transport market; and (ii) not symmetric in both directions. This has profound implications for the spatial distribution of firms and alters several results derived in standard trade and NEG models.

To make sure that trade is always feasible and bilateral, i.e., $q_{HF}^* > 0$ and $q_{FH}^* > 0$ for any interregional allocation of firms, we impose the following *trade feasibility condition* on freight rates:

$$\max\{t_{HF}, t_{FH}\} < \frac{2a}{2b + c}. \tag{5}$$

In what follows, we assume that (5) holds, which simply requires a high enough demand for manufactured goods (as per a large a).

3.2 Transportation and freight rates

As stated before (see footnote 8), the majority of U.S. manufacturing firms does not provide in-house transportation. Instead, these firms rely on for-hire transport services supplied by either privately owned and independent carriers (e.g., maritime freight, trucking, air freight), or by state-owned or regulated carriers (e.g., rail transportation). In unregulated transport industries, many private carriers supply transport services under constant returns to scale in the long run — the building of fleet capacity being usually the most important fixed-cost element. In most regulated transport industries (e.g. railways), transport services are supplied under increasing returns to scale that stem from the cost of infrastructure. As infrastructure is a cause for monopolistic behavior and positions, many countries have separated the infrastructure management from the provision of transport services *per se*. As a result, the transport market has become more competitive as transport services are now supplied by a larger set of independent carriers. For these reasons, we henceforth model the transport sector as a competitive industry.[11]

We start with the equilibrium of the transport sector for a given population distribution (θ_H, θ_F) and a given firm distribution (n_H, n_F). We assume, without loss of generality, that one unit of transport

[11] Our results would be qualitatively similar under cartelization of the transport sector as it would be optimal for cartels to differentiate freight rates according to directional trade imbalances. See Behrens *et al.* (2009) for the case of imperfectly competitive carriers producing a homogeneous transport service within an oligopolistic market structure. These authors find that (symmetric) endogenous freight rates reduce the propensity of economic activity to spatially concentrate since agglomeration makes demands for transport services less elastic and, thereby, increase de facto carriers' market power. The qualitative results are therefore similar to ours, despite a very different mechanism.

service is required to ship one unit of manufacturing output. One unit of transport service requires τ units of labor. For now, we assume for simplicity that there are no loading costs so that τ reflects the full cost of shipping a unit across regions. We will come back to that point in Section 3.3 where we consider the existence of fixed loading costs for goods.

The demand for transport services from i to j, by a manufacturing firm located in i, is thus given by Q_{ij}. The total demand for transport services in that direction can be expressed as follows:

$$D_{ij}(t_{ij}) \equiv n_i Q_{ij} = \frac{1}{2} L\theta_j \left[a + cP_j - (b+c)\, t_{ij}\right] n_i, \quad i \neq j. \tag{6}$$

As can be seen from expression (6), the demand for transport services naturally increases as the freight rate t_{ij} falls. It also increases when region i hosts more exporters (larger n_i) and when region j has a larger population (larger θ_j).

Each carrier provides transport services in both directions and faces a simple logistics problem: he must commit to the capacity required by the largest demand on a return trip. Put differently, the capacity required for the return trip is that in the direction of the largest demand for transport services. Carrier k thus earns the following profit:

$$\Pi^k \equiv t_{HF} S^k_{HF} + t_{FH} S^k_{FH} - 2\tau \max\left\{S^k_{HF}, S^k_{FH}\right\}, \tag{7}$$

where S^k_{HF} and S^k_{FH} denote his supply of transport services from i to j and from j to i, respectively; and where 2τ stands for the physical cost of a return trip that he must commit to. A *competitive equilibrium in the transport sector* is given by the non-negative freight rates (t_{HF}, t_{FH}) and supplies of transport services $(\sum_k S^k_{HF}, \sum_k S^k_{FH})$ such that: (i) carriers supply profit-maximizing quantities of transport services, taking freight rates, manufacturing prices, and the location of firms and consumers (n_i and θ_i) as given; (ii) carriers are free to enter and exit; and (iii) demand for transport services equals supply in each direction ($D_{ij} = \sum_k S^k_{ij}$).

Given profits (7), the carriers' supply depends on the equilibrium freight rates for a return trip. No carrier will enter and supply any service if $t_{HF} + t_{FH} < 2\tau$. Any carrier will enter and supply an infinite amount of transport services if $t_{HF} + t_{FH} > 2\tau$. Last, carriers will enter and supply any amount of transport services at $t_{HF} + t_{FH} = 2\tau$. In other words, transport firms supply a non-zero and finite quantity of transport service and earn zero profits if and only if

the freight rates for a return trip equal its cost. A competitive equilibrium therefore exists in two cases (see Appendix A for technical details). In the first one, both transport markets clear at non-zero freight rates, i.e., $t^*_{HF} > 0$ and $t^*_{FH} > 0$. Because the supplies of transport services are equal in both directions in such an equilibrium, demands must also be equal in both directions: $S^k_{HF} = S^k_{FH} \iff \sum_k S^k_{HF} = \sum_k S^k_{FH} \iff D_{HF}(t^*_{HF}) = D_{FH}(t^*_{FH})$. A competitive equilibrium with non-zero freight rates therefore satisfies the following two conditions: $D_{HF}(t^*_{HF}) = D_{FH}(t^*_{FH})$ and $t^*_{HF} + t^*_{FH} = 2\tau$. In the second case, one transport market clears at a non-zero price whereas the other market clears at a zero price with an excess supply of transport services. Suppose that $t^*_{HF} > 0$ and that $t^*_{FH} = 0$. In equilibrium, the freight rate t^*_{HF} must be equal to the cost of a return trip, i.e., $t^*_{HF} = 2\tau$ for carriers to operate. The first market then clears when $\sum_k S_{HF}^k = D_{HF}(2\tau)$, whereas the second market has excess supply $\sum_k S_{FH}^k > D_{FH}(0)$. Such a competitive equilibrium obviously occurs if and only if $D_{HF}(2\tau) > D_{FH}(0)$, i.e., if demands for transport services in the two directions become sufficiently asymmetric. Finally, given that the maximal transport cost is equal to 2τ, the *trade feasibility condition* (5) can be rewritten as follows:

$$\tau < \tau^{\text{trade}} \equiv \frac{a}{2b+c}. \tag{8}$$

3.3 Factor rents and spatial equilibrium

We now turn to the location of manufacturing firms (n_H, n_F) given the population distribution (θ_H, θ_F) and the equilibrium freight rates (t_{HF}^*, t_{FH}^*). Each manufacturing firm in country $i = H, F$ earns profits equal to $\Pi_i = (b+c)\left[L\theta_i p_{ii}^{*2} + L\theta_j \left(p_{ij}^* - t_{ij}^*\right)^2\right] - fr_i$. In a free entry equilibrium, these profits are absorbed by the payments to the fixed factor, which implies that

$$r_i^* = \frac{L(b+c)}{f}\left[\theta_i p_{ii}^{*2} + \theta_j \left(p_{ij}^* - t_{ij}^*\right)^2\right]. \tag{9}$$

The *factor rent differential* across regions is equal to

$$\Delta r^* = r_H^* - r_F^* = R_H\left(t_{FH}^*\right) - R_F\left(t_{HF}^*\right), \tag{10}$$

where we define the *'access gain' from producing in market i* as follows:

$$R_i\left(t_{ji}^*\right) \equiv \frac{L(b+c)}{f}\theta_i\left[p_{ii}^{*2} - \left(p_{ji}^* - t_{ji}^*\right)^2\right]. \tag{11}$$

The foregoing expression captures changes in profits generated in market i if a firm producing in region j were to relocate to region i. Among other things, expression (11) depends on the equilibrium freight rates. Using the equilibrium prices, it can be expressed as follows:

$$R_i\left(t_{ji}^*\right) = \frac{L(b+c)}{f}\theta_i t_{ji}^*\left(p_{ii}^* - \frac{t_{ji}^*}{4}\right) = \frac{L(b+c)}{f}\theta_i t_{ji}\frac{4a - t_{ji}\left[2b + c\left(n_i - n_j\right)\right]}{4\left(2b+c\right)}. \tag{12}$$

Observe that the factor rent differential (10) is positive when the access gain from producing in region H exceeds that from producing in region F. A positive factor rent differential creates an incentive for factor owners to relocate their factors to region H, whereas a negative differential has the opposite effect. We define a *spatial equilibrium* as a distribution of factors and firms such that: (i) product and factor markets clear at the equilibrium prices p_{ij}^*, t_{ij}^* and r_i^* (for $i = H, F$); and (ii) no factor can secure a higher return by being reallocated to another region. Put differently, a spatial equilibrium is a value of n_H^* that satisfies one of the following three conditions (recall that $n_F = 1 - n_H$): (i) $\Delta r^* = 0$ with $n_H^* \in (0,1)$; or (ii) $\Delta r^* \geq 0$ with $n_H^* = 1$; or (iii) $\Delta r^* \leq 0$ with $n_H^* = 0$. Case (i) will be referred to as an interior equilibrium, whereas cases (ii) and (iii) will be referred to as corner equilibria ('agglomerated' equilibria, to use the NEG terminology) in which one region completely specializes in the production of the traditional constant-returns good.

We now present two versions of the model that have been widely used in the NTT and the NEG literatures: the *footloose capital model* where factor owners are assumed to be immobile capitalists (see, e.g., Baldwin *et al.*, 2003; Forslid and Ottaviano, 2003); and the *core-periphery model* where factor owners are assumed to be mobile entrepreneurs or skilled workers (see, e.g., Krugman, 1991; Fujita *et al.*, 1999; Ottaviano *et al.*, 2002).

4 Footloose capital model

NTT models in the wake of Krugman (1980) emphasize that regional market size asymmetries entice firms to save on transport costs by locating close to their larger markets. In equilibrium, large markets then either: (i) host a share of firms in excess of their share of world demand, an outcome dubbed the Home Market Effect (e.g., Helpman and Krugman, 1985); or (ii) have higher factor prices (e.g., Krugman, 1980). We now show that the presence of a competitive transport sector subject to backhaul problems significantly qualifies these results. The intuition is that too much specialization in manufacturing is no longer feasible since it increases the freight rate differential across regions. Consequently, the HME gets strongly dampened so that a more even spatial equilibrium distribution of firms prevails and regions are less specialized.

