TRADE OPENNESS, TRANSPORT NETWORKS AND THE SPATIAL LOCATION OF ECONOMIC ACTIVITY

Nuria Gallego
José L. Zofío

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Nuria Gallego* and José L. Zofío*

Abstract

This paper introduces a multi-country multi-regional model that allows the evaluation of the effects of trade openness in the internal distribution of economic activity across regions within countries. Relying on the agglomeration and dispersion forces characterizing the analytical framework of the NEG/NTT literature, we consider a general model with two differentiated sectors in terms of preferences, technologies and transport costs, and that allows for any feasible world trade network topology where trade frictions are both transport and non-transport related (tariffs). As benchmark simulations we choose two opposed domestic network topologies characterizing a homogenous space and a heterogenous space. Our findings show that trade openness changes locational patterns in favor of better located regions with respect to the new world topology. These results entail important implications in terms of transport infrastructure (accessibility) and trade (commercial agreements) policies, as both are related when policy makers set regional equality goals.

Key words: Trade openness, international trade, economic geography, location of economy activity.

JEL Classification: D43; F12; R12; R30.

* **Corresponding authors**: Nuria Gallego López. E-mail: nuria.gallego@uam.es and José Luis Zofío. E- mail jose.zofio@uam.es. Departamento de Análisis Económico: Teoría Económica e Historia Económica. Facultad de Ciencias Económicas y Empresariales. Universidad Autónoma de Madrid (UAM), Madrid.

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1. Introduction

Currently, economic geography literature on the effects of trade openness on the location of economic activity is regaining interest for both scholars and policy makers, due to recent changes in political boundaries, and the attempt of some Western European regions to claim independence, which may leave them out of the EU: Flanders in Belgium, Scotland in the United Kingdom or the Basque Country and Catalonia in Spain. The topic is also making the headlines as more countries are getting involved progressively in new or existing free trade agreements or common commercial areas, with implications not just for new members, but also for the incumbents. One example is the 2004 EU enlargement, which integrated ten Central and Eastern European Countries (CEECs) into the EU's internal market, and has shifted Europe's economic center of gravity eastwards (Brülhart et al., 2004). Moreover, globalization processes are reinforcing the reduction in trade frictions related to economic and commercial barriers such as declining transport costs (result of the technological progress and improvements in transport networks), and the previously mentioned non-transport related impediments such as tariffs, quotas, etc. All these changes on international market accessibility of countries are generating prominent changes not only between countries, but also, and more importantly within countries; i.e., in the internal structure of the spatial location of economic activities in the countries involved in trade openness.

The empirical results suggest that a liberalization process in the form of trade openness implies different gains depending on the territorial scale of analysis: *between* countries, resulting in the reallocation of economic activity at the international level, where countries reap the gains of international trade specialization, and *within* countries resulting in a complementary and simultaneous reconfiguration at the regional level, where we can observe whether there are winners or losers at regional level after the openness. Focusing on the analytical framework based on Helpman and Krugman (1987) and Krugman (1991), characterized by Dixit-Stiglitz preferences, iceberg transportation costs, and increasing returns, along with computer simulations, two complementary sets of models have addressed these two issues separately. On one hand, to model the effect of trade openness between countries the literature relies on the analytical framework of the New Trade Theory (NTT). Normally, this type of models studies the effects of changes in non-transport related costs on the location of firms across countries without considering a spatial configuration of the transportation network. An exception to this restriction is Behrens et al. (2007a), Behrens et al. (2009) and Barbero et al. (2015), who allow for spatial configurations of the trading network between countries. On the other hand, to characterize the spatial implications of trade liberalizations within countries the reference literat ure relies on the New Economic Geography (NEG), which studies how transport related costs determine the distribution of the labor force at the regional level. For a set of results for different transport network configurations of the core-periphery model see Ago et al. (2006), Castro et al. (2012), Akamatsu et al. (2012), and Barbero and Zofío (2015).

Both NEG and NTT models share a common structure. Indeed, on the preferences side they normally consider an upper tier Cobb-Douglas (CD) utility function with homogenous and differentiated products, with the latter corresponding to a Constant Elasticity of Substitution (CES) specification, which yields a suitable price index. Also, from a technological perspective, firms are characterized by increasing returns, and the market equilibrium is solved within a monopolistic competition market structure. Based on these assumptions, these models set the theoretical grounds so as to explain why economic activity may end up agglomerating in some countries (NTT) or regions of a given country (NEG), even if departing from a symmetric situation where all are initially identical from the consumers and producers perspective. The final result regarding the agglomeration or dispersion of economic activity depends on the net effect of counterbalancing centripetal and centrifugal forces. In these models agglomeration forces are driven by: i) the price index effect by which areas with large manufacturing sectors enjoy lower prices; ii) the so called home market effect (Krugman, 1980; Head et al., 2002) by which locations with larger markets have proportionally larger manufacturing sectors, paying larger nominal salaries; and iii) the existence of economies of scale in production that result in lower average costs at the single plant level. Dispersing forces are led by transport costs because the larger they are, the more difficult it is to supply other markets while competing with local firms, complemented with an immobile share of workers in one of the sectors, normally the one producing a homogenous product, ensur ing that a sizeable amount of final demand expenditure is territorially fixed[1].

While the theoretical frameworks share a common structure resulting in equivalent centripetal and centrifugal forces, the main differences between NTT force; i.e., the relevant difference when solving for the equilibrium is whether workers are mobile or immobile. While in NTT models it is firms mobility (so as to meet the zero profit condition) and the exports/imports trade balance what clear the market, and the spatial equilibrium can be characterized in terms of equal relative market potentials (RMP), in NEG models it is workers mobility what clears the market so as to equalize real wages across locations; i.e., the instantaneous equilibrium. Therefore, market equilibrium through RMP equalization in NTT and real wage equalization in NEG summarize the main difference between both types of models.

Even if most multiple-country multiple-regions models deal with between and within country effects independently, without considering the complementary and simultaneous effects that trade openness has at both levels, a few contributions have considered jointly both the international and national dimensions; e.g., Krugman and Livas-Elizondo (1996), Alonso-Villar (1999), Behrens et al. (2007b). These authors attempt to characterize the impact of trade openness together with the effect of the topology of the country of interest, gathering both dimensions (between and within countries). To do so, they consider a limited number of countries (two or three maximum), which consist of one, two or three regions, where labour is mobile within countries (NEG assumption) but not between countries (NTT assumption). The main idea put forward in these theoretical contributions based on the NEG/NTT structure is that while the removal of national barriers increases the pressure of competition in domestic economies-being more attractive the farther locations with respect to the new competitors, it also brings global gains from international trade specialization-notably in a context of imperfect competition and scale economies, giving firms the opportunity of serving larger markets. This in turn may make more profitable the location near the foreign new

[1] The homogenous good sector, characterized by constant returns to scale, is normally associated with agriculture as in Krugman (1991), Krugman (1993a), and Krugman (1993b).

markets, particularly, if there are competitive advantages in the form of higher productivities and lower costs. Therefore, the existing balance of centripetal and centrifugal forces prior to trade liberalization changes once a country starts an opening process, generating new equilibria and spatial configurations. For example, if we start from a scenario of autarky (with neither international trade nor free input factors mobility), we know from NEG models that for a given transport cost, when the spatial topology is uneven, production and population will tend to agglomerate in the better connected locations, supplying the whole domestic market (i.e., the internal/central regions). However, once this economy starts a trade openness process and as a result of the aforementioned centripetal and centrifugal forces, we can think of two scenarios: one where the locations that agglomerate the economic activity reinforce their privileged position (centripetal forces are reinforced); and other where the frontier locations start becoming attractive to firms and start to agglomerate (dispersion forces become more relevant). In fact, if this economy starts to supply international markets, producers will seek to locate closer to the border in order to reduce transport costs and be more competitive, and consequently they will leave inner locations, where location was initially concentrated and, in this case, the whole reallocation process may result in lower regional inequality. As an example, this was the case of Mexico after the 1985 trade reform and 1194 NAFTA agreement, where the manufacturing sector left Mexico DF to relocate in the border with the U.S..

Here we formulate a proposal based on this NEG/NTT structure that allows both for the traditional agglomeration and dispersion forces considered in a regional context and for international trade, and whose main contributions can be summarized as follows: i) It models a multi-country multi-regional setting with flexible configurations of the internal (regional) and external (world) network topologies; ii) It allows for transport and non-transport (e.g., tariffs) related trade cost across the national and international networks; iii) The model allows for two sectors of differentiated goods both from the technological (supply) and preferences (demand) sides, and are subject to sector specific elasticities and transports costs —even if symmetry in the parameters will be assumed normally as we focus or analysis on the effect of trade openness. Therefore most models in the literature may be considered as special cases of this generalization. Regarding sectoral production, while the tendency in order to simplify things is to consider that one of the sectors provides homogenous goods with costless trade, several authors have shown that introducing some heterogeneity and transportation costs in the "agricultural" sector has relevant implications, qualifying the attained results significantly (Davis, 1998 and Fujita et al., 1999).

In sum, the model generalizes the exiting literature on the effects of progressive trade openness (transitioning from the autarky scenario to a fully integrated international market) in several dimensions: Topology, nature of trading costs, and sectoral differentiation, allowing us to study the implications of trade liberalization on the spatial configuration of the economic activity within countries. indeed it is the result of combining three key contributions: Krugman and Livas-Elizondo (1996), who developed an international model with two countries to evaluate the process of international trade openness, where the domestic economy is characterize by an internal and external homogenous topology, and whose regions are equally located with respect to each other and the rest of the world; Alonso-Villar (1999), who introduces a heterogenous space within and between the countries, where the two economies are already fully integrated in terms of international trade; and Davis (1998) and Fujita et al. (1999, ch. 7), who consider a single country-closed economy-with two symmetric regions producing differentiated goods in the manufacturing and agricultural sector.

The main results suggest that trade openness tends to favor the new bordering regions. However, the internal topology of the country and the initial location of the economic activity play an important role in the final outcome. While the model we propose allows for any number of countries and regions, to obtain the general results we produce some simple simulations in the context of a global economy constituted by two countries, both composed by three regions and where the country of interest is modeled according to two opposite domestic topologies: homogenous topology (a triangle configuration where no region has a locational advantage) and heterogenous topology (a star network). We have observed that given standard values for the main parameters of the model, in the case of a very centralized domestic transport network (start topology), the inner region of the country enjoying a privileged position, will keep its prominent status even in a context of full integration.

The structure of the paper is organized as follows. Section 2 reviews briefly the empirical literature on this field. Section 3 introduces the model assumptions, the general notation for any network topology representing the world economy, and the spatial conditions characterizing the so-called instantaneous equilibrium. Section 4 presents some simulations that illustrate the analytical potential of our analysis when establishing the effects of trade openness on the location of economic activity within countries, and depending on two opposed network topologies in terms of their centrality. Section 5 concludes.

2. Empirical evidence and theoretical explanations

Brülhart (2011) describes two main concerns about trade openness and its spatial consequences, which literally are: "that trade liberalization increases within-country spatial inequalities, and that it favours regions with better access to international trade routes".

In the literature, there are two main approaches to evaluate the spatial implications of removing international barriers within a country: the urban system approach, based on scale economies that are exogenous at regional level and based on perfectly competitive markets, and the NEG/NTT approach, which considers endogenously scale economies at the firm level and monopolistically competitive markets. Additionally, another distinction between the models of both approaches is related to the ex-ante assumption of locations of the regions within a country. Some models consider regions as geographical featureless units, i.e., regions are identically geo-referenced with respect of the foreign economy (homogenous space) (Henderson, 1982), while others consider that some regions enjoy from a locational advantage in the international relationship (heterogenous space), Rauch (1991).

From an *empirical* perspective, and motivated by Mexico's integration with United States and Canada in the North American Free Trade Agreement (NAFTA), several authors have studied the within-country spatial implications of this trade liberalization agreement under the prism of the NEG/NTT literature. Here we are interested in those contributions whose results can be interpreted in terms of greater or lower regional (in)equality; i.e., whether economic activity has spread across the domestic regions, including lagging locations (a spatial convergence effect) or if the economic activity is even more concentrated in the locations where it was agglomerated before the opening process. Hanson (1992, 1997, and 1998) examines the effect of trade reform on regional employment in Mexico. He focuses on three key factors driving the regional distribution of firms and, consequently, employment: transport costs, which pull firms to locate close to large foreign markets; backward and forward linkages, which encourage sellers to locate close to buyers, and vice versa; and agglomeration economies, which reinforce the initial industrial pattern configuration. The pieces of the NEG/NTT workhorse model are there, but without considering the full-fledge general equilibrium framework that it offers. He found a significant effect of the trade reform, changing the previous agglomeration from Mexico DF manufacturing belt toward the formation of new industrial clusters near the United States.