To build intuition, we first briefly review the HME in a standard setting with exogenous and identical transport costs. We then show that manufacturing firms are enticed to agglomerate less when freight rates are set by a competitive transport sector. We show, in particular, that the HME may entirely disappear when transport costs τ are sufficiently small. We finally check the robustness of our results to the existence of fixed loading/handling costs that are not subject to backhaul problems, and to the absence of the costlessly tradeable homogenous good q_0. As will become clear, our key qualitative results are fairly robust to all those changes.

In the remainder of this section, we assume that market sizes $\theta_H \geq \theta_F \equiv 1 - \theta_H$ are exogenously given and that there is no expenditure mobility across countries. In that model, the fixed factor f can be interpreted as capital used by manufacturing firms, so that r_i stands for the capital rents that are repatriated to their owners.

4.1 Exogenous and identical freight rates

In this benchmark case, we assume that $t_{HF} = t_{FH} = \tau$, i.e., transport costs exactly equal half of the marginal cost of the return trip. The manufacturing prices, as given by (4), can be rewritten as:

$$p_{ii}^* = \frac{1}{2}\frac{2a + cn_j\tau}{2b + c} \quad \text{and} \quad p_{ji}^* = p_{ii}^* + \frac{\tau}{2}, \quad \forall i \neq j. \tag{13}$$

An (interior) spatial equilibrium can be determined from the condition that factor returns be equalized across countries, i.e.,

$$\Delta r^* = \frac{L(b+c)\tau}{f}\left[\theta_H\left(p_{HH}^* - \frac{\tau}{4}\right) - \theta_F\left(p_{FF}^* - \frac{\tau}{4}\right)\right] = 0. \tag{14}$$

Substituting the equilibrium prices (13), the foregoing expression can readily be solved to yield

$$n_H^* = \begin{cases} \frac{1}{2} + \left(\theta_H - \frac{1}{2}\right) \frac{4a - 2b\tau}{c\tau} & \text{if} \quad \theta_H \leq \overline{\theta}_H \\ 1 & \text{otherwise,} \end{cases} \tag{15}$$

where $\overline{\theta}_H \equiv \frac{1}{2} + \frac{1}{2}c\tau/(4a - 2b\tau) < 1$ denotes the threshold market size asymmetry above which all firms agglomerate into the larger region. The disproportionate share of industry in the larger region can then be easily seen by reshuffling the above expression as

$$n_H^* - \frac{1}{2} = \underbrace{\frac{4a - 2b\tau}{c\tau}}_{>1} \left(\theta_H - \frac{1}{2}\right). \tag{16}$$

In words, an increase in the size of a region maps into a more than proportionate increase in the mass of firms established there, which is one way of viewing the HME. As shown by expression (16), the HME is 'magnified' by lower transport costs. In particular, when τ becomes small, the HME becomes so strong that full agglomeration occurs for any regional size asymmetries.

4.2 Endogenous freight rates

We now relax the assumption that freight rates are exogenously given constants. Assume instead that they are determined by the market clearing conditions for transport services. We first characterize the case where freight rates are non-zero, i.e., when interregional shipments are balanced. Assume that $D_{HF} = D_{FH}$ which, as shown in Section 3.2, implies that $t_{HF}^* + t_{FH}^* = 2\tau$, $t_{HF}^* > 0$ and $t_{FH}^* > 0$. The equilibrium freight rate is given by

$$t_{ij}^* = \frac{2[a(\theta_i - n_i) - \theta_i(1 - n_i)(2b + cn_i)\tau]}{2b[n_i(2\theta_i - 1) - \theta_i] - cn_i n_j}, \tag{17}$$

which is feasible if and only if $0 \leq t_{ij}^* \leq 2\tau$. One can readily verify that

$$\lim_{n_i \to 0} t_{ij}^* = 2\tau - \frac{a}{b} < 0 \quad \text{and} \quad \lim_{n_i \to 1} t_{ij}^* = \frac{a}{b} > 2\tau, \tag{18}$$

where the inequalities stem from the trade feasibility condition (8). Expressions (18) show that *configurations close to full agglomeration are never compatible with a situation where freight rates are non-zero in both directions*. This is because carriers' excess capacity in one direction does not vanish at the lowest possible zero freight rate. Some cumbersome computations, making use of the trade feasibility condition, show that

$$\frac{\partial t_{ij}^*}{\partial n_i} > 0 \quad \text{and} \quad \frac{\partial t_{ij}^*}{\partial \theta_j} > 0. \tag{19}$$

As expected, the freight rate from i to j increases with the share of firms operating in region i and with the size of region j. The intuition is that the larger region i's share of firms or the larger its trading partner j's demand, the larger its share of production and exports. This results in an imbalance between the volumes of exports and imports, thereby putting strain on carriers that have to commit resources to return trips. The freight rates for exports from i to j thus rise and reduce region i's firms competitiveness and exports; by contrast, the freight rates for imports from j to i fall and boost regions j's firms competitiveness and exports. When the imbalance gets too large — which occurs close to full agglomeration — the freight rates from the smaller to the larger country fall to zero, thus providing firms with incentives to set up operations there.

We now turn to the impact of the transport sector on firms' locations and the HME. To begin with, we study the conditions under which full agglomeration may occur. When there is full agglomeration in the larger region ($1/2 \leq \theta_H < 1$ and $n_H = 1$), (18) implies that both freight rates cannot be simultaneously positive. Therefore, the freight rate for shipping goods from the region with the smaller demand for transport services must fall to zero ($t^*_{FH} = 0 < 2\tau = t^*_{HF}$). The incentives to locate in region H are then equal to

$$\Delta r^* = R_H(0) - R_F(2\tau) = -\frac{2\tau L(b+c)(1-\theta_H)}{f}\left(p^*_{FF} - \frac{\tau}{2}\right) < 0, \tag{20}$$

where the last inequality directly follows from the equilibrium prices and the trade feasibility condition. Hence, *full agglomeration is never an equilibrium* for any $1/2 \leq \theta_H < 1$ under endogenous freight rates. We can thus already conclude that firms tend to disperse more and regional specialization tends to be less strong in the presence of endogenous freight rates. To see this more formally, we assume that $1/2 \leq \theta_H \leq \overline{\theta}_H$ and fix the firm distribution to the interior equilibrium (15) obtained under exogenous freight rates. We then ask whether firms are enticed to disperse further if freight rates become endogenous. At an interior spatial equilibrium (15), the access gains from producing in each region are identical: $R_H(\tau) = R_F(\tau)$. Now observe that

$$\frac{\mathrm{d}R_i}{\mathrm{d}t^*_{ji}} = \frac{L(b+c)}{f}\theta_i \frac{2a - [2b + c(n_i - n_j)]\, t^*_{ji}}{2(2b+c)} > 0, \tag{21}$$

where the inequality comes from the condition $t_{ji} < 2\tau < 2a/(2b+c))$ for all $0 \leq n_i \leq 1$. Therefore, when $t^*_{FH} < \tau < t^*_{HF}$, we see that $R_H(t^*_{FH}) < R_H(\tau) = R_F(\tau) < R_F(t^*_{HF})$, which implies that $\Delta r^* < 0$. *Firms therefore unambiguously have an incentive to disperse more under endogenous freight rates at any interior equilibrium.*

We can also investigate the location equilibrium when the transport costs τ are close to zero. In that case, because $t^*_{HF} + t^*_{FH} = 2\tau$, both equilibrium freight rates t^*_{HF} and t^*_{FH} also tend to zero. The prices tend to $a/(2b+c)$, so that freight rates are of second-order magnitude when compared to prices. As a result, expression (10) can be approximated to the first order by

$$\Delta r^* \simeq \frac{L(b+c)a}{f(2b+c)}\left(\theta_H t^*_{FH} - \theta_F t^*_{HF}\right). \tag{22}$$

The incentives to relocate to region H simply depend on the difference between the transport bills $\theta_i L t^*_{ji}$ firms have to pay in both directions. The reason is that, since freight rates are very low compared to product prices, the latter ones are very similar in both markets. The factor rent differential then solely stems from the tiny difference between the transport bills when exporting to region H or F. When freight rates are exogenous and identical in both directions, the transport bill is larger for exporting to the larger region H, which entices firms to produce in that region (to minimize transport costs). At the spatial equilibrium, firms fully agglomerate in region H because $\Delta r^* \propto (\theta_H - \theta_F)\,\tau > 0$ irrespective of the spatial structure of the economy. By contrast, when freight rates are endogenous, the logic changes. Indeed, any interior spatial equilibrium is such that transport bills are equalized across regions: $t^*_{FH}\theta_H = t^*_{HF}\theta_F$. *Asymmetries in market sizes and, therefore, in consumption shares are fully absorbed by freight rates.* Plugging the freight rates (17) into (22), and approximating to the first order as τ goes to zero, we obtain the spatial equilibrium condition $n^*_H - 1/2 \cong \theta_H - 1/2$. Therefore, an increase in the population share of region H yields a strictly proportional increase in its share of firms. *For small enough transport costs the* HME *disappears in the presence of endogenous freight rates.*

Proposition 1 (Endogenous freight rates and the HME) *When freight rates are endogenous: (i) the HME is weaker than under exogenous freight rates; (ii) firms never fully agglomerate in the larger region; and (iii) the HME vanishes when transport costs are close to zero.*

Unfortunately, we cannot characterize the spatial equilibrium analytically by substituting product prices and freight rates into the relocation incentives Δr^*. However, we can illustrate Proposition 1 with the help of a numerical example.

Insert Figure 1 about here.

Figure 2 depicts the spatial distribution n^*_H of firms for transport costs τ ranging from 0 to τ^{trade}.[12] The steeper curves on the left-hand side depict the firm distributions under exogenous and identical freight rates, whereas the flatter curves on the right-hand side depict the firm distributions under endogenous freight rates. For each case, the arrows indicate how the locus of the spatial distribution moves as transport costs τ increase. Figure 2 clearly illustrates the results highlighted by Proposition 1: firms are more dispersed when freight rates are endogenous and the HME vanishes as transport costs τ become sufficiently small.

The foregoing analysis suggests that trade imbalances — via their effects on freight rates — dampen agglomeration forces generated by footloose capital which would otherwise lead to strong regional specialization. In the above analysis we assumed zero cost for a return trip for the sake of exposition. This assumption implies that freight rates fall to zero in the direction of excess demand for transport services, thereby creating large asymmetries in shipping rates. In practice, freight rate asymmetries can be quite large but freight rates rarely (if ever) fall to zero. The reason is that freight rates *per se* generally represent about two-thirds of cumulative transport costs, whereas the remaining one-third consists in various items such as insurance and loading/handling. One may wonder whether the presence

[12]The parameter values in Figure 2 are set as follows: $a = b = c = 1$ and $f = 0.1$.

of other transport costs such as loading/handling costs alters our foregoing results. This is the question we discuss in detail in the next subsection.

4.3 Endogenous freight rates and exogenous loading costs

Assume that manufacturing firms must pay an additional loading/handling cost μ for each unit of good shipped to the other country.[13] For simplicity, we assume that loading/handling services are provided by firms in a competitive sector that is distinct from that of the carriers. Hence, the price of these services equals their marginal cost and is the same whatever the direction of shipments. The per-unit cost of exporting from country i to j then becomes $T_{ij} \equiv \mu + t_{ij}$, where $t_{ij} \in [0, 2\tau]$ is the freight rate set by the carriers. This specification allows us to avoid having zero freight rates in the direction of excess supply. It also covers the intermediate cases where some parts of transport costs react to trade imbalances, whereas others do not.

All expressions derived in Section 2 remain unchanged, except that t_{ij} must be replaced with T_{ij} and the trade feasibility condition becomes $(\mu + 2\tau)/2 < \tau^{\text{trade}}$. Observe that a loading cost is formally equivalent to an exogenous freight rate. At one end of the spectrum, the benchmark model with exogenous freight rates in Section 3.1 is recovered by setting $T_{ij} = \mu = 2\tau$. At the other end of the spectrum, the model with endogenous freight rates in Section 3.2 follows from setting $\mu = 0$ so that $T_{ij} = t_{ij}$. Given that the case in this section features freight rates that are partly endogenous, we conjecture that the equilibrium distribution of firms lies in between the two former cases.

With endogenous freight rates t_{ij} and loading costs μ, the freight rates become

$$t_{ij}^{*} = \frac{2[a(\theta_i - n_i) - \theta_i(1 - n_i)(2b + cn_i)\,(\mu + \tau)]}{2b[n_i(2\theta_i - 1) - \theta_i] - cn_i n_j} \tag{23}$$

for $0 < t_{ij}^{*} < 2\tau$. In expression (23), the one-way transport cost τ of expression (17) is replaced by the one-way 'cumulative' transport cost $\mu + \tau$: the presence of a loading cost increases firms' trade cost, reduces the demand for transport services and, therefore, lowers freight rates. Similarly, it can be checked that *the presence of the transport sector and of endogenous freight rates reduces firms' incentives to agglomerate*. The access gain from producing in region $i = H, F$ is given by the same decreasing function $R_i\,(T_{ji})$ as in (19), which is now evaluated at the cumulative transport rate T_{ji} instead of t_{ji}. Consequently, for any $T_{FH}^{*} < \mu + \tau < T_{HF}^{*}$, we have $R_H\,(T_{FH}^{*}) < R_H\,(\mu + \tau) = R_F\,(\mu + \tau) < R_F\,(T_{HF}^{*})$, which implies that $\Delta r^{*} < 0$.

The existence of loading costs $\mu > 0$ gives rise to three equilibrium regimes. Regime I occurs when a sufficiently small number of firms locate in the larger region. Cumulative transport rates T_{ij} then vary with trade imbalances and slow down agglomeration forces. As in Subsection 4.2, the location equilibrium is determined by condition (10) and the interior freight rates (23). In regime II, the existence of loading costs changes the firms' location incentives when a sufficiently large number of firms locate in

[13] The extra cost μ can also be interpreted as delay costs, harbor infrastructure costs, and possibly symmetric (specific) import tariffs. The important point is that this cost is exogenous to trade volumes and incurred in both directions.

the larger region — trade imbalances push the cumulative transport rates (T_{HF}, T_{FH}) to their boundary values $(\mu + 2\tau, \mu)$ in that case. Once at those boundaries, freight rates remain constant and cannot react to trade imbalances anymore to counteract agglomeration forces. Plugging the boundary values into condition (10) allows us to solve for the equilibrium number of firms, which is given by:

$$n_H^{**}(\theta_H) = \frac{2b+c}{2c} + \frac{2}{c}\frac{\left[2a\left(\tau+\mu\right) - b\mu^2\right]\theta_H - a\left(2\tau+\mu\right)}{\left(2\tau+\mu\right)^2 - 4\tau\left(\tau+\mu\right)\theta_H}.$$

By the trade feasibility condition, this expression is increasing in θ_H.[14] Finally, in regime III, the existence of loading costs leads firms to fully agglomerate in the larger region — which is impossible in the absence of such costs. When $n_H = 1$, the cumulative transport rates T_{HF} and T_{FH} hit their highest and lowest values $\mu + 2\tau$ and μ so that the incentives to locate in region H are given by

$$\begin{aligned}\Delta r^* = R_H(\mu) - R_F(\mu+2\tau) \quad &= \quad -2\frac{L(b+c)}{f}\theta_F\tau\left(p_{FF}^* - \frac{\mu+2\tau}{4}\right) \\ &\quad +\mu\frac{L(b+c)}{f}\left[\theta_H\left(p_{HH}^* - \frac{\mu}{4}\right) - \theta_F\left(p_{FF}^* - \frac{\mu+2\tau}{4}\right)\right].\end{aligned}$$

The first term in that expression is the dispersion force generated by the unbalanced freight rates, which we discussed in the previous section. The second term is an additional agglomeration force caused by the loading costs — higher loading costs, which act as an exogenous trade barrier, foster the incentives to locate in the larger market. When loading costs are large as compared to freight rates, that force may dominate and yields an equilibrium with full agglomeration. Plugging prices into the foregoing expression, one can show that $\Delta r^* > 0$ (i.e., full agglomeration is an equilibrium) if and only if

$$\theta_H > \bar{\bar{\theta}}_H \equiv \frac{\left(2\tau+\mu\right)\left[4a - \left(2\tau+\mu\right)\left(2b-c\right)\right]}{4\left[2a\left(\tau+\mu\right) + c\tau\left(\mu+\tau\right) - b\left(\mu^2 + 2\mu\tau + 2\tau^2\right)\right]},$$

where the denominator is positive by the trade feasibility condition. In the limit where $\mu = 0$, we get $\bar{\bar{\theta}}_H = 1$ which is our earlier result that states that full agglomeration is never an equilibrium in the absence of loading/handling costs.

Insert Figure 2 about here.

Figure **??** depicts the spatial equilibrium for the same set of parameter values as in Figure 2 (with $\mu = 0.2$ and $\tau \in \{0, 0.1, 0.2, 0.3\}$). When freight costs are nil ($\tau = 0$), the location equilibrium exactly corresponds to the case with exogenous freight rates that is displayed in Figure 2. As θ_H increases, the location equilibrium initially involves regime II — where the number of firms linearly increases with regional size asymmetries — and then regime III where firms firms fully agglomerate in the larger region. When freight costs are larger (e.g., $\tau = 0.2$), the location equilibrium goes through all three regimes. As θ_H firstly increases, the location equilibrium initially involves regime I where freight rates

[14] This equilibrium boils down to $n_H^*(\theta_H)$, obtained under exogenous freight rates in (15), when $\tau \to 0$. It suffices to note that μ then plays the role of the exogenous transport cost parameter.

respond to trade imbalance and dampen agglomeration forces (hence the less-than-linear effect); then regime II where freight rates hit their border values and do not dampen agglomeration forces anymore (the linear part); and, finally, regime III where firms fully agglomerate in the larger region. Which regime the economy is in crucially depends on the relative magnitudes of τ and μ, i.e., the endogenous and the exogenous part of transport costs.

Observe that, even in the presence of exogenous loading costs, the effect of endogenous freight rates is sizable as regime I occurs for a large range of country size asymmetries. In the example where freight rates make up half of the cumulative transport costs ($\tau = 0.2$ and $\mu = 0.2$), endogenous freight rates dampen agglomeration (regime I) whenever the larger country has less than 73% of the total population, while full agglomeration occurs (regime III) only if the larger country hosts more than 75% of the population. As a point of comparison, firms fully agglomerate in the larger region under comparable exogenous transport costs ($2\tau = 0.4$) whenever that region hosts a population share in excess of 56%. Hence, the presence of loading costs does not preclude freight rates from responding to trade imbalances and to dampen agglomeration forces. Freight rates only stop to play their stabilizing role when regional size asymmetries become too large, i.e., trade imbalances become so huge that most ships return empty.

4.4 Absence of a costlessly tradeable good

In the NEG literature, the traditional good is often described as an 'agricultural good' that can be traded at no cost. The resulting pattern implied by the footloose capital model is then that of the concentration of productive capital in a core region (e.g., China over the last two decades), which leads to a manufacturing trade surplus, a trade deficit in other goods, and asymmetric freight rates for shipping manufactures across regions. This pattern and interpretation is broadly consistent with U.S.–China trade trends (the U.S. having a huge trade deficit in manufactures and a smaller trade surplus in agricultural produce) and freight rate trends (with much higher freight rates from China to the U.S., the gap widening with the trade deficit). [15] However, trade imbalances in the manufacturing sector and the traditional sector must compensate each other in our foregoing model. One may wonder how much of the results are then driven by our assumption that the traditional good can be costlessly shipped — an assumption that directly maps manufacturing imbalances into imbalances in demand for transport services.

There are two possible replies to this criticism. First, one could reinterpret the costlessly tradeable homogenous good in terms of financial assets (e.g., treasury bonds). In that case, the model predicts that the trade surplus in manufactures is compensated by a flow of financial assets (e.g., purchases of U.S. treasury bonds by China). The latter are 'costlessly tradable' and not likely to substantially

[15] In 2009, the U.S. was running a \$10 billion trade surplus in agricultural goods and a \$6 billion trade surplus in services with China. The U.S. manufacturing trade deficit with China was about \$226 billion (Office of the U.S. Trade Representatives).

influence freight rates for manufacturing goods. Second, one could look at a situation where all goods incur trade costs (and thus require shipping services). Davis (1998), Fujita *et al.* (1999), and Picard and Zeng (2005) have shown that when trading the traditional good is costly, agglomeration and strong regional specialization are less likely to occur. The key reason is that imbalances in economic activity drive up wages in the economic core, thereby reducing its attractiveness as a production site. As a result, one expects that the latter dispersion effect due to rising wages would add to the dispersion effect caused by endogenous freight rates.

In this subsection, we take another route and check the robustness of our results by simply dropping the costlessly tradable good from the analysis. Consider hence that all goods require transport services to be traded. Although the structure of the model becomes too complicated for detailed analytical investigation, we can readily 'simulate' it numerically. Our key objective is to show that, despite the absence of a costlessly tradable good, trade imbalances in the *volume of manufacturing goods* generate freight rate differentials and mitigate the importance of agglomeration forces in the model. Although there is in general less agglomeration in the absence of a costlessly tradeable good than in the presence of such a good — because of factor price differences — there is even less agglomeration when freight rates are endogenously set by the transport sector. Our qualitative insights are thus robust to the introduction of trade costs for all goods.