Other authors have studied the consequences of European integration, where the existing research does not provide a clear answer. In general, it seems that EU integration has promoted the convergence among countries, while regional inequality growth is country specific. Egger et al. (2005) find that for the Central and Eastern European countries, export openness brought an increase of regional inequalities in terms of real wages. Puga (2002) claims that, parallel to trade openness, "despite large regional policy expenditure, regional inequalities in Europe have not narrowed substantially over the last two decades, and by some measures have even widened". On the other hand, there are also evidences suggesting that trade integration promotes regional convergence, such as Redding and Sturm (2008). They studied the effect of German division (during 1945-1990) and later reunification, concluding that the iron curtain (representing both an ideological and socioeconomic conflict and a physical boundary) had a strong negative impact on border regions, so that disintegration leads to a core-periphery pattern. By contrast, with the reunification, they found signs of economic recovering in border regions. Bickenbach and Bode (2013) analyze the same phenomenon comparing qualitatively the parallelism between the NEG prediction and stylized facts on Germany economic integration. They conclude that NEG predictions matches quite well with the integration process, described as a U-curve between agglomeration (in East Germany) and integration, highlighting that Germany could be near to the turning point of the curve by the years 2001-2011. Therefore we can observe different results in term of regional inequalities depending on where a specific country is located in Europe, but also within countries it seems that border regions are initially favored by trade liberalization. However, from a modelling perspective, the European Union integration process implies a more complex mechanism than the more limited NAFTA; as the former involved many countries, free trade of commodities, but also labor as a mobile input factor, which must be considered in theoretical models trying to explain reality.

Hu and Fujita (2001) examined the trends of regional inequality in China, in terms of income distribution and production agglomeration during the period 1985-1994. They choose this period because it captures the effects of globalization and economic liberalization in the Chinese economy. They found that income disparity between inner and coastal regions increased, with industrial production agglomerating in the coastal area. So while the disparities increased at a country level, the convergence of coastal provinces increased.

These results concur with those of Kanbur and Zhang (2005), where trade openness favored the already-richer regions in the coast. So again, the empirical evidence seems to indicate that openness favors bordering regions, while convergence depends on the initial distribution of the economic activity; so that, convergence will just take place when the lagging regions were the new bordering regions.

Finally, while it is true that most studies are country-specific, and therefore no general results can be drawn, Ezcurra and Rodríguez-Pose (2013, 2014) and Rodríguez-Pose (2012) find a positive and significant relationship between trade openness and spatial internal inequality across a representative sample of countries; an association that is stronger for the case of poor and emerging countries.

Driven by these empirical evidences, Krugman and Livas-Elizondo (1996), Alonso-Villar (1999), Brülhart et al. (2004) and Hanson (2001), propose a series of *theoretical* models based on the NEG/NTT analytical framework that allow the study of dispersion processes as a consequence of trade openness, and by which peripheral locations draw economic activity as a result of the change in the economic conditions that favored the pre-openness agglomerated equilibrium. By contrast, other researchers have found that these results are subject to subtle modelling choices which may qualify the previous results (Brülhart, 2011), particularly the actual trade network topology (i.e., the geographical features of each specific country and its place in it), on which we focus in this study.

The first theoretical contribution addressing the effects of trade openness in the location of economic activity between and within countries is Krugman and Livas-Elizondo (1996), who consider an economy composed by a 2-region domestic economy and a foreign country ("the rest of the world"), whereas international transport and non-transport related costs (tariffs) become progressively lower between countries while domestic transport cost keeps constant or is costless. Their model explains the existence of large cities in some developing countries as a consequence of the strong forward and backward linkages that appear in a context of a relatively small closed economy with a strong manufacturing sector. They assume a homogenous space where locations are identically distributed; i.e., none of them enjoy a location advantage with respect to the "rest of the world" and the distance between them is also symmetric. In their study these authors study how the agglomeration equilibrium breaks up once a country starts a trade liberalization process. They argue that in nearly closed developing countries, characterized by significant economies of scale and high trade barriers, where manufacturing production is basically addressed to domestic demand, the agglomeration forces prevail over the disadvantages of overcrowded locations (congestions costs which they model through the typical land-rent approach). Instead, as the degree of openness of the country increases, "centripetal forces" weakens against "centrifugal forces", and production tends to become evenly spread across domestic regions, even when none of them initially agglomerates the entire mobile sector.[2] An alternative model to Krugman and Livas-Elizondo (1996) is

[2] Building on Krugman and Livas-Elizondo (1996), Fujita et al. (1999, chap. 18) explore the sectoral dimension. They introduce an additional agglomeration force, by including input-output linkages between production sectors, therefore becoming more profitable being closer to other

by Behrens et al. (2007a). These authors adopt a model based on the monopolistic competition framework of Ottaviano et al. (2002), where, instead of congestion costs, they consider two dispersion forces *à la* NEG (Krugman, 1991): on the one hand, part of the labor force is immobile-farmers; and on the other, local agglomeration increases competition resulting in a reduction of revenues. They draw the same conclusions: In so far an economy removes its barriers to international trade, agglomeration forces weaken while dispersion ones begin to play a more important role.

Alonso-Villar (1999) enhances Krugman and Livas-Elizondo's (1996) model by introducing a more realistic assumption about the existence of a heterogenous location of regions with respect to the rest of the world and among themselves. Thus, some regions enjoy better access to foreign markets, since they are located closer to the national border-and vice versa. More specifically, she considers a world economy composed by three countries along a line (a star topology), where the country in the middle has three regions (yet another star configuration with two external and one interior location), while the other two countries consist of one single region (a 1+3+1 setting). All regions are equidistant of their neighbors. In a situation of no international trade barriers (full economic integration), where only transport costs (proxied by distance) matter as impediment to trade, she finds that if one foreign country is economically large enough (acting as global attracting force), the agglomeration in the internal region of the central country would never be a stable equilibrium. Instead, the activity of the country would tend to agglomerate in the border region with better access to the foreign rich region. However, the final solution is more involved, since under this model both agglomeration forces and dispersion forces might be weakened. From the side of agglomeration forces, domestic producers can find more attractive to locate their firms close to foreign demand; however, on the other side, if foreign competitors exert a strong competition, domestic producers might look for less exposed locations while serving their own domestic market, where they have a privileged position. Therefore, the final equilibrium is not cut clear and once again depends on various initial features,

suppliers or client firms. They conclude that with trade openness appears a tendency toward the agglomeration among some sectors (clustering).

as where is economic activity concentrated prior to trade liberalization (i.e., its distribution resulting from historical reasons), the relative size of the foreign demand, and the productive efficiency of foreign competitors (e.g., technological features).

Another interesting version is Brülhart et al. (2004). Inspired on the EU enlargement, under which ten Central and Eastern European Countries (CEECs) were integrated into the EU's internal market, these authors study how changes in market access with the new members affect the peripheral regions of the pre-enlargement incumbents (i.e., new border regions). They propose a model of two countries (domestic and foreign countries) and three regions. Two of the regions belong to the domestic country while the other just contains one. The agglomeration forces are the usual backward and forward linkages. In the NEG fashion the dispersion force arises from the fact that one of the sectors (agriculture) only uses the immobile factor (farmers), while the other (manufacturing) employs also a factor (human capital) that is mobile. The results of their model remain relatively close to those found by Alonso-Villar (1999) in so far as, for most of the parameters, when the domestic economy is increasingly opened, the mobile industry tends to locate closer to the foreign region. However, this does not take place always. If, for instance, the internal region of the domestic country exhibits a sufficiently high industry concentration, then, this agglomeration can result in a stable equilibrium. This model presents two advantages in comparison to Alonso-Villar's (1999) approach: On one side, it allows the evaluation of the progressive effect of trade liberalization (in spatial networks characterized either by a homogenous or a heterogenous topology); on the other, it can be solved analytically.

3. The model

The multi-country multi-regional model that we introduce to address the issue of trade openness and the spatial location of economic activity enhances the existing literature in three distinctive ways, so as to gain more insight of the agglomerating and dispersing forces driving the spatial equilibria. Firstly, as in Krugman and Livas-Elizondo (1996) we intend to capture the effect of trade openness on the internal distribution of production and population adopting a suitable NEG/NTT analytical framework, while considering more general and realistic assumptions. Secondly, following Alonso-Villar (1999) we formulate our model for a multi-country multi-regional setting that allows us to study the role of the spatial topology on the spatial distribution of economic activity. We propose a flexible setting based on a bilateral distance matrix that characterizes any type of network topology with both transport and non-transport related trading costs, including the homogenous space where no region has a locational advantage, or a heterogenous space with locations enjoying better accessibility both within countries (e.g., central regions) or between countries (e.g., border regions). Thirdly, as in Fujita et al. (1999) we adopt a general model with two sectors differentiated in several ways, from the degree of product substitutability, individual transport costs, and technological characteristics. The result of these generalizations is that the model does not have closed form solutions, and therefore we solve it computationally to perform suitable simulations that allow us to address the research hypotheses for the specific topologies of interest, and test under what condition would trade liberalization increase or reduce within-country spatial inequalities (section 4).

We assume a world economy with a number of regions situated in different countries that are denoted by way of a double subscript R_{ik}, with the first one referring to the specific region $i = 1,..., j,...,n,$ and the second one to the particular country they belong to $k = 1,...,l,...,m$. Within countries we consider a NEG framework with two differentiated sectors, $s = 1,\ 2,$ with preferences characterized *à la* Dixitz and Stiglitz (1977). Production is subject to increasing returns to scale within a monopolistic competition market structure in the first sector and constant returns to scale in a perfectly competitive setting in the second. Trade takes place over a trading network connecting all regions and countries. Trade costs between regions and countries are of the iceberg form and include both a distance related cost over the transport network, and *ad valorem* tariffs when trade takes place between regions of different countries-to study the effect of trade liberalization. Each region j of a given country k is endowed with an exogenously given mass of $L_{ik} = L_{1ik} + L_{2ik}$ workers-consumers, each supplying one unit of labor —thereby coinciding country population and country labor. In each country labor is fixed and normalized to one for each sector, $\sum_i L_{sik} = 1$. Labor in the first sector is mobile within countries, i.e., workers can migrate across regions, but immobile across countries due to immigration restrictions. It is also assumed that labor is immobile in the second sector as it is based on local resource endowments (e.g., agriculture).

3.1. Preferences

Preferences of a representative consumer in region j and country l are defined over a continuum of varieties of two horizontally differentiated goods Ω_{si} :

$$U_{jl} = D_{1jl}^{\mu_1} D_{2jl}^{\mu_2}, \qquad (1)$$

where D_{sjl} stands for the aggregate consumption of each differentiated good in sectors $s = 1, 2$; $0 < \mu_s < 1$ is the share of income spent on each differentiated good, and $\mu_1 + \mu_2 = 1$. The aggregate consumption of each differentiated good is given by a constant elasticity of substitution (CES) sub-utility function

$$D_{s(jl)} = \left[\sum_k \sum_i \int_{\Omega_{si}} d_{s(ik,jl)}(\phi)^{(\sigma_s - 1)/\sigma_s} d\phi \right]^{\frac{\sigma_s}{\sigma_s - 1}}, \qquad (2)$$

where $d_{s(ik,jl)}(\phi)$ is the individual consumption in region j of country l of sector-s variety ϕ produced in region i situated in country k, including that to which i belongs; and Ω_{si} is the set of sector-s varieties produced in i. The parameter $\sigma_s > 1$ measures the constant price elasticity of demand and the elasticity of substitution between any two varieties. Let $p_{s(ik,jl)}(\phi)$ denote the price of sector-s variety ϕ produced in region i in country k and consumed in region j in country l; and let w_{jl} denote the wage rate in region j in country l. Maximization of (1) subject to the budget constraint:

$$\sum_k \sum_i \left[\int_{\Omega_{1i}} p_{1(ik,jl)}(\phi) d_{1(ik,jl)}(\phi) d\phi + \int_{\Omega_{2i}} p_{2(ik,jl)}(\phi) d_{2(ik,jl)}(\phi) d\phi \right] = w_{jl}, \qquad (3)$$

yields the following individual demands:

$$d_{s(ik,jl)}(\phi)=\frac{p_{s(ik,jl)}(\phi)^{-\sigma_s}}{g_{sjl}^{1-\sigma}}\mu_s w_{jl}\,, \tag{4}$$

where

$$g_{sjl}=\left[\sum_k \sum_i \int_{\Omega_{si}} p_{s(ik,jl)}(\phi)^{1-\sigma_s}\, d\phi\right]^{\frac{1}{1-\sigma_s}} \tag{5}$$

is the CES price index in sector *s* and region j of country l.

3.2. Technology, trade costs and networks

Technology is symmetric between firms, regions and countries, thus implying that, in equilibrium, firms differ only by the region they are located in. We thus henceforth suppress the variety index ϕ to alleviate notation. Production of any of the continuum of varieties in the first sector involves a fixed labor requirement, F, and a constant marginal labor requirement, c. The total labor requirement for producing the output $x_{1ik} \equiv \sum_l \sum_j x_{1(ik,jl)}$ is then given by $l_{1ik} = F + c\,x_{1ik}$[3]. Increasing returns to scale, costless product differentiation, and the absence of scope economies yield a one-to-one equilibrium relationship between firms and varieties.

For the second sector, each region produces a single differentiated output under constant returns and perfect competition, ensuring that the price of the variety in each region equals the salary in this sector. Trade of the differentiated goods is costly and sector-specific[4]. We follow standard practice and assume that trade costs are of the *iceberg* form: $\delta_{s(ik,jl)} \geq 1$ units must be dispatched from region i in country k in order for one unit to arrive in region j in country l. We further assume that trade costs are symmetric, i.e., $\delta_{s(ik,jl)} = \delta_{s(jl,ik)}$. Besides

[3] For the sake of simplicity, in our simulations we consider that the technological parameters F and c are also the same across regions and countries. This assumption could be relaxed to explore the effects of different sectoral productivities on the spatial location of economic activity.

[4] Davis (1998) proved that the home market effect depends on the relative size of transport costs in the differentiated and homogenous goods, insofar when both industries incur the same level of transport costs the home market effect disappears. Picard and Zeng (2005) empirically proved how the transport cost parameter for the agricultural sector could be a determinant factor for the spatial configuration of economic activity.

transport costs, shipping goods between regions of different countries is normally subject to *non-transport frictions*. These normally include tariff barriers, non-tariff barriers (red tape, administrative delays, different product standards...), and other barriers (language, currency, accounting…). Contrary to transport frictions between all regions, regardless the country they belong to, these non-transport barriers are country pair specific, and we denote them by $\rho_{s(ik,jl)}$, with $\rho_{s(ik,jl)} = 0$ if i and j belong to the same country $k = l$, or both countries belong to a free trade area; otherwise $\rho_{s(ik,jl)} > 0$ -we also assume reciprocity in tariffs: $\rho_{s(ik,jl)} = \rho_{s(jl,ik)}$. These barriers are considered as an *ad valorem* tariff in addition to transport costs, and therefore, total trade frictions between any two pair of regions are given by $\tau_{s(ik,jl)} = (1+\rho_{s(ik,jl)})\delta_{s(ik,jl)}$, with $\tau_{s(ik,ik)} = 1$, since $\rho_{s(ik,ik)} = 0$ and $\delta_{s(ik,ik)} = 1$[5].

Departing from the standard approach in international trade that considers two regions in a single country and the rest of the world, with the latter being either a single location as in Krugman and Livas-Elizondo (1996), or symmetrically located on both sides of the country as in Alonso-Villar (1999), requires the introduction of the *transport network* representing the world geography. The transport network characterizes a specific configuration of the spatial topology both between countries and within countries. When shipping goods it is assumed that firms minimize the transport costs between any two regions choosing least cost itineraries, Zofío et al. (2014). According to the latter premise, if, for simplicity, the distance between any two neighboring regions is normalized to one: $r_{(ik,jk)} = 1$ (regardless whether they belong to the same country or they are border regions between two countries), and the unit transport cost corresponds to a single and common value $t_s > 1$, then the overall transport cost between any two regions separated by a distance $r_{(ik,jl)}$ is given by $\delta_{s(ik,jl)} = t_s^{r_{(ik,jl)}}$.

The whole trade cost structure including transport (network related) and non-transport frictions can be described by way of the following symmetric matrix T_s

[5] Therefore, our transport cost metric δ corresponds to an exponential network metric as in Behrens et al. (2005, 2007a) or Barbero and Zofio (2015).

where each element represents trade frictions between a specific pair of regions.

$$T_s = \begin{bmatrix} 1 & \dots & \delta_{s(11,n1)} & \dots & (1+\rho_{s(11,1m)})\delta_{s(11,1m)} & \dots & (1+\rho_{s(11,nm)})\delta_{s(11,nm)} \\ \delta_{s(21,11)} & \dots & \delta_{s(21,n1)} & \dots & (1+\rho_{s(21,1m)})\delta_{s(21,1m)} & \dots & (1+\rho_{s(21,nm)})\delta_{s(21,nm)} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \delta_{s(n1,11)} & \dots & 1 & \dots & (1+\rho_{s(n1,1m)})\delta_{s(n1,1m)} & \dots & (1+\rho_{s(n1,nm)})\delta_{s(n1,nm)} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ (1+\rho_{s(1m,11)})\delta_{s(1m,11)} & \dots & (1+\rho_{s(1m,n1)})\delta_{s(1m,n1)} & \dots & 1 & \dots & \delta_{s(1m,nm)} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ (1+\rho_{s(nm,11)})\delta_{s(nm,11)} & \dots & (1+\rho_{s(nm,n1)})\delta_{s(nm,n1)} & \dots & \delta_{s(nm,1m)} & \dots & 1 \end{bmatrix} \quad (6)$$

This is a both a symmetric and partitioned matrix, where the elements in the diagonal correspond to the intra-regional transport costs, i.e., equal to 1 reflecting costless trade, and therefore origin and destination prices are the same. The first and last elements of the transport cost matrix represent the transport costs within countries 1 and m. The off-diagonal elements of the upper-right corner and lower-left matrices represent the cross-country transport costs between countries 1 and m, and m and 1, respectively, which are symmetric. Therefore the topological properties of the spatial network characterize the transport cost part δ_{sij} of the trade frictions matrix T_s, while the non-transport related costs have no relationship whatsoever with the topology.

3.3. Market outcome and spatial equilibria

For the first differentiated sector, a firm in region i and country k has to produce $x_{1(ik,jl)} \equiv L_{jl} d_{1(ik,jl)} \tau_{1(ik,lj)}$ units to satisfy final demand in region j in country l.

$$x_{1ik} \equiv \sum_l \sum_j L_{1jl} d_{1(ik,jl)} \tau_{1(ik,jl)}. \quad (7)$$

Using the previous expression, each firm in *i* maximizes its profit

$$\pi_{1ik} = \sum_l \sum_j \left(\frac{p_{1(ik,jj)}}{\tau_{1(ik,jl)}} - cw_{1ik} \right) x_{1(ik,jl)} - Fw_{1ik}, \quad (8)$$

with respect to all its quantities $x_{1(ik,jl)}$, and taking wages w_{1j} as given. Because of CES preferences, profit-maximizing prices display the standard constant-markup pricing rule:

$$p_{1(ik,jl)} = \frac{\sigma_s}{\sigma_s - 1} c w_{1ik} \tau_{1(ik,jl)}. \tag{9}$$

Free entry and exit implies that profits are non-positive in equilibrium which, using the pricing rule (9) into the total production function satisfying final demand (7), yields the standard condition:

$$x_{1ik} \equiv \frac{F(\sigma_s - 1)}{c}, \tag{10}$$

and the corresponding labor input is $l_{1ik} = F + c x_{1ik}$.

For the second sector, constant returns and perfect competition result in the price of the variety produced in region i equaling the salary $p_{2ik} = w_{2ik}$, while the delivered price in other regions is $p_{2(ik,jl)} = w_{2ik}\ \tau_{2(ik,jl)}$.

3.3.1. The world spatial equilibria

Adopting a suitable set of normalizations, it is possible to determine the system of equations corresponding the so-called instantaneous equilibrium, characterizing both unstable short-run and stable long-run spatial solutions. Within a country k, labor in each region is shared between both sectors, $L_{ik} = L_{1ik} + L_{2ik}$, and adding across regions: $\sum_i L_{sik} = 1$.

We denote by λ_{1ik} the share of labor supply in region i of country k in the first sector where labor is mobile, and assume an even distribution of the labor force for the second sector for which labor is immobile: $\lambda_{2ik} = 1/n$.

We present the spatial equilibrium that exists within each country in the case of an open economy where trade between countries takes place; i.e., $0 < \rho_{sij} < \infty$.

The spatial general equilibrium is completely defined by the following system of equations including the income, y_j, price, g_{si}, and nominal wage, w_{is}, equations, which are complemented with the real wage equations, ω_{si}:

$$y_{ik} = \mu_1 \lambda_{1ik} w_{1ik} + \frac{\mu_2}{n} w_{2ik}, \quad i = 1,\ldots,n, \quad k = 1,\ldots,m, \tag{11}$$

$$g_{1ik} = \left(\lambda_{1ik} w_{1ik}^{1-\sigma_1} + \sum_{j \neq i}^{n-1} \lambda_{1jk} \left(w_{1jk} \delta_{1(jk,ik)} \right)^{1-\sigma_1} + \sum_{j=1}^{n} \sum_{l \neq k}^{m} \lambda_{1jl} \left(w_{1jl} \tau_{1(jl,ik)} \right)^{1-\sigma_1} \right)^{1/(1-\sigma_1)}, \tag{12}$$

$$g_{2ik} = \left(\lambda_{2ik} w_{2ik}^{1-\sigma_2} + \sum_{j \neq i}^{n-1} \lambda_{2jk} \left(w_{2jk} \delta_{2(jk,ik)} \right)^{1-\sigma_2} + \sum_{j=1}^{n} \sum_{l \neq k}^{m} \lambda_{2jl} \left(w_{2jl} \tau_{2(jl,ik)} \right)^{1-\sigma_2} \right)^{1/(1-\sigma_2)}, \tag{13}$$

$$w_{1ik} = \left(y_{ik} g_{1ik}^{\sigma_1 - 1} + \sum_{j \neq i}^{n-1} y_{jk} g_{1jk}^{\sigma_1 - 1} \delta_{1(ik,jk)}^{1-\sigma_1} + \sum_{j=1}^{n} \sum_{l \neq k}^{m} y_{jl} g_{1jl}^{\sigma_1 - 1} \tau_{1(ik,jl)}^{1-\sigma_1} \right)^{1/\sigma_1}, \tag{14}$$

$$w_{2ik} = \left(y_{ik} g_{2ik}^{\sigma_2 - 1} + \sum_{j \neq i}^{n-1} y_{jk} g_{2jk}^{\sigma_2 - 1} \delta_{2(ik,jk)}^{1-\sigma_2} + \sum_{j=1}^{n} \sum_{l \neq k}^{m} y_{jl} g_{2jl}^{\sigma_2 - 1} \tau_{2(ik,jl)}^{1-\sigma_2} \right)^{1/\sigma_2}, \tag{15}$$

$$\omega_{1ik} = w_{1ik}\, g_{1ik}^{-\mu_1}\, g_{2ik}^{-\mu_2}, \quad i = 1,\ldots,n, \quad k = 1,\ldots,m. \tag{16}$$

Both the sectoral price g_{sik}. and wage w_{sik} equations include the variables referring to region i itself in the first term of their RHS, those related to the rest of the regions within the same country k in the second term, and the interactions with the regions of the rest of the countries in the last term.

As for the income equations (11), they are the sum of the workers' incomes in both sectors (depending on the share of the production in the first sector λ_{1ik} and the equiproportional labor force in the second sector, $1/n$). Regarding the price indices (12) and (13), representing a weighted average of delivered prices, they are lower: 1) the larger are the shares of the production in the first sector in region *i* (which is domestically produced), 2) the larger the imports from nearby regions rather than distant regions within the same country —as transport costs $\delta_{s(jk,ik)}$ are lower with the former that the latter, and 3) the larger the trade with both nearby countries and those with existing trade agreements —as tariffs ρ_{sij} will be smaller in $\tau_{1(jl,ik)}$. With respect to the wage equations (14) and (15), they will be higher if incomes in other regions and countries with low transport costs and tariffs with i are also high, as firms pay higher wages if they have inexpensive access to large markets.

Finally, from the price and wage equations one obtains real salaries- equation (16)-as the cornerstone of the model driving the migration of the workers of the first sector across regions in a country. Comparing the real salaries within a country, an equilibrium is observed if they are equal across regions $\omega_{1ik} = \omega_{1jk} \; \forall i, j \in k$. Otherwise, and following standard NEG migration rules, if there are differences between real salaries, simple dynamics ensure that regions with higher salaries draw workers from below-average salaried regions until real wages equalize. Note that real salaries could be different between countries but not across regions in each country. This is because of the restrictive migration laws and physical barriers (e.g., US-Mexico wall, Spanish-North African fence...) preventing people movements across the borders.