Towards this aim, we adapt the foregoing model by dropping the costlessly tradeable good q_0. For the sake of analytical convenience and consistency, we make some additional simplifications. In particular, we assume that manufacturing varieties are poor substitutes ($\gamma = 0$), that each firm requires $m > 0$ units of labor input to produce a unit of the good, and that workers earn the wage w_i ($w_i \neq 1$) in region $i = H, F$. Finally, shipping a unit of each good requires τ units of labor, and the transport sector hires l_i and l_j workers in regions i and j, respectively. For simplicity, we do not assume loading costs in this subsection, though we could integrate them quite easily into the analysis. See Appendix B for the full details of this modified version of the model.

As before, we can firstly study the case of exogenous freight costs ($t_{ij} = \tau m w_i$ and $t_{ji} = \tau m w_j$). In words, transportation requires that firms hire (locally) τ additional workers per unit produced and who are paid at the prevailing market wage. The freight cost is exogenous in the sense that the transport input requirement τ is constant (though wages change). Because shipping becomes more expensive as labor costs rise, this model must deliver more spatial dispersion of firms than the model with a costlessly tradable good. The amount of labor hired for shipping goods is given by $l_i = Lmn_i\theta_j q_{ij}\tau$ and $l_j = Lmn_j\theta_i q_{ji}\tau$ where q_{ij} and q_{ji} are the individual export demands. The equilibrium distribution of firms and of mobile capital is then determined by the market clearing conditions in the product, labor and transport markets, as well as by the condition that capital returns be equalized across countries.

Turning to endogenous freight rates, we assume that there is a perfectly competitive and perfectly mobile transport sector that draws from the same labor pool than manufacturing firms. Perfect mobility implies that transportation services will be produced in the region with the lowest wage. Market clearing for transportation services requires that $l_i + l_j = 2L\tau \max\{n_i q_{ij}\theta_j, n_j q_{ji}\theta_i\}$. Furthermore, freight rates will be non-zero if and only if $D_{ij}(t^*_{ij}) = D_{ji}(t^*_{ji})$ and $t^*_{ij} + t^*_{ji} = 2\tau \min\{w_i, w_j\}$. Perfect mobility of the transport sector (both between and within regions) makes sure that wages across the two regions will be equalized whenever the transport sector operates in both regions: $w \equiv w_i = w_j$. The equilibrium distribution of firms and mobile capital is then determined by the market clearing conditions in the product, labor and transport markets, as well as by the condition that capital returns be equalized across countries.

As stated above, the resulting model is unfortunately too complex to allow for simple analytical solutions. Yet, numerical simulations are straightforward to implement and yield clear insights (see Appendix B for details). Figure 3 depicts the equilibrium share of firms in the large region, n^*_H, as a function of the share of consumers located in that region, θ_H. The thin solid line depicts the equilibrium allocation of firms across the two regions in the case of exogenous trade costs, while the bold solid line depicts that same allocation in the case of endogenous trade costs.[16]

Insert Figure 3 about here.

Several comments are in order. First, the larger region always hosts a larger share of firms so that a HME exists even in the absence of a costlessly tradeable good. Second, as expected, firms disperse more in this model than in the model with a costlessly tradeable good (compare Figures 2 and **??**). Finally, and most importantly, *the spatial distribution of firms and of production is more dispersed when transport costs are endogenous than when they are exogenous.* Put differently, even though there is in general less concentration of economic activity in manufacturing in the absence of a costlessly tradeable good, it is still less concentrated when freight rates are endogenously set by the transport sector. The absence of a costlessly tradeable good therefore does not eliminate the effect of endogenous freight rates on the spatial distribution of firms and the concentration of economic activity. Both endogenous factor prices and endogenous freight rates contribute to a more even distribution of economic activity.

5 Core-periphery model

Until now we have assumed that labor is geographically immobile. We now relax that assumption and turn to the core-periphery (CP) model where firms co-locate with the owners of their production factors (Krugman, 1991; Ottaviano *et al.*, 2002). We show that the structure of spatial equilibria can be fundamentally altered when freight rates are endogenous and respond to trade imbalances in manufactures. In particular, whereas the standard CP model predicts that low trade costs foster the agglomeration of firms and workers in a single locale, the same model augmented with a transport sector predicts that low trade costs can be compatible with the dispersion of firms and workers.

[16]Figure 3 is drawn for labor requirement $m = 2.6$ and marginal labor requirement in transportation $\tau = 0.7$ while other parameters are the same as those reported for Figures 1 and 2. The qualitative results are not sensitive to the chosen parametrization.

Assume that the population $L > 1$ can be split into entrepreneurs and workers. Entrepreneurs are the owners of the firms' fixed factors — they are each endowed with one unit of 'entrepreneurship'. They are mobile across regions and work in the manufacturing sector only. Workers, by contrast, are immobile and work in either the constant returns or in the transport sector. We assume that the immobile workers are evenly distributed across the two regions so that no region has a priori a locational advantage in terms of market size. For simplicity, and without loss of generality, we also assume that each firm needs one unit of entrepreneurship, i.e., $f = 1$. Assuming that firms and entrepreneurs have a one-to-one relationship, the mass of immobile workers in each region is given by $A \equiv (L-1)/2$. All agents spend their income in the region they are located in. Hence, the mass of consumers in region $i = H, F$ is given by $\theta_i L = A + n_i$, which shows that market size (as given by θ_i) is now endogenously determined by the location decisions of mobile entrepreneurs (as given by n_i). Contrary to the FC model, where factors are allocated across regions based on nominal rates of returns, entrepreneurs in the CP model choose their locations based on the utility they can get in each region (i.e., their nominal returns adjusted for cost-of-living in the region).

The indirect utility in region i is given by $V_i \equiv S_i + r_i$, where

$$S_i = \frac{a^2}{2b} - a\left(n_i p_{ii} + n_j p_{ji}\right) - \frac{c}{2}\left(n_i p_{ii} + n_j p_{ji}\right)^2 + \frac{b+c}{2}\left(n_i p_{ii}^2 + n_j p_{ji}^2\right) \tag{24}$$

stands for the consumer surplus and where r_i is the return to entrepreneurship (the firm's profit, as given by (9)).[17] The relocation incentives — now given by the indirect utility differential — can be expressed as follows: $\Delta V^* = \Delta S^* + \Delta r^* = S_H^* - S_F^* + R_H^* - R_F^*$. A spatial equilibrium is a distribution of entrepreneurs $n_H \in [0,1]$ that satisfies one of the following three conditions: (i) $\Delta V^* = 0$ with $n_H \in (0,1)$; or (ii) $\Delta V^* \geq 0$ with $n_H = 1$; or (iii) $\Delta V^* \leq 0$ with $n_H = 0$. Such an equilibrium is said to be (locally) stable if any small deviation from that distribution triggers an adjustment process that leads the economy back to the initial equilibrium. In what follows, we consider the following law of motion for entrepreneurs:

$$\frac{\mathrm{d}n_H}{\mathrm{d}t} = \begin{cases} \Delta V^* & \text{if} \quad n_H \in (0,1) \\ 0 & \text{if} \quad n_H = 0 \text{ or if } n_H = 1 \end{cases}$$

Hence, an interior equilibrium distribution of entrepreneurs is stable if moving to another region decreases their utility; whereas it is unstable if moving to another region increases their utility.

5.1 Exogenous and identical freight rates

We first briefly state the properties of the benchmark model with identical and exogenous freight rates ($t_{HF} = t_{FH} = \tau$). In that case, Ottaviano and Thisse (2004) have shown that the incentives to locate in region H are given by $\Delta V^* = \kappa\left(n_H - 1/2\right)\tau\left(\tau^* - \tau\right)$, where τ^* and κ are positive bundles

[17] The notation S_i, standing for the consumer surplus in region i, should not to be mistaken for the earlier notation S_{ij}^k which denotes the supply of transport service by carrier k and which is no longer used in the sequel.

of parameters (see Appendix C for details). When some entrepreneurs agglomerate in region H ($n_H > 1/2$), other entrepreneurs increase their utility by relocating there for any $0 < \tau < \tau^*$, which leads to full agglomeration in that region. By contrast, entrepreneurs see their utility increase by relocating away from the larger region when $\tau > \tau^*$, which fosters an even spatial distribution. Hence, when $\tau > \tau^*$, dispersion ($n_H^* = 1/2$) is the only spatial equilibrium. When $\tau < \tau^*$, full agglomeration ($n_H^* = 0$ or $n_H^* = 1$) of all mobile entrepreneurs into either region is the only stable equilibrium. In the knife-edge case where $\tau = \tau^*$, any distribution is an equilibrium.

The foregoing results establish that entrepreneurs disperse for high freight rates, whereas they concentrate in a single region for low ones. This results from the opposing effects of demand linkages, cost of living, and competition. Demand linkages exist because mobile entrepreneurs spend their income in the region where they set up business, which increases product demand there and attracts other entrepreneurs. The effect of cost of living stems from the fall in product prices and increased product diversity in the region where firms agglomerate, which raises consumer surplus there and thus attracts other entrepreneurs. The competition effect is driven by fiercer price competition in the region where entrepreneurs cluster, which reduces their incomes and tends to make them disperse. The competition effect dominates for high transport costs and induces an even dispersion of firms, whereas the effect of demand linkages and cost of living dominate and induce agglomeration of firms for low transport costs.

5.2 Endogenous freight rates

We now show that agglomeration patterns differ markedly when freight rates are determined in a competitive transport market. The reason is that the entrepreneurs' incentives to locate in a region do not only depend on the effects of demand linkage, cost of living, and competition as in the traditional CP models, but also on the effects of endogenous freight rate asymmetries. The presence of endogenous freight rates indeed gives rise to two additional dispersion and agglomeration forces. Because an increase in economic activity in a region increases the trade imbalances and leads to freight rate differentials, exports from a larger region become more expensive while imports into that region get cheaper. The negative effect on exports reduces entrepreneurs' incomes and, therefore, attenuates demand linkages, whereas the positve effect on imports increases entrepreneurs' consumer surplus and reduces their cost of living.

Symmetric equilibrium. Around the symmetric equilibrium with $n_H^* = 1/2$, trade imbalances are small enough so that freight rates do not reach their maximal or minimal values. In Appendix D, we show that the net effect of endogenous freight rates is to generate an additional dispersion force, i.e., *agglomeration forces are weaker and the symmetric equilibrium stable for a wider range of parameter values than under exogenous freight rates.* As shown in Appendix D, the symmetric equilibrium is stable when:

$$\left[\frac{\mathrm{d}(\Delta V^*)}{\mathrm{d}n_H}\right]_{n_H=1/2} < 0 \iff -\Phi_0 + \Phi_1\tau - \Phi_2\tau^2 < 0, \tag{25}$$

where Φ_0, Φ_1 and Φ_2 are positive bundles of parameters. Hence, (25) is a quadratic and concave function of τ, negative at $\tau = 0$ and negative for the freight rate τ^* that makes entrepreneurs indifferent between locations under exogenous freight rates. We thus have the following result:

Proposition 2 (stability of the symmetric equilibrium) *If $\Phi_1^2 < 4\Phi_2\Phi_0$ the symmetric equilibrium is stable for all values of τ; whereas if $\Phi_1^2 \geq 4\Phi_2\Phi_0$, there exist two thresholds $0 < \tau_1 < \tau_2 \leq \tau^{trade}$ such that the symmetric equilibrium is stable for $[0, \tau_1]$ and $[\tau_2, \tau^{trade}]$.*

Proposition 2 is congruent with the spatial distribution of entrepreneurs in the benchmark model with exogenous freight rates only when transport cost are high enough ($\tau \in [\tau_2, \tau^{\text{trade}}]$). However, Proposition 2 differs from this benchmark model in two ways. First, symmetric equilibria are stable for transport costs $\tau \in [0, \tau_1]$ for which the benchmark model would predict full agglomeration. Second, there exists a set of parameter values such that the symmetric equilibrium is stable for all values of τ, whereas the benchmark model would predict a change in the spatial distribution of firms as τ falls. In those situations, freight rates respond to trade imbalances and eliminate entrepreneurs' potential incentives to quit their region for a slightly larger market.

Note that these results are congruent to the ones derived by Puga (1999) and Picard and Zeng (2005 and 2010), where 're-dispersion' also arises for low values of trade costs. Whereas 're-dispersion' is driven by an upward pressure on the prices of scarce local factors in the core region (e.g. land or immobile labor) in those papers, it is driven by the endogeneity of freight rates in our setting. Put differently, once freight rates are set by a competitive market, dispersion may be the equilibrium outcome even in the presence of very low transport costs when industry is a priori mobile across regions. The intuition underlying both Puga's (1999) results and ours is that production costs for manufactures rise in the agglomerating region, though the effect is channeled by wages in the former model and by freight rates in the latter model.

Full agglomeration. Assume next that firms are fully agglomerated ($n_H^* = 1$). From Sections 3.2 and 3.3 we know that freight rates reach their corner solutions $t_{HF}^* = 2\tau$ and $t_{FH}^* = 0$ under full agglomeration — beyond some level of agglomeration, transport markets no longer work to reduce agglomeration forces because carriers start to return empty irrespective of the rates they set. The role of the transport sector is, therefore, quite similar to that of an asymmetric import tariff that would protect region F from foreign competition. This has two implications for entrepreneurs' location incentives. On the one hand, entrepreneurs face no competitive disadvantage in serving the larger core market H from the smaller peripheral market F. This gives entrepreneurs larger incomes in the periphery and incentives to locate there. On the other hand, entrepreneurs have a lower consumer surplus in the peripheral region where prices are higher for a large share of goods. This gives them incentives to stay in the core region. In Appendix E, we prove the following result.

Proposition 3 (fully agglomerated equilibrium) *Full agglomeration in region H is a stable equilibrium for all admissible values of τ if $A < 2\,(b+c)^2 \,/\, [(2b+3c)\,(2b+c)]$. It is never a stable equilibrium if $A > (b+c)\,/\,(2b+c)$. Otherwise full agglomeration is a stable equilibrium if $\tau < \widehat{\tau} \equiv 2a\,[(b+c) - A\,(2b+c)] \,/\, [2b\,(b+c) - A\,(4b^2 - c^2)]$.*

Proposition 3 shows that, in the case of full agglomeration, the standard conclusions derived under exogenous and identical freight rates carry through to the setting with endogenous freight rates. Indeed, even under endogenous freight rates, full agglomeration is never an equilibrium for a large enough immobile population A because some entrepreneurs find it profitable to locate in the smaller region to serve its immobile population while being relatively sheltered from competition. On top of that, shipping their products to the core region entails no competitive disadvantage. Being protected from competition in the smaller region compensates for the higher prices entrepreneurs must pay for their consumption bundle there. Furthermore, it is worth noting that when the immobile population A is small enough, there exist multiple stable equilibria where both dispersion and full agglomeration coexist. One the one hand, dispersion can occur because the transport sector weakens agglomeration forces as entrepreneurs in the larger region pay higher transport costs. On the other hand, full agglomeration can arise because the transport market then saturates in one direction so that freight rates hit their maximal and minimal values. The transport sector then no longer dampens agglomeration forces, i.e., agglomeration becomes profitable for entrepreneurs who are able to ship their goods at a fixed freight rate while consuming at lower prices in the core region.

Partial agglomeration. Unfortunately, it is not possible to characterize the interior spatial equilibria other than $n_H = n_F = 1/2$, as this involves solving a higher-order polynomial equation in n_H. To make the analysis even more involved, the trade feasibility condition depends on n_H^*, which depends itself on the values of t_{HF} and t_{FH}. It is, however, possible to obtain additional insights by considering some numerical examples. Figure 4 plots the zero level iso-curve of the utility differential ΔV^* in (τ, n_H)-space for τ varying between 0 and τ^{trade}.[18] The bold lines correspond to stable location equilibria while dashed lines correspond to unstable equilibria. The arrows indicate the direction of $\mathrm{d}(\Delta V^*)/\mathrm{d}t$, i.e., the relocation process that takes place after small perturbations of the equilibrium.

Insert Figure 4 about here.

As one can see from Figure 4, full agglomeration is always an equilibrium whereas symmetric dispersion is a stable equilibrium only for values of trade costs τ smaller than 0.15. In addition, there exist asymmetric interior equilibria for $\tau \in [0.15, 0.20]$. It is worth pointing out that, under endogenous freight rates, one of the key results of the standard CP model may get reversed: dispersion may prevail for low trade costs and full agglomeration does not necessarily arise. The reason why dispersion can arise even for low trade costs is the elasticity of freight rates to asymmetries in export volumes, which

[18]The parameter values are set as follows: $a = b = c = 1$ and $A = 0.3$

constitutes a stabilizing force working against agglomeration. It is further worth pointing out that changes in freight rates, due to changes in the spatial distribution of firms, are key to understanding why dispersion or partial agglomeration and full agglomeration may coexist. Consider, for example, the case in which firms split themselves evenly across the two regions. More agglomeration in region H then has the following effects. First, it increases local market size and offers consumers in H cheaper access to varieties. Since at the same time freight rates from F to H fall, imports also become cheaper. When taken together, this consumer surplus effect constitutes a stronger agglomeration force than in the model with exogenous freight rates and may explain why full agglomeration can be stable for all values of τ. At the same time, the positive consumer surplus effect is partly offset by a negative competition effect that depresses the returns to the fixed factor. Indeed, agglomeration raises freight rates from H to F, thus making access to the foreign market more expensive. This constitutes a dispersion force that becomes dominant when the foreign market is large enough. In particular, assume that dispersion prevails. Then the increase in freight rates t_{HF}, and the associated increase in the costs of serving F from H, may make a relocation from F to H unprofitable since it decreases profits and the returns to the mobile factor. Put differently, the positive consumer surplus effect is more than offset by the negative freight rate effect so that dispersion is a stable spatial equilibrium.

6 Conclusions

We have shown that the simplifying assumptions of exogenous and symmetric trade costs in models of NTT and NEG have important consequences for regional specialization and the agglomeration of economic activity. When carriers must commit to capacities and offer transport services in both shipping directions, trade imbalances lead to asymmetric freight rates because of the presence of 'empties'. The resulting freight rate differentials create an additional dispersion force that favors a more balanced distribution of economic activity across regions. In the footloose capital model, the Home Market Effect is significantly attenuated by the presence of a competitive transport sector. This result holds even when transportation is subject to handling/loading costs that are independent of the backhaul problem. It also holds regardless of the presence or not of a costlessly tradeable good. The reason is that, even when trade is balanced in value, it will generally not balance in volume, thereby leading to under-utilization of capacity on one shipping leg. In the core-periphery model, the spatial equilibrium distribution of economic activity can also be strongly affected by the presence of a competitive transport sector. The impact of freight rate differentials, which serve to drive cost wedges across regions, can be so strong that manufacturing firms may have incentives to evenly disperse under endogenous freight rates, whereas they would have remained agglomerated under exogenous ones. Our analysis thus suggests that, even when factors are perfectly mobile, the potential impacts of globalization — viewed as a uniform reduction of trade costs — on regional disparities might well be overstated.

As is well known, there are a variety of channels that may reduce agglomeration forces in NEG-type models. Fujita *et al.* (1999) discuss the possibility of decreasing returns in the production of the numéraire good, which implies that agglomeration reduces labor supply to the numéraire sector, drives up marginal productivity and increases factor prices there so that manufacturing firms have less incentives to spatially concentrate. In our model, agglomeration draws resources into the transport sector and raises costs for manufacturing firms to deliver their goods internationally. One advantage of our approach is, we believe, that the microeconomic underpinnings of the mechanism are clear and that this mechanism seems to widely operate in the world's shipping markets. Put differently, our model points at a simple dispersion force that seems to have empirical bite.