3.3.2. Autarky and trade-openness equilibria

Looking at the system of non-linear equations representing the instantaneous equilibrium, it can be seen that when $\rho_{s(ik,jl)} = \infty$, the last sets of terms in the RHS corresponding to other countries tend to zero, and therefore the spatial location of economic activity corresponds to a standard multi-regional NEG model without a multi-country dimension—i.e., from a trade perspective a situation of autarky equivalent to that discussed by Barbero and Zofío (2015) for different network topologies. In this framework each country presents specific locational patterns depending on how its geography and transport network shape its spatial topology, as well as the existing transport cost levels.

4. The effects of trade openness on the distribution of economic activity within a country

As argued above, it is very difficult to obtain general results in the multi-region multi-country setting, because the equilibrium allocation of economic activity in the first mobile manufacturing sector is determined by a complex trade-off between the inherent NEG/NTT centrifugal and centripetal forces, model's parameters, network topology and transport and non-transport related costs. This is particularly true for our model as any world trade network both within and between countries can be defined. However we can gain more systematic insights into how trade liberalization and the structure of the trading network influence the equilibrium distribution of economic activity by choosing some relevant configurations and resorting to systematic numerical simulations aimed at determining the critical break-point and sustain-point values.

The research strategy is as follows. First, we study the standard NEG results within a single country, and determine the long run-equilibria of economic activity in its regions by way of the bifurcation diagram (tomahawk) summarizing the locational patterns of economic activity. This is equivalent to study a closed economy (autarky) within a world trading network. Subsequently, we allow for trade openness with a second country, and study how international trade flows alter the distribution of economic activity within our first reference country; i.e., a systematic comparison of pre and post openness situations. In doing so, we consider for our first benchmark country two different topologies that are completely opposed; namely a homogenous topology where all regions are equally located with respect to each other and there are no locational advantages (geometrically represented by an equilateral polygon —known as the race-track economy in the literature), and a heterogenous topology where one central region enjoys a comparative advantage (geometrically represented by a star—hub and spoke—topology). While other alternative network topologies are possible, our results for these two extreme cases of network centrality allow us to set lower and upper bounds (range) for the results that would be obtained for intermediate topologies, see Barbero and Zofío (2015).

Once the research strategy has been laid out, we illustrate the effects of trade liberalization for the particular case of two countries consisting of three regions each, and focusing the analysis on the two opposed domestic topologies already mentioned: a triangle topology (all regions are equidistant and there are not transport related advantages), and a line topology (a region is in the center of the domestic network)[6]. The main results refer to the usual critical values

[6] These two extreme topologies for three regions have been also studied in the NEG literature by Ago et al. (2006) and Castro et al. (2012), even if for the simpler seminal model of Krugman (1991) considering a homogenous and a differentiated sector.

determining the disperse or agglomerated outcomes; i.e., those identifying the transport cost thresholds for the mobile sector for which full dispersion is no longer stable (break-points), and for which full agglomeration is unfeasible (sustain-points). Therefore we first assess these scenarios in the context of autarky, and afterwards once the economy progressively opens to international trade. In doing so we change the transport cost of sector 1 and trade barriers to determine a wide range of scenarios, and identify the stable and unstable equilibria for each degree of openness.

4.1. A closed economy with homogenous space

Figure 1 shows the complete topology including two countries and their associated distance matrix, each consisting of three regions with a homogenous triangle topology. The second country is symmetric to the first one in this case, so we assume that its labor force in both sectors is also evenly distributed: $\lambda_{sj2} = 1/3, s = 1,2, j = 1,2,3$ [7]. Both countries are connected through two of its regions situated at their shared border (at the same distance as that between the regions of each country)[8]. It is among the regions belonging to the different countries where one finds different distances, which are no longer the same for all regions, thereby altering the neutrality of space as a force shaping the

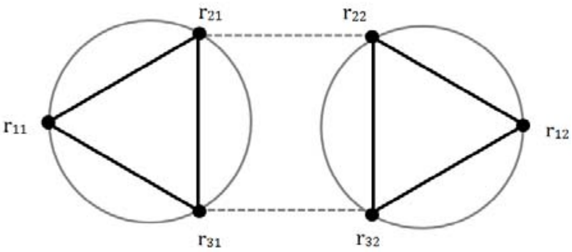
[7] The location of the first sector activity in the second country: λ_{1l2}, is also subject to the forces that shape that of the reference country; i.e., real salaries in the regions of the second country will be affected by the same trade openness process. We shall take into account these feedback effects associated to changes in the distribution of the first sector in the second country when they result in different equilibria for the location of economic activity in the first country: λ_{1i1}. For brevity, these results are not reported, but are available upon request. Nevertheless, we highlight that the rank of the real wages among the three domestic regions does not change for the three extreme scenarios: all workers of the sector 1 are evenly spread across the foreign regions ($\lambda_{1j2} = 1/3$, $j = 1, 2, 3$); all workers of the sector 1 are equally agglomerated on the two bordering regions ($\lambda_{1j2} = 1/2$, $j = 1, 2$; and when all workers are concentrated on the farthest location ($\lambda_{112} = 1$). The most remarkable result is that in this last scenario the domestic salaries achieve their higher levels, while when the agglomeration is at both sides of the national border wages are lower. This might be motivated for the agglomeration costs in terms of an extreme increase of the other sector's prices (sector 2), which becomes scarce under this agglomeration situation.

[8] There are other possible connections or links, such as: the union of a single region of each country; or one region of one country with two regions of the other country. In order to simplify matters, in this paper we focus on only one of them, which resembles the network configuration of countries like Spain; where Madrid would be region 1 and Catalonia and the Basque Country would be regions 2 and 3, both connected to the French Border.

location of economic activity through transport costs. In fact, the distance between region 1 in country 1 and region 1 in country 2 is the longest: $r_{(11,12)} = 3$.

In sum, we go from two homogenous topologies to a single heterogeneous network, where two groups of regions arise: those four situated at the border with better accessibility, and two remote regions in the *cul-de-sac* of the two countries.

Figure 1 Graphical representation of two countries characterized by a homogenous topology and the equivalent matrix of distances (within and between countries).



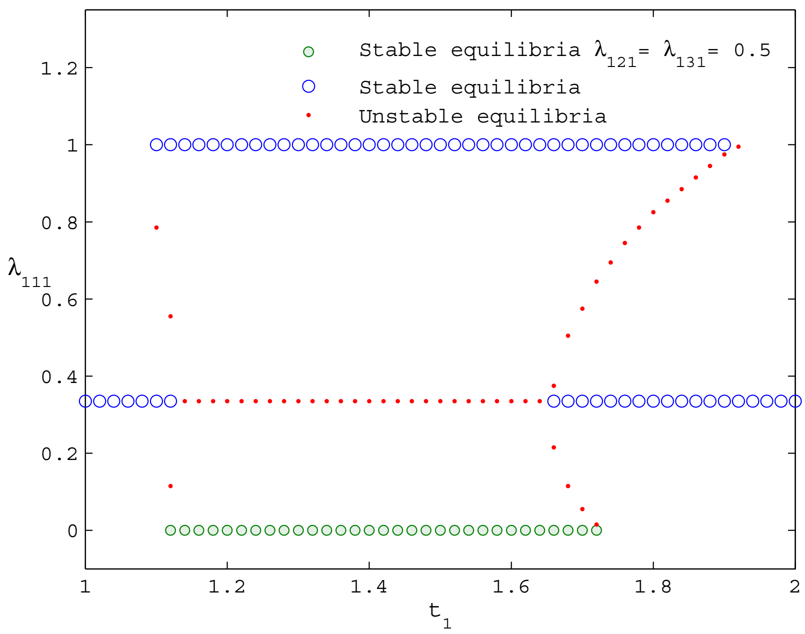
$$r_{(ik,jl)} = \begin{bmatrix} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} & \begin{bmatrix} 3 & 2 & 2 \\ 2 & 1 & 2 \\ 2 & 2 & 1 \end{bmatrix} \\ \begin{bmatrix} 3 & 2 & 2 \\ 2 & 1 & 2 \\ 2 & 2 & 1 \end{bmatrix} & \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} \end{bmatrix}$$

For the autarky scenario

Figure 1 is reduced to the first triangle, where no region has a geographical advantage in its trade relationship with the others. Alike the *T* matrix including the total cost of transportation between regions only includes as elements these bilateral distances, which are normalized to one.

Figure 2 represents the tomahawk with respect to the transport costs of sector 1 (mobile sector) comprised between the values 1 and 2. In other words, it depicts all the population shares which are in equilibrium, distinguishing whether they are long-run stable (blue or green hollows) or are short-run unstable; i.e., sensitive to small changes (red dots), for the different transportation costs of sector 1. For comparison purposes, the values of the rest of parameters considered henceforth, unless indicated otherwise, correspond to those normally adopted in the literature initiated by Fujita et al. (1999): $\mu = 0.4$, $\sigma_1 = 5$, $\sigma_2 = 10$, $t_2 = 1.275$, and assume that workers of the immobile sector 2 are evenly distributed; i.e., $\lambda_{2i1} = 1/3$ for each region. The results show that at relatively low levels, and from relatively high levels of transport costs borne by sector 1, the symmetric equilibrium is stable; i.e., each region holds an equal share of manufacturing activity and associated population, $\lambda_{1i1} = 1/3,\ i = 1,\ 2,\ 3$.

Figure 2 Bifurcation with two differentiated sectors, t_2=1.275. Autarky economy composed of 3 regions, $\rho_{s(ik,jl)} = \infty$. Triangle topology.



However, for intermediate values of transport costs, agglomeration forces prevail, resulting in a stable core-periphery equilibrium (blue hollows, where sector 1 is fully agglomerated on location 1 ($\lambda_{111} = 1$)) or, for a smaller range of trade costs, in a semi-core-periphery equilibrium (green hollows, where the mobile economic activity is concentrated on the bordering regions ($\lambda_{1i1} = 1/2$, where $i = 2,\ 3$)). Therefore we refer to a core-periphery equilibrium when one region concentrates all the labor and industrial activity of sector 1. Whereas we talk about a semi-core-periphery equilibrium when two regions concentrate all their industry in sector 1. The symmetric balance becomes unstable for this rank of intermediate transport costs. Between the two extreme solutions, core-periphery and flat-earth, just arise some unstable equilibria that gather different degrees of population. These are between the critical values of break-point (which breaks up the stable symmetric equilibrium) and sustain-point (at which the core-periphery equilibrium becomes unstable). This result generalizes the most complex NEG outcome in Fujita (1999) to three regions, concluding that

under a symmetric topology and given the agglomeration and dispersion forces considered in the model, for sufficiently high or sufficiently low transport costs for sector 1, the homogenous distribution of the mobile sector appears as a stable equilibrium.
However, for intermediate transport costs, the stable equilibrium corresponds to a core-periphery structure, where all the activity of sector 1 is either concentrated in a single location, or symmetrically in the two opposing locations. In the next section we analyze the effect of trade liberalization on these results, identifying which regions gain/lose from the opening up process.

4.2. How trade openness favors bordering regions by changing the trade network topology

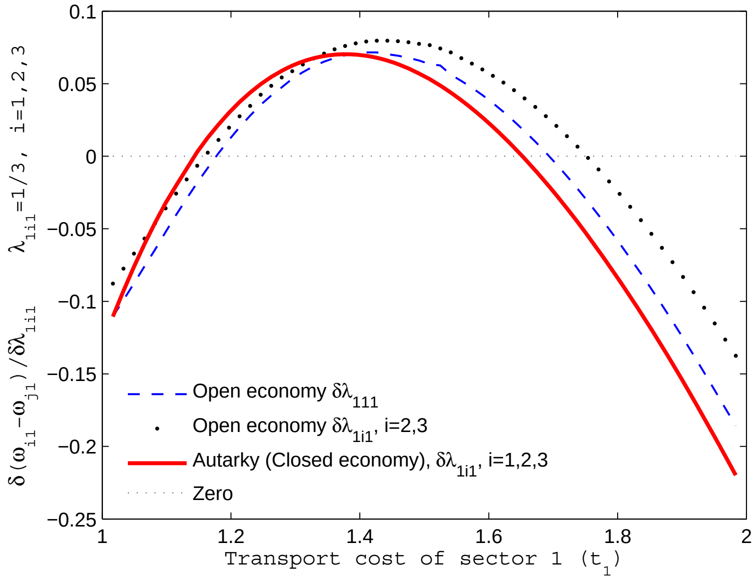
The stability of the dispersed (flat-earth) equilibrium: Triangle topology in both countries