Like most NEG contributions, our analysis remains highly stylized. First, we focus on a two-region model only. Yet, in practice carriers optimize their trips by including multiple destinations in their routes. Such trip chaining is, however, unlikely to matter a lot for inter-continental transportation since carriers cannot simply 'walk around' the large trade imbalances between continents via an appropriate choice of routes. Second, we have assumed that countries have access to the same transportation technology. Yet, casual evidence suggests that many developing countries use high variable and low fixed cost technologies (e.g., many ports in the developing world have, at best, little technology for handling containerization), whereas the reverse holds true for developed countries. In a multi-region setting, these technological differences would directly affect shipping routes chosen by carriers, freight rates across routes, and the location of economic activity. Last, we have not investigated how our results would be affected if the same vessels could carry different types of goods (e.g., manufactures on the inbound leg, and agricultural produce on the outbound leg). In practice, much effort has been devoted to containerize return cargoes to utilize ship space more efficiently. However, many returning cargoes (e.g. logs, cocoa, oil etc.) have inappropriate characteristics for containerization so that the substitutability between cargoes is far from perfect (e.g., about two-thirds of the container ships still return empty from West Africa; Stopford, 2009, p.530). It would be interesting to see how sectoral trade imbalances in specific goods (as opposed to aggregate trade imbalances) map into freight rate asymmetries, and what the impact of those asymmetries is for trade patterns and the location of production. Such considerations raise interesting empirical questions. Are freight rate asymmetries driven by sectoral imbalances or, more generally, by macroeconomic factors? What is the effect of freight rate asymmetries on trade imbalances? And what is the effect of freight rate asymmetries on firms' location and the pattern of trade? Those questions have, we believe, to date not received the attention they deserve. Given their empirical relevance we hope that they will be tackled more carefully in the future.

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Appendix A: Carriers' profit maximization

Each carrier maximizes its profits with respect to its output:

$$\max_{S_{ij}^k, S_{ji}^k} \Pi^k = t_{ij} S_{ij}^k + t_{ji} S_{ji}^k - 2\tau \max\left\{S_{ij}^k, S_{ji}^k\right\}.$$

Without loss of generality, we assume that region i has the larger demand for transport services, which then implies that $S^k_{ij} \geq S^k_{ji}$. Two cases may arise:

1. $S^k_{ij} > S^k_{ji}$.

In that case, the problem reduces to

$$\max_{S^k_{ij}, S^k_{ji}} \Pi^k = (t_{ij} - 2\tau) S^k_{ij} + t_{ji} S^k_{ji}$$

which implies that the carrier: (i) does not offer any service from i to j when $t_{ij} < 2\tau$; (ii) does provide an infinite amount of service from i to j when $t_{ij} > 2\tau$, and an infinite amount from j to i when $t_{ji} > 0$; and (iii) does provide a positive and finite market-clearing quantity and earns zero profits when $t_{ij} = 2\tau$ and $t_{ji} = 0$.

2. $S^k_{ij} = S^k_{ji}$.

The first-order conditions (in vector notation) are given by

$$\begin{pmatrix} t_{ij} \\ t_{ji} \end{pmatrix} - 2\tau\xi = 0, \quad \text{where} \;\; \xi \in \left\{ \delta \begin{pmatrix} 1 \\ 0 \end{pmatrix} + (1-\delta) \begin{pmatrix} 0 \\ 1 \end{pmatrix}, \;\; 0 < \delta < 1 \right\}$$

Put differently, $t_{ij} = 2\tau\delta > 0$ and $t_{ji} = 2\tau(1-\delta) > 0$. Note that the value of δ, which pins down the equilibrium freight rates, will be endogeneously determined by the market clearing conditions.

Appendix B: FC model without a costlessly tradeable good

We adapt the model of Sections 3.1 and 3.2 to the case where there exists no costlessly tradeable homogenous good q_0. Such a model requires, however, some minor changes in assumptions and some simplifications to remain workable. In particular, we now require (i) non-zero variable labor inputs in manufacturing, (ii) a more precise description about the labor input used in the transport sector, and (iii) a slight change in the modeling of preferences. More precisely, we here assume that each consumer in region i maximizes her utility

$$U_i = \alpha \int_0^1 q_i(v)\mathrm{d}v - \frac{\beta}{2} \int_0^1 q_i^2(v)\mathrm{d}v$$

subject to her budget constraint $\int_0^1 p_i(v) q_i(v)\mathrm{d}v = e_i$, where e_i denotes her earnings which consists of her wage and her capital income.[19] Each firm requires m units of labor to produce a unit of output and pays its workers the wage w_i.[20] Shipping each good requires τ units of labor. The transport sector hires l_i and l_j units of labor in regions i and j, respectively. For simplicity, we do not assume loading costs in this modeling framework, though we could add them easily.

As before, we assume that the economy has L individuals who are each endowed with one unit of labor and f/L units of capital. As each firm requires f units of capital, the capital market clears at a

[19] Although $\gamma = 0$, substitution between varieties still takes place because of the budget constraint.

[20] In this model, labor intensity must be high enough ($m > 2$) to prevent excess labor supply and zero wages.

firm distribution (n_H, n_F) with $n_H + n_F = 1$. Given the new preferences, the demands in region i for local and imported varieties can then be expressed as $q_{ii}(v) = \alpha - \beta\lambda_i p_{ii}(v)$ and $q_{ji}(v) = \alpha - \beta\lambda_i p_{ji}(v)$, with symmetric expressions holding for consumers in region j. In the foregoing expressions, $\lambda_i > 0$ is the Lagrange multiplier of the budget constraint. Plugging these demand functions into the budget constraint and focusing on symmetric equilibria ($p_{ii}(v) = p_{ii}$ and $p_{ji}(v) = p_{ji}$ for all v) yields

$$\lambda_i^* = \frac{\alpha\left(n_i p_{ii} + n_j p_{ji}\right) - e_i}{\beta\left(n_i p_{ii}^2 + n_j p_{ji}^2\right)}. \tag{26}$$

The profit of a region-i firm is given by

$$\pi_i = (p_{ii} - mw_i)L\theta_i q_{ii} + (p_{ij} - mw_i - t_{ij})L\theta_j q_{ij} - r_i, \tag{27}$$

where $L\theta_i$ and $L\theta_j$ denote the regions' respective sizes, w_i and r_i the wage and capital return in region i, and $t_{ij} \geq 0$ the freight rates for shipping one unit of the variety to the other region. Because there is a continuum of firms, each firm maximizes its profit taking the indices λ_i and λ_j as given and set the following prices: $p_{ii} = \alpha/(2\beta\lambda_i) + mw_i/2$ and $p_{ij} = \alpha/(2\beta\lambda_j) + (m\omega_i + t_{ij})/2$. Symmetric expressions hold for firms in region j. Since capital is mobile across regions, equilibria are such that capital returns are equalized: $r_i = r_j = r$. This yields the following condition:

$$q_{ii}(p_{ii} - mw_i)\theta_i + q_{ij}(p_{ij} - mw_i - t_{ij})\theta_j = q_{jj}(p_{jj} - mw_j)\theta_j + q_{ji}\left(p_{ji} - mw_j - t_{ji}\right)\theta_i. \tag{28}$$

Capital owners are the residual claimants to firms' profits, so the capital returns r absorb all operating profits as given by (27). Individual incomes are then equal to $e_i = w_i + rf/L$ and $e_j = w_j + rf/L$.

To close the model, we impose labor market clearing. Formally, the labor market clears in each region when

$$L\theta_i = Lmn_i[\theta_i q_{ii} + \theta_j q_{ij}] + l_i \quad \text{and} \quad L\theta_j = Lmn_j[\theta_j q_{jj} + \theta_i q_{ji}] + l_j, \tag{29}$$

where l_i and l_j is labor hired by the transport sector in regions i and j, respectively.

We can firstly study the case of exogenous freight rates where $t_{ij} = \tau mw_i$ and $t_{ji} = \tau mw_j$. In words, transportation requires that firms hire (locally) τ additional workers who are paid at the prevailing market wage. The freight cost is therefore exogenous in the sense that the transport input requirement τ is constant. Because shipping becomes more expensive as labor costs rise, this model must deliver more spatial dispersion of firms than the model with a costlessly tradable good. The amount of labor required for shipping is given by $l_i = Lmn_i\theta_j q_{ij}\tau$ and $l_j = Lmn_j\theta_i q_{ji}\tau$. Expressions (26), conditions (28) and (29), as well as $n_i + n_j = 1$ fully characterize the equilibrium in terms of the tuple (n_i, n_j, λ_i, λ_j, w_i, w_j) where we use capital rentals as the numéraire ($r \equiv 1$).

Secondly, we can study the case of endogenous freight costs. We assume again a perfectly competitive and perfectly mobile transport sector where carriers use the same labor than manufacturing firms. Perfect mobility implies that transportation services will be produced in the region with the lowest wage. Market clearing for transportation services requires that $l_i + l_j = 2L\tau \max\{n_i q_{ij}\theta_j, n_j q_{ji}\theta_i\}$. Furthermore, freight rates will be non-zero if and only if $D_{ij}(t_{ij}^*) = D_{ji}(t_{ji}^*)$ and $t_{ij}^* + t_{ji}^* = 2\tau \min\{w_i, w_j\}$.

Perfect mobility of the transport sector (both between and within regions) makes sure that wages will be equalized across regions whenever the transport sector operates in both regions: $w \equiv w_i = w_j$. Expressions (26), conditions (28) and (29), as well as $n_i + n_j = 1$ and $l_i + l_j = 2L\tau \max\{n_i q_{ij}\theta_j, n_j q_{ji}\theta_i\}$ fully characterize the (interior) equilibrium in terms of the tuple $(n_i,\, n_j,\, \lambda_i,\, \lambda_j,\, w,\, l_i,\, l_j)$ where we again use capital rentals as the numéraire ($r \equiv 1$).

The foregoing two models can be easily simulated to generate figures like Figure 3 in the paper.

Appendix C: Exogenous and identical freight rates

We characterize the spatial equilibrium with exogenous and identical freight rates ($t_{HF} = t_{FH} = \tau$). The consumer surplus differential, evaluated at the equilibrium prices (4), is given by

$$\Delta S^* = S_H^* - S_F^* = \frac{(b+c)^2}{(2b+c)^2}\,(2a - \tau b)\,\tau\left(n_H - \frac{1}{2}\right),$$

whereas the factor price differential (14) can be expressed as follows (recall that $f = 1$):

$$\Delta r^* = R_H^*(\tau) - R_F^*(\tau) = \frac{b+c}{2(2b+c)} L\tau\left(n_H - \frac{1}{2}\right)[4a - \tau\,(2b + Lc)]\,.$$

Some standard calculations show that $\Delta V^* = \kappa\left(n_H - \frac{1}{2}\right)\tau\,(\tau^* - \tau)$, where

$$\tau^* = \frac{4a\,(3b + 2c)}{6b^2 + 6bc + c^2 + 2Ac\,(2b + c)}$$

and where κ is a positive bundle of parameters that is independent of τ. The foregoing expression reveals that $n_H = 1/2$ is always a spatial equilibrium. Furthermore, $[\partial(\Delta V^*)/\partial n_H]_{n_H=1/2} < 0$ for all values of n_H if and only if $\tau > \tau^*$. In that case, starting from the symmetric distribution $n_H = 1/2$, as more entrepreneurs move to region H ($n_H > 1/2$) their utility falls so that such a move is not profitable. By contrast, when $\tau < \tau^*$, as more entrepreneurs move to region H ($n_H > 1/2$) their utility increases, which makes such a move profitable. Since the relocation incentives ΔV^* are positive for all $n_H > 1/2$ when $\tau < \tau^*$, full agglomeration of all mobile entrepreneurs in region H will be the equilibrium outcome. This establishes the results of Section 4.1.