To study the break-points
Figure 3 [Panel a] plots the variation in the difference in real wages between workers of sector 1 across regions of the same country ($k=1$) under autarky: $\rho_{s(ik,jl)} = \infty$, and complete trade openness: $\rho_{s(ik,jl)} = 0$, when a marginal change in population takes place: $\delta\lambda_{1i1} > 0$. Note that only workers of sector 1 move across regions of a given country, being drawn by the region(s) with the highest real wage(s); i.e., workers respond to changes in real wage differentials.
Figure 3 [Panel a], known as the wiggle diagram, depicts the transport costs values for which the symmetric distribution of workers is stable. As a typical break-point exercise, the starting point is the symmetric —flat-earth— distribution of workers across regions ($\lambda_{1i1} = 1/3$, in our case). Therefore, the graph records the change in real wage differentials under marginal changes in the population, $\delta(\omega_{i1} - \omega_{j1}) / \delta\lambda_{1i1}$, along the range of transport costs of said sector 1 comprised between the values 1 and 2. Thus the symmetric equilibrium will only be stable if an increase of population brings a lower real wage in the

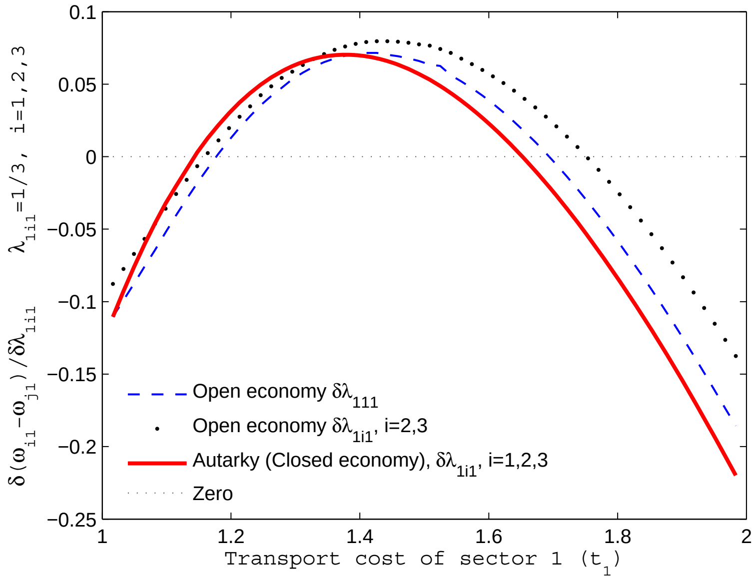
incoming (receiving) region. Graphically, this is observed for transport costs where the wage differentials are below zero, corresponding to a stable condition; by contrast, when they are above, we face reinforcing agglomeration dynamics.

Figure 3 Break point [Panel a] and Sustain Point [Panel b] in region 1 and region 2 (or 3) in country 1 before and after the openness of the economy. Where both countries have a triangle topology, $t_2 = 1.275$, $\lambda_{1ik} = 1/3$, $i = 1,\ 2,\ 3$ and $k = 1,\ 2$.

[Panel a]



[Panel b]



The solid line recalls the break point results of the previous section for the case of a closed economy, an autarky. Note that since this is a closed economy characterized by the triangle topology, the results between two regions will be independent of which two regions are chosen. On the opposite side, when the economy is in a liberalization process, the triangle topology does not longer prevail, emerging the two aforementioned groups of regions: central (r_{21} and r_{31}) and peripheral (r_{11}). This means that under the same characteristics, in terms of population and transport costs (here, in sector 1), there are different reactions of wage differentials to population shocks. That is, the marginal increase in the population will have a different effect depending on whether the increase occurs in a region closer or further away from the new market. The dashed line includes the case in which the most peripheral region suffers a positive immigration shock. Whereas the dotted line reports the change in the real wage differential when it is one of regions closest to the new market the one experiencing a population increment. The dashed and dotted line corresponds to complete openness, and therefore the difference between these curves and the solid line, which corresponds to closed economy, delimit the bounds for the long-run symmetric equilibrium for all other intermediate degrees of trade openness: $0 < \rho_{s(ik,jl)} < \infty$.

The study of the

Figure 3 [Panel a] shows that for low values of transport costs in sector 1, the break point comes first under the scenario of a closed economy, followed by the situation of an almost fully integrated trade area when the positive shock of migration affects one of the new core locations. So the break-point arises later when, in an open situation, it is the peripheral region (r_{11}) which receives immigrants. This means that the transport costs that keep sustainable the homogenous distribution have to be higher when we study a more peripheral region in an open economy, than in the other extreme scenarios; i.e., in an open scenario it is easier for peripheral regions to lose economic activity and depopulate. At the other end, when transport costs are high enough to make sustainable an even distribution of the economic activity/population, this becomes stable first in the situation of closed economy. The opposite case is when a region closest to the outside border begins to agglomerate, which requires the highest transport costs to make stable the flat-earth distribution; i.e., it is easier for better located regions to start agglomerating by drawing economic activity from the peripheral regions. An alternative way to analyze this is to note that the dotted curve (for a border region, such as r_{21}) is always above the dashed line (for a more internal — peripheral— region, such as r_{11}), which means that under the same circumstances (migratory shock and transport costs), the change in the real wage differential in the frontier region is always greater than for the new periphery, in an open economy. This also means that the range of values for which the homogenous space is unstable is greater when the incoming or receiving region has a locational advantage in an open economy, since it is more probable that it generates a self-reinforcing agglomeration effect.

The stability of the agglomerate (core-periphery) equilibrium: Triangle topology in both countries

Figure 3 [Panel b] shows the levels of transport cost in sector 1 in a situation where one of the regions agglomerating all the economic activity is stable; i.e., a sustain-point exercise. As in the previous case, we take as

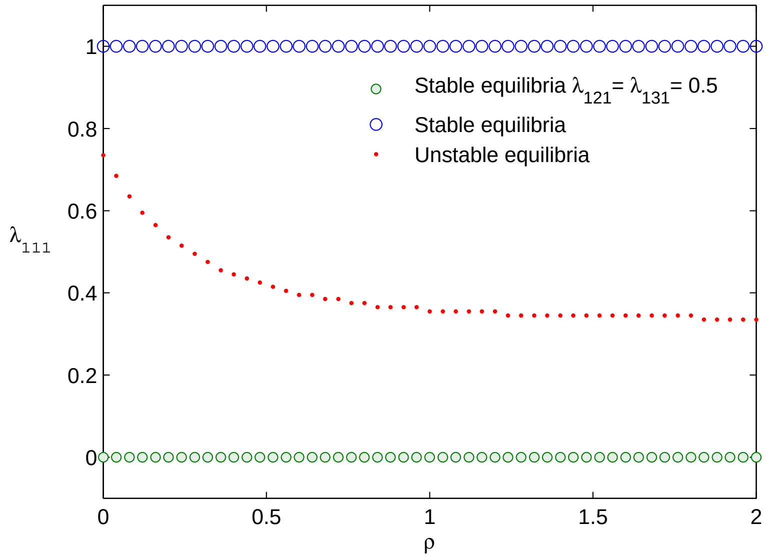
reference two extreme scenarios: a closed economy: $\rho_{s(ik,jl)} = \infty$ (solid line) and an open economy: $\rho_{s(ik,jl)} = 0$ (dashed and dotted lines). The values shown in the graph are the differences in real wages between an empty region j, in terms of workers from sector 1, and a region that agglomerates all the workers, i. $\omega_{j1} - \omega_{i1}$, for each value of transport costs between 1 and 2. Thus, the core-periphery equilibrium is stable if the wage difference is negative, i.e. the curve is below zero, meaning that the region that holds all workers also shows the higher real wages. In all cases this only occurs among intermediate values of transport costs. Once again consistent with the bifurcation diagram in

Figure 2 for the autarkic economy, we recall the well-known centrifugal effect that breaks the core-periphery equilibrium when transport costs reach a high enough value, as a result of the existence of an immobile demand associated to the workers of the second sector. The fact that no agglomeration is fully stable at very low transport costs is uncommon. Just to clarify, this is due to two features of the second sector that go against the agglomeration (besides the aforementioned fixed demand): On one hand, it produces differentiated products, what makes more attractive those products; on the other hand, its trade incurs in transportation costs, which increases the consumption price index, especially in areas with high demand (large population). In other words, this result does not appear if the second sector were to produce perfectly homogenous goods, $\sigma_2 = \infty$, and did not incur transport costs $t_2 = 0$. This result is also observed for the open economy. However, the graph shows that the outcome for a closed economy situates between the extreme cases in which, in an open economy, all mobile workers agglomerate in the peripheral region (with worse accessibility than any region in the homogenous autarky network) and the better located border regions (with better accessibility); being the region that becomes remote after the full commercial opening the one that shows the lowest real wages. On the opposite side, there is the case of an open economy where the working population is located in a region near the foreign market; in this case, the range of intermediate transport costs for which this situation is stable is greater. That is, compared to a closed economy situation where no region has a geographical advantage, trade openness polarizes the effects of transport costs, being more stable the agglomeration in regions closer to the new trading partner. Graphically, the lower the wage differential curve, the larger the wages in the agglomerating region, leaving a wider range of transport costs for which the initial agglomeration is sustainable.

Trade openness and instantaneous equilibria

We now explore the results for different degrees of trade openness in the form of alternative values of the non-transport frictions —ad valorem tariffs ρ. Figure 4 shows the distribution patterns of the mobile sector that represent an equilibrium, for relevant ranges of openness: $\rho = [0, 2]$. These equilibria may be stable (symbolized with hollows); i.e., robust to small changes in population, or unstable (symbolized by dots); i.e., sensitive to small changes in the population, which would lead to one of the stable equilibria. Surprisingly, the results show that given transportation costs $t_1 = 1.4$ and $t_2 = 1.275$, the core-periphery structure $\lambda_{111} = 1$, or $\lambda_{1i1} = 1/2,\ i = 2,\ 3$, is always a stable equilibrium for any degree of trade openness, regardless of whether the regions that agglomerates are bordering regions or the most inner region, i.e. opening to trade does not have regional consequences. This shows the resilance of the agglomerated equilibrium. Indeed, when the economy is an autarky; i.e., ρ tends to infinity, the alternative distribution of the mobile sector between the three regions emerges as an unstable equilibria (all regions hold economic activity in the mobile sector representing the so-called pseudo flat-earth by Barbero and Zofío (2015); and depicted graphically with red dots).

Figure 4 Bifurcation in region 1 in country 1 respect to the degree of openness of the economy, t_1=1.4 and t_2=1.275. Triangle topology in both countries, where $\lambda_{1i2} = 1/3,\ i = 1,2,3$.



However, when an opening process starts (ρ tends to zero), only those combinations in which the farthest region to the external market (r_{11}) progressively increases its population are equilibria, though unstable, making smaller the area where the whole agglomeration in the new periphery location is stable —otherwise a process of relocation toward the other two regions will begin. In short, if a closed economy starts from a symmetric distribution, the openness process will tend to agglomerate the mobile sector in one of the bordering regions. Only if the inner region were to increase its share of population with the integration process, the core-periphery equilibrium would not emerge. Therefore we note that having a large share of population allows offsetting the locational disadvantages of the inner region emerging from the new network, through the home market effect and the productive advantage of the economies of scale.

Finally, the set of graphics in

Figure 5 illustrates a detailed analysis of the indirect utility of individuals (hereafter real wages) in each region under the two traditional spatial distributions studied for the mobile sector: core-periphery and full dispersion configurations[9]. This analysis complements those already made when searching of the break and sustain points presented in

Figure 3 [Panel a] and [Panel b]. In those figures the comparative statics analysis between the wages was dyadic; i.e., between two regions (real wage in the central region versus real wage in one of the peripheries), and for extreme values of tariffs ($\rho = 0$, which approaches the case of full openness and $\rho = 2$, which leads to the autarky scenario). Here we analyze simultaneously the salaries for the three regions and we do it for all values of ρ comprised in the selected range. The transport costs assumed are $t_1 = 1.4$ for sector 1 and $t_2 = 1.275$ for sector 2. Given these intermediate transport costs we observe a rich range of equilibria. Moreover, as the range of real wages in the *y*-axis is the same, we can compare the three cases analyzed (full dispersion, agglomeration in region 1 and agglomeration in one of the regions closely located to the other country), and see under what circumstances regional wages reach higher values. The first panel of

Figure 5 [Panel a] depicts the case in which economic activity is equally distributed across the three domestic regions ($\lambda_{1i1} = 1/3$, in our case, where $i = 1,\ 2$ *and 3*). For high values of $\rho \approx 2$ we get the same results that those obtained under the symmetric network economy in autarky. We know from the analysis of the autarky that under these circumstances all regions have the same wage and this is a stable equilibrium distribution for transport costs in sector 1 lower than 1.1 ($t_1 < 1.1$) or above 1.7 ($t_1 > 1.7$), approximately, and unstable for the intermediate costs (

Figure 2). With the opening up process; i.e., the smaller are the level of tariffs ρ, a significant increase is observed in real wages in the bordering regions, and only when ρ is sufficiently small, region 1 also yields a slight growth. In conclusion, trade liberalization appears to cause in the short term a clear real wage increase in border regions, which in the long run suggests that people would tend to agglomerate in them. According to the results of the tomahawk (Figure 4), we know that this is a stable equilibrium distribution.

[9] These indirect utility values may be considered as a straightforward measure of welfare (Castro et al., 2012). However, it is clear that from a comprehensive perspective, these measures do not take into account the real wages of workers in the immobile sector, neither the likely externalities, in terms of regional inequality, that emerges from the full concentration of mobile sector in a unique location. For different definitions of welfare in the NEG model see Charlot et al. (2006).

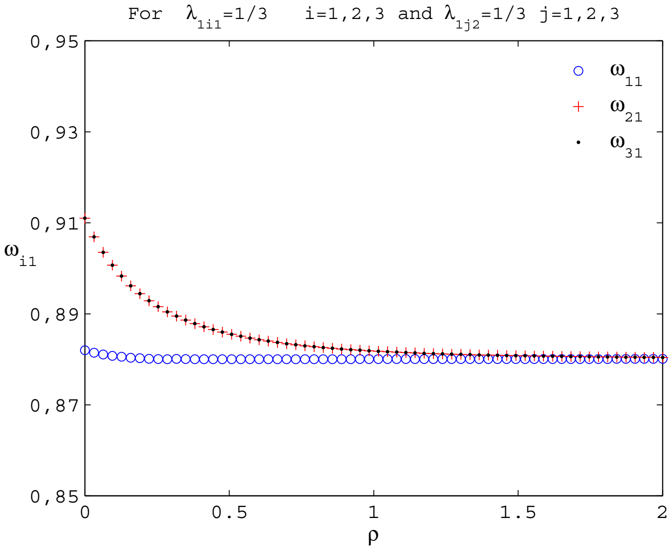
The following panel of

Figure 5 [Panel b] shows the scenario in which the entire population working in the mobile sector is concentrated in the furthest region to the foreign country ($\lambda_{111} = 1, \lambda_{1i1} = 0, \quad i = 2, 3$). Whereas [Panel c] reflects the opposite scenario, where the economic activity of sector 1 is concentrated in one the frontier regions ($\lambda_{111} = 0, \lambda_{1i1} = 1, \; i = 2$ *or* 3). In the case of autarky ($\rho = 2$), as expected, results in both graphs are equivalent, accruing from the triangle topology. However, with trade liberalization (reduction of ρ) the evolution of real wages differs. In both cases, the regions that agglomerate the economic activities of the mobile sector show the highest salary for the whole range of tariff costs considered, but when the economic activity of sector 1 is concentrated in the furthest region of the home country (r_{11}), the opening process means a progressively reduction in the wages in this region and an increase in the periphery.

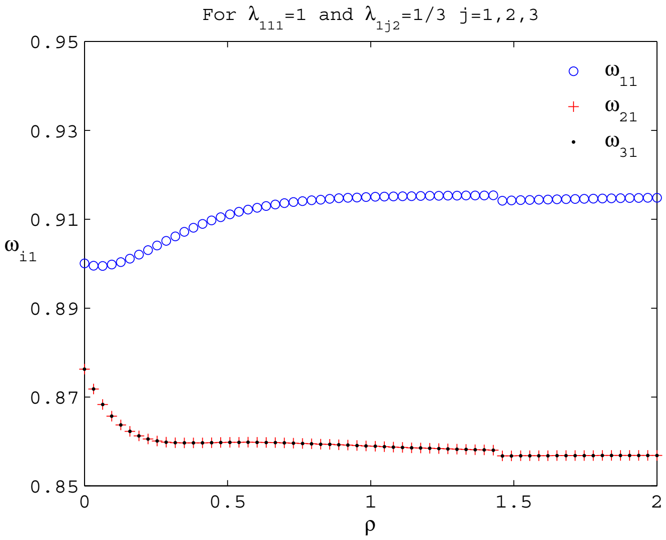
By contrast, when the agglomeration takes place in the frontier, the opening up process to international market entails a monotonic increase in wages in this location and in the other border region (with increased accessibility), while in the new periphery (r_{11}, after the openness) hardly there are any changes[10].

Figure 5 Real wage in each domestic region for different degrees of openness $\rho \in [0,2]$, $t_1 = 1.4$ and $t_2 = 1.275$. Triangle topology in both countries.

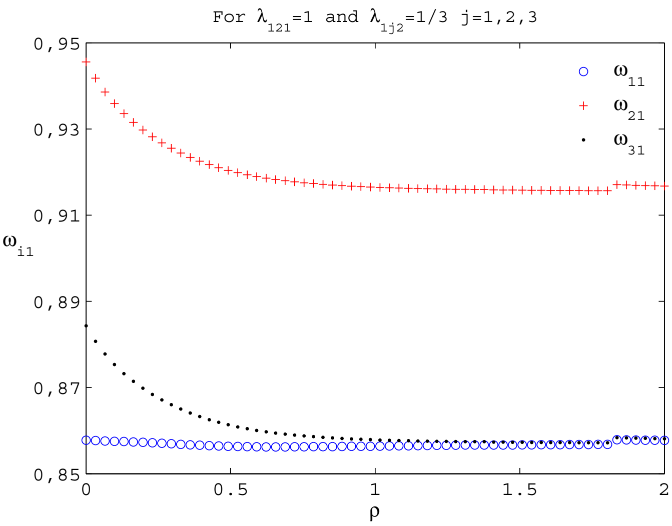
[10] As it was mentioned these results are robust to alternative distributions of the economic activity of sector 1 in the second country, that in our base simulation is set evenly across regions; i.e., $\lambda_{1j2} = 1/3, \; j = 1, 2, 3$. Real wages in all three regions as trade liberalization increases for alternative distributions of economic activity are available upon request. These alternative scenarios agglomerate economic activity either in the farthest region: $\lambda_{112} = 1$, or symmetrically in the border regions: $\lambda_{1j2} = 0.5, \quad j = 2, 3$. Real wage patterns and the sign of the differences between regions are unaffected by these changes.



[Panel a]



[Panel b]



[Panel c]

In general, we have observed that assuming a homogenous (triangle) topology, trade liberation increases real wages in the case of the border regions. This result aligns with the expectation, given the expressions that define sector's 1 real wages (16), which are positively related to nominal wages (14) and negatively related to the price indices (12) and (13). In the case of the nominal wage, if we assume that all regions face a similar price index, then its value would be larger the higher is the income of the closest neighbors (lower transport costs). As for the price indices, both for the sector 1 and 2, if we assumed a nominal wage similar across the different locations, these indices would be lower the higher is the share of these sectors in regions with low transport costs. Therefore, through the reduction of tariff barriers, the emergence of new trading partners will benefit more the border regions, since they are closely located to them, having three direct neighbors under trade openness instead of two in autarky.

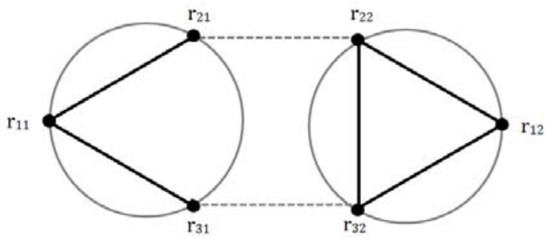
4.3. A closed economy with heterogenous space

Figure 6, like

Figure 1, shows the trade network with its corresponding distance matrix consisting of two countries with three regions each. In this case the country of interest presents a star topology, where the central region is that located further away from the foreign economy, so again their exports must go through another domestic (border) region[11]. However, according to the domestic market, this topology gives a locational advantage to the central region (r_{11}, in this case). Their graphical representation could be a straight line or, as here, an open equilateral triangle to ease comparisons with the previous topolgy.

[11] This resembles the situation of Landlocked Developing Countries (LLDCs); i.e., r_{11} could be considered as a third country on its own, facing difficulties to develop economically through foreign trade. See the reports by the UN Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States, http://unohrlls.org/about-lldcs/.

Figure 6 Graphical representation of two countries: Country 1 with the star topology and country 2 with the triangle topology. And the equivalent matrix of distances (within and between countries).



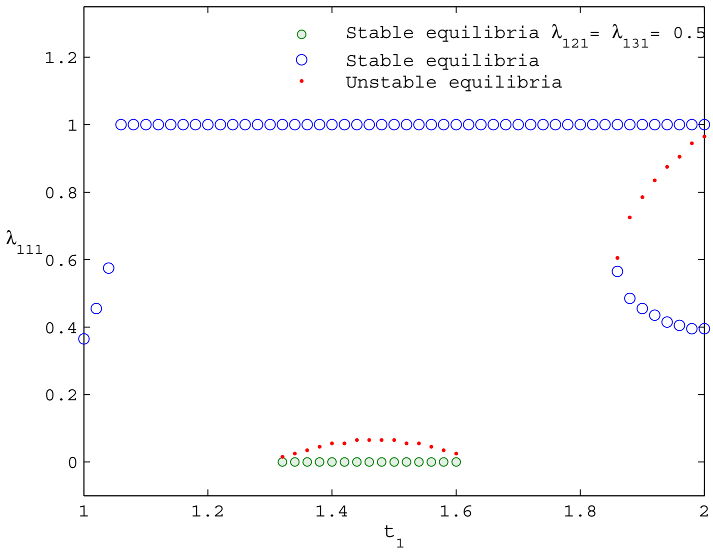
$$r_{(ik,jl)} = \begin{bmatrix} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 2 \\ 1 & 2 & 0 \end{bmatrix} & \begin{bmatrix} 3 & 2 & 2 \\ 2 & 1 & 2 \\ 2 & 2 & 1 \end{bmatrix} \\ \begin{bmatrix} 3 & 2 & 2 \\ 2 & 1 & 2 \\ 2 & 2 & 1 \end{bmatrix} & \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} \end{bmatrix}$$

Figure 7 represents the tomahawk diagram of the 3 region closed economy characterized by the star topology, regarding alternative transport costs of sector 1 (mobile sector). This graph draws the shares of the population in the central region 1, being the rest of the population perfectly divided among the other regions, for which the economy is in equilibrium. As in
Figure 2, the stable equilibria are represented by blue and green circles while the unstable equilibria by red dots. The results show that for relatively low transport costs the core-periphery configuration, where the entire population is agglomerated in region 1 (blue hollows), emerges as stable equilibrium —indeed much earlier than for the homogenous topology in
Figure 2. By contrast, the symmetric distribution of the whole population between the two peripheral regions (green hollows) —leaving the central location without manufacturing sector, is now only stable for a relatively smaller range of intermediate transport costs, in contrast to the larger range for the fully connected triangle topology. The symmetric distribution of the population is only stable for extremes transport costs. Instead, for relatively low or high transport costs the stable equilibrium arises when the share of population in region 1 gathers levels above 0.33 (which represents the homogenous distribution of the population); more precisely these are between 0.3 and 0.6[12]. And only for relatively high transport costs (greater than 1.8), shares of population in region 1 above 0.6 appear as unstable equilibrium. In conclusion, the central region (

[12] This corresponds to the concept of *pseudo* flat-earth introduced by Barbero and Zofío (2015), as that distribution of manufacturing activity that represents a long-run equilibrium with all regions holding manufacturing activity, $\lambda_i^* > 0$, but in different proportions.

r_{11}) tends to agglomerate the entire economic activity for a wider range of transport costs or concentrate a higher share of the population for extreme transport costs.

Figure 7 Bifurcation with two differentiated sectors ($t_2 = 1.275$). Autarky economy composed of 3 regions. Star topology.