Appendix D: Stability of the symmetric equilibrium

Let $[\cdot]_{n_H^*=1/2} \equiv [\cdot]_{1/2}$ to alleviate notation. The symmetric equilibrium is stable if and only if

$$[\partial(\Delta V^*)/\partial n_H]_{1/2} < 0.$$

Note that the price of a variety depends only on the number of local producers and on the freight rates of imports: $p_{HH}^* = p(n_H, t_{FH})$ and $p_{FF}^* = p(n_F, t_{HF})$. Because $n_F \equiv 1 - n_H$, the access gain R_H defined in (12) depends on the distribution on workers (θ_H, θ_F), consumer prices p_{HH}, and freight rates t_{FH}. It can thus be expressed as a function $R(\theta_H, p_{HH}, t_{FH})$. Similarly, the consumer surplus S_H defined in (24) depends on the distribution of firm (n_H, n_F), consumer prices p_{HH}, and freight rates t_{FH}. Thus, it can be expressed as a function $S(n_H, p_{HH}, t_{FH})$.

We can decompose the impact of a relocation of firms towards region H at the symmetric equilibrium as follows:

$$\left[\frac{\mathrm{d}(\Delta V^*)}{\mathrm{d}n_H}\right]_{1/2} = 2\left[\frac{\mathrm{d}R}{\mathrm{d}n_H}\right]_{1/2} + 2\left[\frac{\mathrm{d}S}{\mathrm{d}n_H}\right]_{1/2} \tag{30}$$

where

$$\begin{aligned}\left[\frac{\mathrm{d}R}{\mathrm{d}n_H}\right]_{1/2} = & \underbrace{\left[\frac{\partial R}{\partial \theta_H}\right]_{1/2}}_{+}\underbrace{\left[\frac{\partial \theta_H}{\partial n_H}\right]_{1/2}}_{+} + \underbrace{\left[\frac{\partial R}{\partial p_{HH}}\right]_{1/2}}_{+}\underbrace{\left[\frac{\partial p_{HH}}{\partial n_H}\right]_{1/2}}_{-} \\ & + \left\{\underbrace{\left[\frac{\partial R}{\partial t_{FH}}\right]_{1/2}}_{+} + \underbrace{\left[\frac{\partial R}{\partial p_{HH}}\right]_{1/2}}_{+}\underbrace{\left[\frac{\partial p_{HH}}{\partial t_{FH}}\right]_{1/2}}_{+}\right\}\underbrace{\left[\frac{\mathrm{d}t_{FH}}{\mathrm{d}n_H}\right]_{1/2}}_{-}\end{aligned} \tag{31}$$

and

$$\begin{aligned}\left[\frac{\mathrm{d}S}{\mathrm{d}n_H}\right]_{1/2} = & \underbrace{\left[\frac{\partial S}{\partial n_H}\right]_{1/2}}_{+} + \underbrace{\left[\frac{\partial S}{\partial p_{HH}}\right]_{1/2}}_{-}\underbrace{\left[\frac{\partial p_{HH}}{\partial n_H}\right]_{1/2}}_{-} \\ & + \left\{\underbrace{\left[\frac{\partial S}{\partial t_{FH}}\right]_{1/2}}_{-} + \underbrace{\left[\frac{\partial S}{\partial p_{HH}}\right]_{1/2}}_{-}\underbrace{\left[\frac{\partial p_{HH}}{\partial t_{FH}}\right]_{1/2}}_{+}\right\}\underbrace{\left[\frac{\mathrm{d}t_{FH}}{\mathrm{d}n_H}\right]_{1/2}}_{-}\end{aligned} \tag{32}$$

Expression (31) captures entrepreneurs' location incentives through the change in their incomes. The first terms denotes the demand linkages, the second term the competition effect, and the last term the impact of endogenous freight rates. Expression (32) captures the location incentives driven by changes in the consumer surplus. The first two terms are positive and capture the effect of cost of living on local prices and product diversity. The last term is negative and relates to the effect that endogenous freight rates have on profits and, therefore, entrepreneurs' incomes.

The derivatives in (31) and (32) can be signed as follows. Note first that $[t_{FH}]_{1/2} = [t_{HF}]_{1/2} = \tau$, so that $[p_{HH}]_{1/2} = [p_{FF}]_{1/2} = p = (2a + c\tau/2)\,/\,[2(2b+c)]$, $[\partial p_{HH}/\partial t_{FH}]_{1/2} = c/\,[4(2b+c)] > 0$ and $[\partial p_{HH}/\partial n_H]_{1/2} = -c\tau/\,[2(2b+c)] < 0$. The comparative statics of freight rates with respect to market size θ_i and industry location n_i at the symmetric equilibrium are given by $\partial t_{HF}/\partial n_H = -\partial t_{HF}/\partial n_F = 8(a - \tau b)/\,(4b+c) > 0$, $\partial t_{HF}/\partial \theta_H = -\partial t_{HF}/\partial \theta_F = 2\tau - 8a/\,(4b+c) < 0$, and $\mathrm{d}t_{HF}/\mathrm{d}n_H = -\mathrm{d}t_{FH}/\mathrm{d}n_H = 2\,[8A\,(a - b\tau) + c\tau]\,/\,[L\,(4b+c)] > 0$. Turning to the impacts of firms' location on market size, we obviously have $[\partial\theta_H/\partial n_H]_{1/2} = 1/L$. Concerning the relocation incentives, we obtain the following derivatives: $[\partial R/\partial p_{HH}]_{1/2} = L(b+c)\tau/2 > 0$ and $[\partial R/\partial t_{FH}]_{1/2} = L(b+c)\,[4a - (4b+c)\tau]\,/\,[8(2b+c)] > 0$, and $[\partial R/\partial \theta_H]_{1/2} = L(2a - b\tau)(b+c)\tau/\,[2(2b+c)] > 0$, where the second inequality comes from the trade feasibility condition. Turning finally to the consumer surplus, we have: $[\partial S/\partial n_H]_{1/2} = (2a - b\tau)(b+c)\tau/\left[4(2b+c)\right] > 0$, $[\partial S/\partial p_{HH}]_{1/2} = -(b+c)(2a-b\tau)/\left[2(2b+c)\right] < 0$ and $[\partial S/\partial t_{FH}]_{1/2} = -(b+c)[4(a-b\tau) - c\tau]/\left[16(2b+c)\right] < 0$. When taken together, these results establish the signs in expressions (31) and (32).

We next compare the stability of the symmetric equilibrium under exogenous and under endogenous freight rates. Note that, because the first two terms in expressions (31) and (32) are exactly the same as under exogenous freight rates, their sum is positive if and only if $\tau < \tau^*$ (see Section 4.1). Consequently, the agglomeration forces will be weaker under endogenous freight rates if and only if the sum of the last terms in (31) and (32) — associated with the endogenous freight rates — is negative. Using $\theta_H = (A + n_H)/L$, standard computations show that these terms are given by:

$$-\frac{(b+c)(a-b\tau)\left[8A(a-b\tau)+c\tau\right]}{(4b+c)(2b+c)} < 0 \text{ and } \frac{(b+c)\left[8A(a-b\tau)+c\tau\right]\left[8a(b+c)-\tau\left(8bc+8b^2+c^2\right)\right]}{8L(4b+c)(2b+c)^2} > 0$$

where both inequalities come from the trade feasibility condition. Their sum is given by:

$$-\frac{1}{8}(b+c)\left(8A(a-b\tau)+c\tau\right)\frac{8(a-b\tau)\left[b+2A(2b+c)\right]+c^2\tau}{L(4b+c)(2b+c)^2} < 0, \tag{33}$$

where the inequality is also due to the trade feasibility condition. We can, therefore, conclude that agglomeration forces are weaker and the symmetric equilibrium stable for a wider range of parameter values under endogenous freight rates. In particular, it is obvious that firms will disperse under endogenous freight rates when τ is sufficiently close to τ^* since the sum of the two first terms in expressions (31) and (32) is approximately zero so that the negative term (33) dominates.

We are now in a position to derive the condition for which $[\mathrm{d}(\Delta V^*)/\mathrm{d}n_H]_{1/2} < 0$. Note that

$$\begin{aligned}
\left[\frac{\partial R}{\partial \theta_H}\right]_{1/2}\left[\frac{\partial \theta_H}{\partial n_H}\right]_{1/2} + \left[\frac{\partial R}{\partial p_{HH}}\right]_{1/2}\left[\frac{\partial p_{HH}}{\partial n_H}\right]_{1/2} &= \tau(b+c)\frac{4a-(2b+Lc)\tau}{4(2b+c)} \\
\left\{\left[\frac{\partial R}{\partial t_{FH}}\right]_{1/2} + \left[\frac{\partial R}{\partial p_{HH}}\right]_{1/2}\left[\frac{\partial p_{HH}}{\partial t_{FH}}\right]_{1/2}\right\}\left[\frac{\partial t_{FH}}{\partial n_H}\right]_{1/2} &= -\frac{(a-b\tau)\left(8A(a-b\tau)+c\tau\right)(b+c)}{(4b+c)(2b+c)}
\end{aligned}$$

and

$$\begin{aligned}
\left[\frac{\partial S}{\partial n_H}\right]_{1/2} + \left[\frac{\partial S}{\partial p_{HH}}\right]_{1/2}\left[\frac{\partial p_{HH}}{\partial n_H}\right]_{1/2} &= \tau(b+c)^2\frac{2a-b\tau}{2(2b+c)^2} \\
\left\{\left[\frac{\partial S}{\partial t_{FH}}\right]_{1/2} + \left[\frac{\partial S}{\partial p_{HH}}\right]_{1/2}\left[\frac{\partial p_{HH}}{\partial t_{FH}}\right]_{1/2}\right\}\left[\frac{\partial t_{FH}}{\partial n_H}\right]_{1/2} &= \frac{(b+c)\left(8A(a-b\tau)+c\tau\right)\left(8a(b+c)-\tau\left(8b^2+8bc+c^2\right)\right)}{8L(4b+c)(2b+c)^2}
\end{aligned}$$

We then get

$$\left[\frac{\mathrm{d}R}{\mathrm{d}n_H}\right]_{1/2} + \left[\frac{\mathrm{d}S}{\mathrm{d}n_H}\right]_{1/2} = \frac{(b+c)}{8(4b+c)(2b+c)^2 L}\Phi(\tau),$$

where $\Phi(\tau) = -\Phi_0 + \Phi_1\tau - \tau^2\Phi_2$, and where

$$\begin{aligned}
\Phi_0 &= 64Aa^2(b+4Ab+2Ac) \\
\Phi_1 &= 8a\left[32A^2b(2b+c) + \left(40b^2+18bc+c^2\right)A + 2(3b+c)(2b+c)\right] \\
\Phi_2 &= 8(2b+c)\left(4bc+16b^2+c^2\right)A^2 + 8A\left(5bc^2+15b^2c+20b^3+c^3\right) \\
&\quad + (2b+c)\left(14bc+24b^2+3c^2\right).
\end{aligned}$$

This establishes Proposition 2.