4.4. How trade openness offsets the locational advantage of the central region by changing the world trade network topology

The stability of the dispersed (flat-earth) equilibrium: Star and triangle topologies for each country, respectively

Figure 8 [Panel a] shows the analysis of the stability of the symmetric equilibrium in the mobile sector 1, taking as starting point the even distribution of this sector's activity among the regions of the country of interest. As in previous cases the symmetric distribution is a stable equilibrium whenever the real wage in the region receiving immigrants becomes smaller than in the departing regions. Therefore, the graph records the change in real wage differentials under marginal changes in the population, $\delta(\omega_{i1}-\omega_{j1})/\delta\lambda_{1i1}$, along the range of transport costs of sector 1 comprised between the values 1 and 2. Graphically, this occurs when the change in the differential wage curve is negative, below zero. With respect to

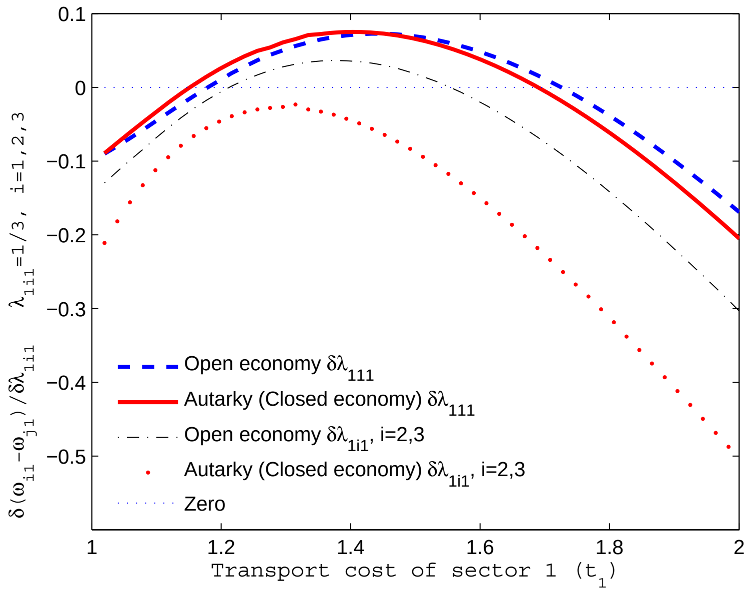
Figure 3 [Panel a], there is now an autarky scenario where the central region enjoys a privileged locational advantage (r_{11}), as the other regions (r_{21} or r_{31}) must ship their products through it. However, as in the previous case, once trade openness takes place it results, ceteris paribus, in uneven effects across regions, with a growth in economic activity in those regions whose geographical location improves in relative terms, and the opposite for those whose location worsens. Therefore, departing either from an even distribution of population (flat-earth) or full agglomeration (core-periphery), it is necessary to study the existence of break-points and sustain-points at the individual level, since they are different for each region. For the break points, whether a positive migration shock takes place in a central region or a peripheral one. Note that under the chosen world topology, the privileged central region under autarky becomes peripheral with a locational disadvantage with respect to the foreign economy and its border counterparts, leading to conflicting forces without a clear net outcome.

If we analyze the case of the closed economy and compare it with

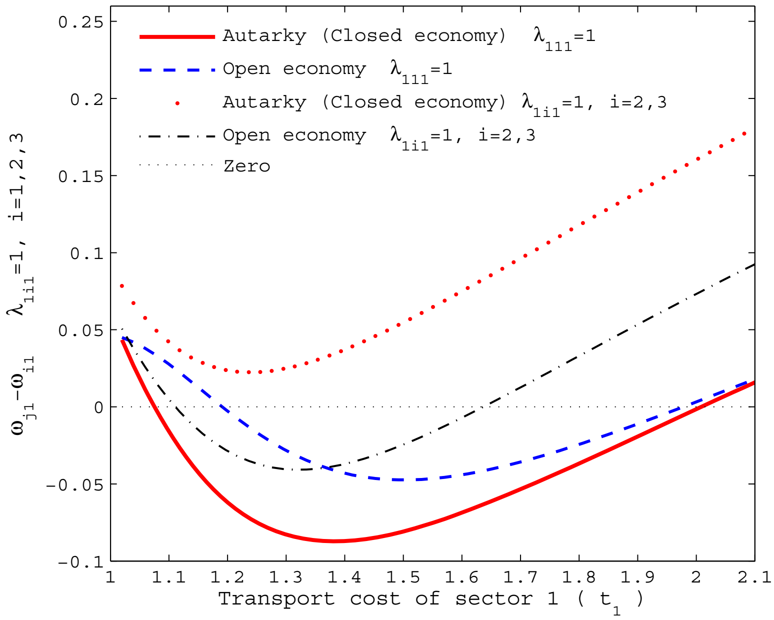
Figure 3 [Panel a] (triangle topology), the central region (r_{11}) provides higher (relative) salaries than any of the other regions poorly positioned in the home network (r_{21} or r_{31}), even when it is one of the peripheral region receiving a positive migration shock. Graphically the curve that refers to a peripheral region (r_{21} or r_{31}) is *always* below zero, thus for any level of transport cost a small increase in population will never trigger an agglomeration process in the periphery, breaking up the symmetric equilibrium. On the other hand, when the best located region (r_{11}) receives the immigration inflow, the results are more similar to those obtained in the closed economy with the homogenous topology (triangle), being at intermediate values of transport costs when the symmetric equilibrium ceases to be stable, thereby triggering a process of agglomeration.

Figure 8 Break points [Panel a] and Sustain Points [Panel b] in region 1 and region 2 (or 3) in country 1 before and after the openness of the economy. Star and triangle topologies, respectively, t$_2$=1.275, $\lambda_{1ik} = 1/3$, $i = 1, 2, 3$ and $k = 1, 2$.

Panel a



Panel b



Given the world trade network in

Figure 6, trade liberalization reverses the asymmetric effects that arise in autarky due to the star topology. So that regions that were originally peripheral (r_{21} and r_{31}), before the openness to the new market, show higher real wages that break the symmetric equilibrium for intermediate transport costs; i.e., r_{21} or r_{31} can now agglomerate all the economic activity of sector 1 either individually or jointly. Nevertheless, the range of transport costs for which the symmetric equilibrium is broken in their favor is still narrower than for the domestic central region, even in a context of full trade liberalization. The results for region r_{11} experience a small change with full opening, as the curve is shifted slightly to the right, which means that this region will begin to agglomerate, and therefore to break the homogenous equilibrium, for higher transport costs. This shows that for this network, although trade liberalization favors the border regions, the internal uneven topology still weighs considerably. Nevertheless, these results are against those in

Figure 3 [Panel a] (triangle topology), with bordering regions presenting higher real wages in relative terms with the full opening process, than the “new” inner region, and for all levels of transport costs. Note that the only difference with the previous topology is the absence of the link between r_{21} or r_{31}, whose existence would reinforce the locational advantage of the bordering regions by easing trade between them instead of having to use r_{11} as corridor, since it is still the minimum distance between the two: $r_{(21,31)} = 2$, *via* r_{11}. If such link existed by way of transport infrastructure policy, the results in this section would be equivalent to those presented before.

The stability of the agglomeration (core-periphery) equilibrium: Star and triangle topologies

Figure 8 [Panel b] presents the sustain points. Thus, as in
Figure 3 [Panel b], this Figure shows the difference in real wages between an empty region j, in terms of sector 1 workers, and a region that agglomerates all workers, i: $\omega_{j1} - \omega_{i1}$, for each value of transport cost between 1 and 2. Thus, the core-periphery equilibrium is stable if the wage difference is negative; i.e., the curve is below zero, meaning that the region that holds all sector 1 economic activity also exhibits the higher real wages. Even for the case of autarky, since we analyze a heterogenous space (star topology), we study separately the stability of the core-periphery that results when it is the central region (r_{11}) or a peripheral region (r_{21} or r_{31}), the one constituting the core; i.e., starts agglomerating. Results show that, in an autarkic context, peripheral regions *never* agglomerate regardless the transport cost level (i.e., for $\lambda_{1i1} = 1$, $i = 2, 3$, the curves are always above zero). At the other extreme, $\lambda_{111} = 1$, with the most central region agglomerating the entire labor force of sector 1 for a wider range of intermediate transport costs; the range being much larger than for the case of a region in a closed economy with a triangle topology.

With full trade liberalization, the results indicate that the initial central region in an autarkic economy still enjoys a privileged position compared to the other regions of the country, even if for a shorter range of transport costs for which agglomeration in this region is stable. A significant change compared to autarkic situation appears in the results under the range of the lower transport costs, as the inner region (r_{11}) starts agglomerating at higher transport costs after full openness. In this range of lower transport costs, the regions closely located to the foreign market are the ones that begin to agglomerate before. In short, trade liberalization allows agglomeration in border regions, mainly for relatively lower transport costs, but when transport costs are relatively high, the central region of the domestic network is the one maintaining its hegemony.

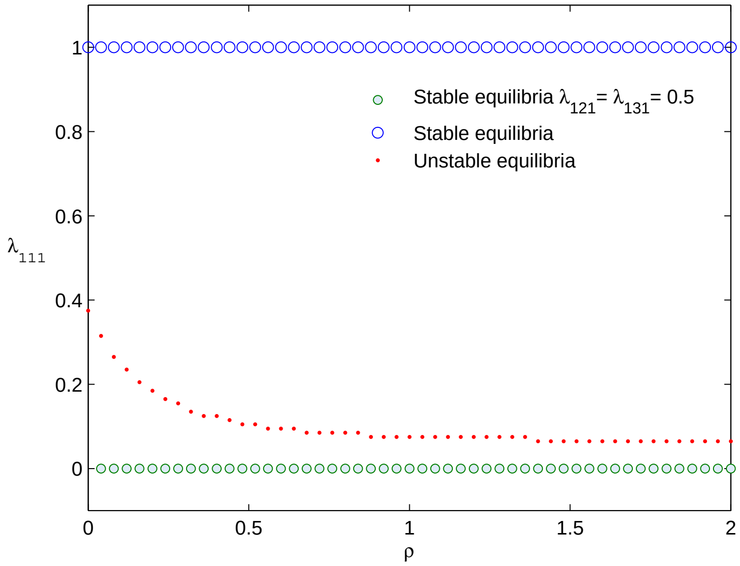
In the homogenous space, trade liberalization gave a clear advantage to the border regions. With the introduction of a heterogenous domestic topology, where the network favors the furthest region to the foreign market as a result of its centrality, the centripetal forces gain relevance without a clear result at first sight; i.e., regarding accessibility the domestic network favors the central region, while liberalization favors the border regions. In terms of transport costs ranges for which agglomeration is feasible, results show that the inner topology prevails, especially for relatively high transport costs, and not for relatively low transport costs. Even in a context of full opening: $\rho = 0$, where other regions from foreign countries are involved, the importance of the relatively high transportation costs, which intensify the cost of trade between the regions, make the domestic network to prevail favoring the central region r_{11}, over the positive effect of openness in favor of the best internationally located regions, r_{21} or r_{31}.

Trade openness and instantaneous equilibria

In Figure 9, we summarize the results for different degrees of trade openness in the form of alternative values of the non transport frictions —ad valorem tariffs ρ. Compared to Figure 4, the results show that in this case, and given transportation costs $t_1 = 1.4$ and $t_2 = 1.275$, the core-periphery structure $\lambda_{111} = 1$ or

$\lambda_{1i1} = 1/2, \ \ i = 2, 3,$ is a stable equilibrium for any degree of trade openness, regardless of whether the region that agglomerates is a bordering region or the most inner region. When the economy is an autarky; i.e., ρ tends to infinity, we find the same unstable equilibria than in the single country scenario, where the inner location holds a 10% on the industry activity in sector 1 and the remaining 80% is perfectly distributed among the border regions.

Figure 9 Bifurcation in region 1 of country 1 respect to the degree of openness of the economy, $t_1 = 1.4$ and $t_2 = 1.275$. Star and triangle topologies, respectively, where $\lambda_{1i2} = 1/3, \ \ i = 1, 2, 3$.



However, when a process of opening starts (ρ tends to zero), only those combinations in which the farthest region to the external market (r_{11}) progressively increases its population are equilibria; otherwise a process of relocation will begin toward the other regions. Therefore we note then that the increase in the share of population in region 1 allows offsetting the locational disadvantages emerging from the new network, through the model's centripetal forces. It is remarkable that, in comparison with the homogenous topology (Figure 4), the levels of population for the short run unstable equilibria is much lower, being under 1/3 of the population, which represents pseudo flat-earth situations.

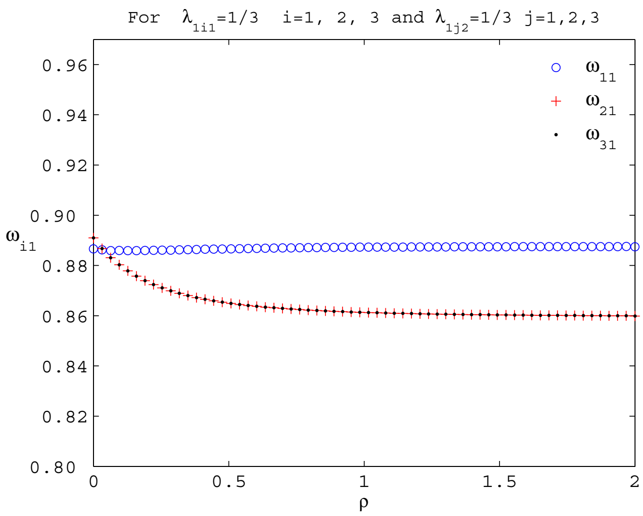
Finally, the set of graphs in Figure 10 records the real wages in each region for the conventionally analyzed distributions: symmetric dispersion of the mobile industry [Panel a], the agglomeration of this sector in the inner region 1 [Panel b], and its concentration in one of the border regions [Panel c]. As in

Figure 5, real wages are observed for each value of tariffs ρ comprised between 0 and 2, but here the country of interest is characterized by the star topology. Panel [a] depicts the scenario where the mobile activity is evenly distributed across the three regions ($\lambda_{1i1} = 1/3, \ \ i = 1, 2, 3$). Note that given the model parameters, when the tariff is $\rho = 2$ the results correspond to the situation in autarky where the star topology entails that real wages in the inner region r_{11} are much higher than in the peripheries r_{21} and r_{31}. The trade liberalization hardly brings a change in the evolution of these series. It is only when tariffs go below 0.5 when we find a process of convergence among the real wages. This convergence basically comes from the increase of real wages in the border regions. However, only when ρ is practically 0 (as in a single market area such as EU or NAFTA) wages in peripheral regions exceed those in the central region, and they would start agglomerating.

[Panel b] shows the case where sector 1 is concentrated in the central region of the country of interest. Under this scenario the differences of the real wages between the inner region r_{11} and the peripheries r_{21} and r_{31} are more intense than in the previous case with the homogenous distribution. In fact the real wages in the center region are always higher than wages in the border regions, and no opening process can reverse that initial situation. It is for very low values of ρ when we observe a smooth reduction in the real wages of region 1 and a slight increase of them in the border regions. In short, the impact of the home network effect, which favors region 1, dominates over the effect of trade liberalization, which favors frontier regions.

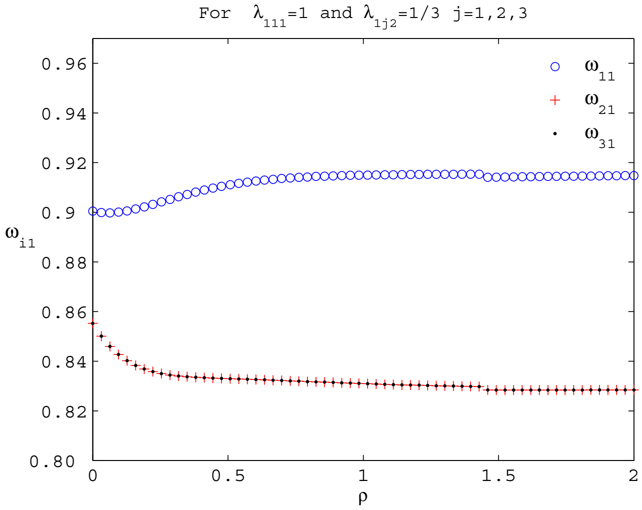
Finally, [Panel c] reflects the scenario where one of the border regions, r_{21}, agglomerates the activity of sector 1 symmetrically ($\lambda_{111} = 0, \lambda_{1i1} = 0.5, \ \ i = 2, 3$). This graph shows the most striking results observed so far. In general we can see, leaving aside for a moment the ranking of the regions, that real wages in the border regions are higher when the economic activity of sector 1 is agglomerated in a border location than when it is located in the domestic hub, r_{11}, which hardly suffers a change in its real wage levels in both scenarios. The next aspect that must be highlighted, starting from the autarchy scenario: $\rho = 2$, is that the border region that accumulates said activity does not hold the highest real wages of the sector. Instead, the agglomerating region has the lowest real wages, followed by the domestic hub region, and being the further border region the one that collects the most attractive real wages. One of the main factors that is driving this result is the large share of income spent on sector 2 varieties, ($1-\mu = 0.6$)[13], whose prices have a negative impact on the real wages of this region.

Figure 10 Real wage in each domestic region for different degrees of openness ($\rho \in [0,2]$), $t_1 = 1.4$ and $t_2 = 1.275$. Star and triangle topologies, respectively.

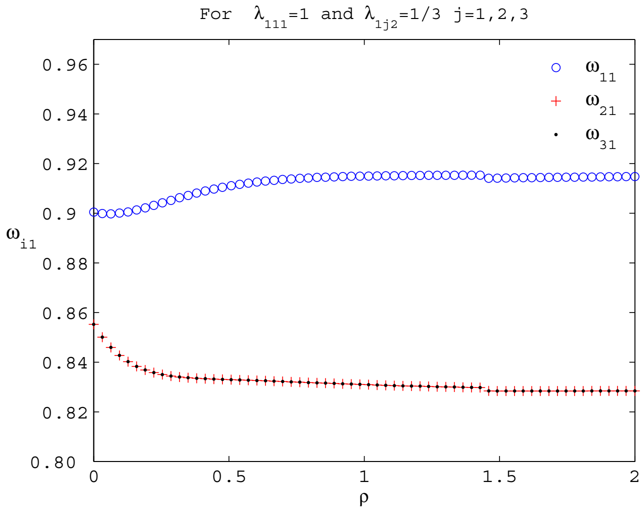


[Panel a]

[13] We observe that the results are sensible to the value of income spent in each sector. For an even 50% share, it is the agglomerating region, regardless its location in the domestic network, the one with the highest real wages. However, when the share of income spent in sector 2 is larger than 50%, we observe an inverse result. Therefore, the results are specific depending on the spending structure in each economy.



[Panel b]



[Panel c]

More specifically, the mechanism observed behind these results is as follows: i) workers employed in sector 1 of the agglomerating region have the lowest nominal wage as they are in large labor supply; ii) by contrast, being one-to-one with the firms in the same region, which work under increasing return, allows them to buy this sector's varieties at low prices; iii) resulting as a net result in the highest real wages in sector 1. However, the existence of another sector 2 that also produces differentiated goods, but whose immobile industry is evenly distributed across regions ($\lambda_{2j1} = 1/3$) and also incurs in transport costs, implies higher prices for the most crowed and now remote locations. The result is that our agglomerating region 2, which has the largest population but does not have a privileged position in the domestic network, ends paying the highest prices for sector's 2 varieties, followed by its core neighbor region 1, which ends up driving the wages of sector's 1 workers down—i.e., counterbalancing the previous positive effect of sector 1's low prices on real wages. Only the emergence of new neighbors from other countries through openness, drawing a more symmetric topology, offsets the disadvantages coming from the agglomeration of sector 1 in one of the periphery regions. With full liberalization, this region ends up having the highest real wages, followed by the other border region[14].

5. Conclusions

We model the effect of trade openness on the location of economic activity of the mobile (manufacturing) industry within a country in a general multi-region multi-country NEG/NTT model, paying special attention to different results depending on its internal topology; i.e., triangle (homogenous space) or star network (heterogenous space), and its connection with that the rest of world economy. To carry out this analysis we adapt and extend the models by Krugman and Livas-Elizondo (1996), Alonso-Villar (1999) and Fujita (1999) and provide a theoretical answer to the questions posed by Brülhart (2011) regarding the effect that trade liberalization has on regional (within-country) spatial inequality, depending on their specific geographical location and transportation networks (i.e., accessibility). Therefore, considering a comprehensive model and alternative network topologies, we can establish how the centrifugal and centripetal forces shape the long-term distribution of the mobile industry.

Based on standard assumptions, we analyze the stability of the symmetric (flat-earth) and the agglomerated (core-periphery) distributions before and after full trade openness. We rely on the systematic study of the break-points and sustain-points and characterize short and long-run equilibria. Other authors (Barbero et al., 2015) studied the effect of the network centrality in a closed

[14] Again, these results are robust to alternative distributions of the economic activity of sector 1 in the second country, one we change the default distribution: $\lambda_{1j2} = 1/3,\ \ j = 1,\ 2,\ 3.$ Despite the alternative distributions agglomerating economic activity either in the farthest region: $\lambda_{112} = 1;$ one of the border regions, $\lambda_{122} = 1$ or $\lambda_{132} = 1;$ or symmetrically in the border regions: $\lambda_{1j2} = 0.5,$ $j = 2,\ 3,$ real wage trends and differences are the same. Results of these simulations are again available upon request.

economy, being their main results that, departing from the flat-earth situation, the higher centrality the less likely is the dispersed outcome (and vice versa).
Here, given the chosen (and opposite) network configurations that we adopt as starting points, we consistently observe that trade opening processes *always* favor border regions, and the dispersed equilibrium becomes more likely in relative terms, regardless the initial inner spatial topology, either neutral (triangle) or in favor of a central region (star). Therefore, we observe that with trade liberalization border regions result favored as a result of their improved accessibility in the world transport and trade networks, which can offset an initial privileged position of inner regions in the domestic economy if they were to agglomerate economic activity in the first place (vice versa, if economic activity were already located in border regions). As a result, and keeping in mind this result, the redistributive effects of trade liberalization will be therefore subject to the topology of the home and international networks as well as to the initial distribution of the industry in the mobile sectors. Many simulations with alternative topologies are feasible, but these results are robust by constituting lower and upper bounds for other topologies.

From our main results we may summarize the distributive effects of trade openness by adopting a narrative that, departing from an autarky scenario where transport costs of the mobile sector bear intermediate values, ends up in a fully integrated "free trade" area:

i) if the departing point is flat-earth, trade liberalization unambiguously results in the breaking up of this structure in favor of agglomeration in border regions, regardless the network topology; particularly the more central are the border regions-as they are in the homogenous space (triangle) with respect to the star considered in this study.

ii) if under autarky the mobile industry is completely located in the central region (which is the most likely long-run outcome under the described heterogenous star topology), and that region situates farther from the foreign market, trade liberalization implies that real wages fall slightly in the central region, triggering the dispersion of economic activity towards border regions for a wider range of transport costs t_1 and trade openness ρ. In a homogenous space topology, trade openness makes the dispersive effect more intense as a result of the lower centrality (in the case of this topology real wage differences are lower than for the heterogenous star network). However, long-run agglomeration in the inner region remains feasible.

iii) if the region that agglomerates the production of the mobile sector is at the border, the effect of trade liberalization depends on the inner topology. In the case of the triangle topology, where the border regions are well connected with each other, trade liberalization does not break this equilibrium, and makes real wages in both border regions higher (a net gain in welfare). In the case of the star topology, trade liberalization compensates the strong disadvantages that the agglomerating region suffers due to its remote location and populated situation.

Consequently, in the case of a star topology, which is what emerges historically in economies with a hub-and-spoke transport network as a result of strong central states as would be the case of France or Spain (in the latter case in the periphery of the European continent), and where inner locations such as Paris or Madrid enjoy better domestic accessibility, trade liberalization along with improved cross-border transport infrastructure results in a weakening of the agglomerating forces in favor of border regions. Therefore, a reduction in spatial inequality is expected as economic activity shifts to border locations, whose connections to foreign markets in the new world trading network are developed; i.e., a dispersed equilibrium or even full agglomeration on the border regions may emerge when trade liberalization is high enough. Otherwise, economic activity remains in the most inner region or, at most, divided between border regions, depending on the degree of openness (for a reasonable range of model parameters, including the size of the immobile sector); i.e, the inner network prevails until non-transport related trade barriers (tariffs) reduce to an almost free trade area. Indeed, as we observe in the autarky scenario, the agglomeration in one extreme (border) location is not a stable equilibrium as a consequence of the high transport costs borne by this region in the consumption of the products from the mobile industry, which increase the price index reducing the real wage in that location (the centrifugal force), more than the increase of nominal wages as a result of its larger income and scale economies (the centripetal forces). However, trade liberalization, when paired up with better connections (e.g., the triangle topology), can relieve the pressure of prices through the reduction of relative transport costs and the increase the nominal wages.

In conclusion, while in autarky the flat-earth equilibrium can emerge within a homogenous space, in a context of trade liberalization, the final long-run equilibrium will depend on the particular topology of the case at hand. More abstractly, if we think about more complex trading networks than those described here, as may be the Spanish case where just some regions are in the border (i.e., the Basque Country and Catalonia) and there is a strong central hub (Madrid), we can expect that trade liberalization will favor the border regions by increasing their accessibility to new markets, but also the consolidation of the hub status of the Madrid region at the expense of farther peripheral regions such as Andalusia, Extremadura, Castile-La Mancha,... situated in the south, which certainly helps to explain their lagging position in terms of manufactured and other tradeable goods production, as their location both in the domestic and international networks worsens with the liberalization process.

These results have important implications in terms of trade and infrastructure policies, which are related in a way that cannot be overlooked as the existing literature suggests. As a country decides to reduce protectionism, local, regional and central administrations should bear in mind the long term effects of trade liberalization on firms' and workers' location decisions. Particularly, the attractiveness of locations with better accessibility in terms of the transportation network. We have shown that trade liberalization may result in larger or smaller spatial inequalities depending on the *initial* (path dependency) locational patterns of the economic activity and the configuration and changes of the domestic and international networks, but the direction of these forces have been clearly identified. Indeed, as the behavior of economic agents can be anticipated, if larger regional inequalities are expected, this undesirable effect could be compensated by appropriate infrastructure investments that may counterbalance the centripetal forces associated to trade openness. Indeed, while geographical features are given by nature, "second nature" transport and non-transport related trade barriers are within the realm of human action that our model seeks to explain, and that policymakers and government officials should incorporate in their decision making processes.

6. References

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