Appendix E: Fully agglomerated CP equilibrium

We establish the condition for full agglomeration of entrepreneurs in region H to be an equilibrium ($n_H^* = 1$). As shown in Section 3.2., we have $t_{HF}^* = 2\tau$ and $t_{FH}^* = 0$. This is because an interior solution for freight rates would yield $t_{FH}^* = 2\tau - a/b$, which is negative for all admissible values of $\tau < \tau^{\text{trade}}$. Under full agglomeration in region H, consumer prices are given by $p_{HH}^* = a/(2b+c)$ and $p_{FF}^* = (a + c\tau)/(2b+c)$. The factor price and consumer surplus differentials are given by:

$$[\Delta r^*]_{n_H^*=1} = -\frac{(b+c)A\tau\left[2(a-b\tau)+c\tau\right]}{(2b+c)} < 0 \quad \text{and} \quad [\Delta S^*]_{n_H^*=1} = \frac{2(b+c)^2\tau(a-b\tau)}{(2b+c)^2} > 0.$$

Adding the factor price and the consumer surplus effects, we obtain the indirect utility differential under full agglomeration in H as follows:

$$[\Delta V^*]_{n_H^*=1} = \frac{\tau(b+c)}{(2b+c)^2}\left\{2(b+c)(a-b\tau) - A(2b+c)\left[2(a-b\tau)+c\tau\right]\right\}.$$

Hence, full agglomeration is an equilibrium, if and only if $[\Delta V^*]_{n_H^*=1} > 0$, i.e.,

$$A < G(\tau) \equiv \frac{2\,(b+c)\,(a-\tau b)}{(2b+c)\left[2(a-b\tau)+c\tau\right]},$$

where $G(\tau) \in (0, 2)$ decreases with τ. In words, *full agglomeration can occur only if the local immobile demand A is small enough.* Because $G(\tau)$ decreases in τ, full agglomeration is an equilibrium for all transport costs $\tau \in (0, \tau^{\text{trade}}]$ if $A < G(\tau^{\text{trade}})$. It is never an equilibrium if $A > G(0)$. Otherwise it is an equilibrium if $\tau < G^{-1}(A)$. This establishes Proposition 3.

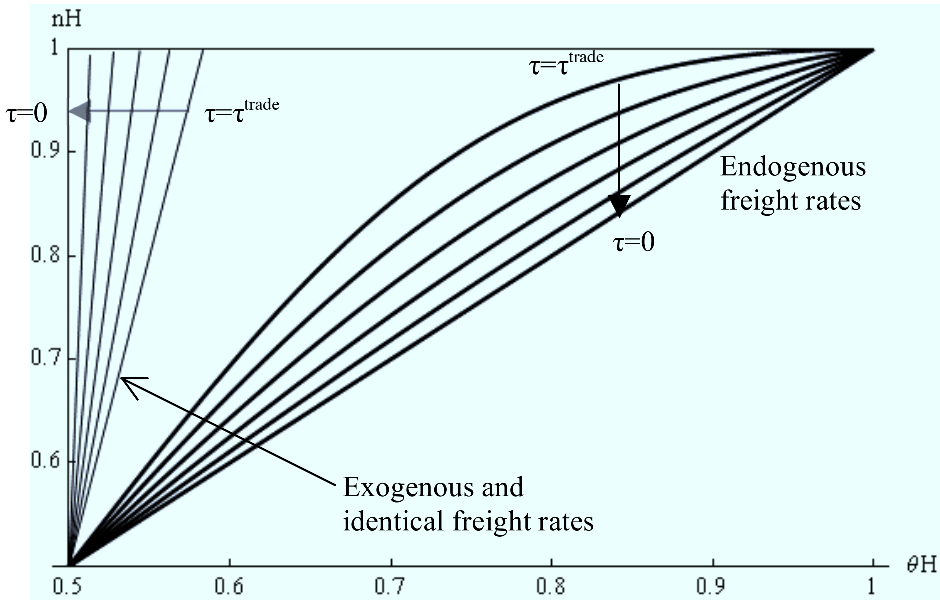

Figure 1: Spatial distribution of firms in the footloose capital model

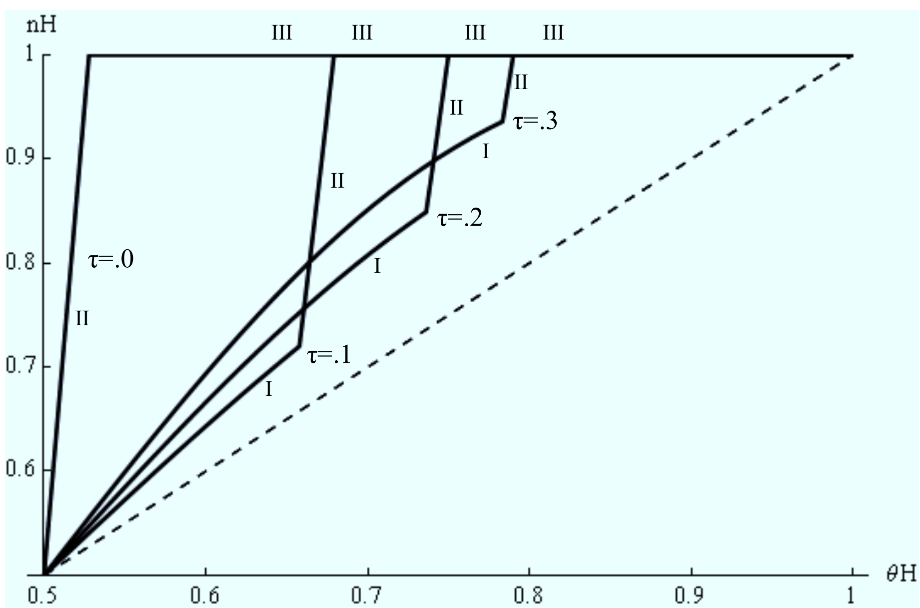

Figure 2: Spatial distribution in the footloose capital model with loading costs

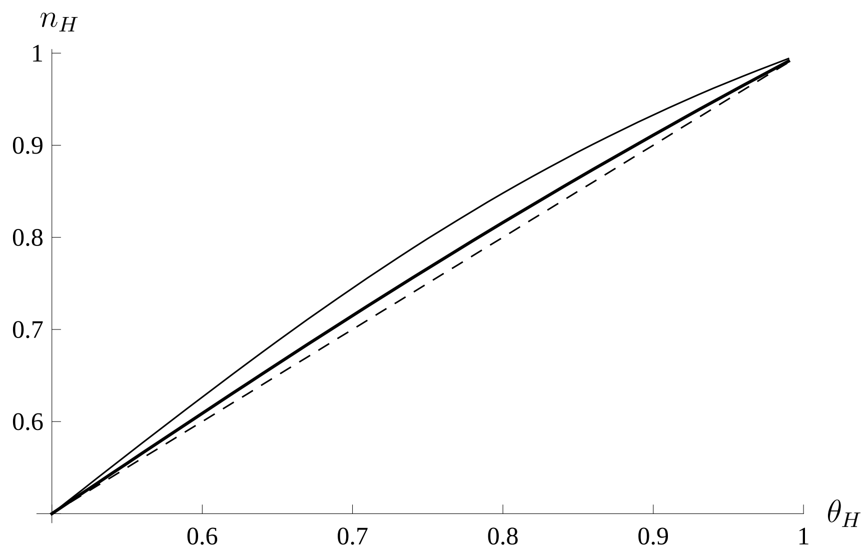

Figure 3: Spatial distribution of firms without costlessly tradable numeraire.

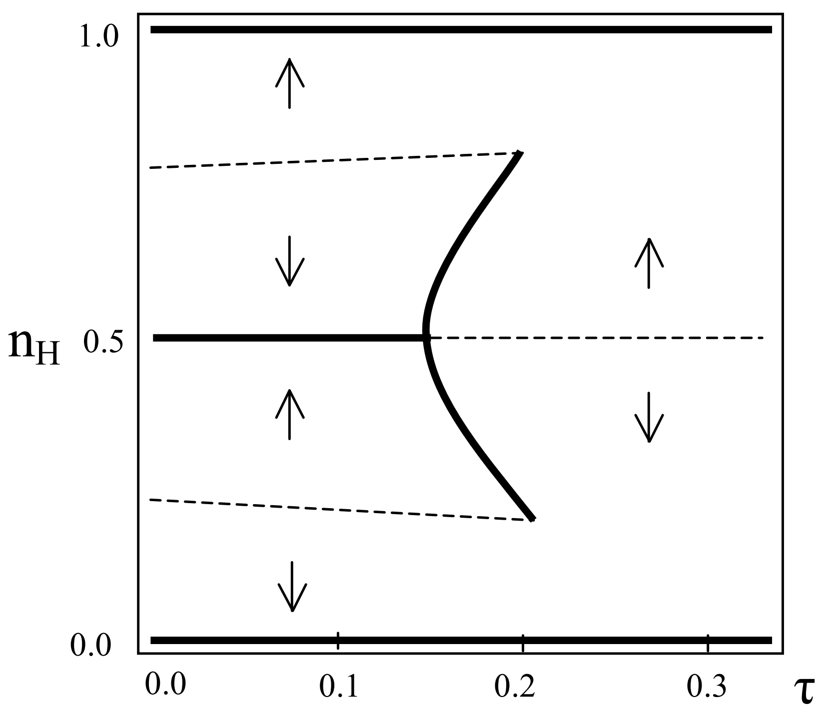

Figure 4: Spatial distribution of firms in the core-periphery model