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# Trade Openness, Transport Networks and the Spatial Location of Economic Activity

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**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 New Economic Geography and New Trade Theory (NEG/NTT) literature, we consider a general model with two differentiated sectors in terms of preferences, technologies and transport costs, allowing for any feasible world trade network topology where trade frictions are both transport and non-transport related (tariffs). We study systematically the critical thresholds that characterize the long run equilibria of economic activity. As benchmark simulations we choose two opposed domestic network topologies characterizing a homogenous space and a heterogeneous space with some regions enjoying locational advantages. Our findings show that trade openness changes locational patterns in favor of better located regions with respect to the new world topology, which nevertheless may result in larger or lower spatial equality depending on the initial distribution of the economic activity. These results entail important implications in terms of transport infrastructure (accessibility) and trade (commercial agreements) policies, as both are interrelated when policy makers set regional equality goals.

**Keywords** Trade openness · international trade · economic geography · location of economy activity

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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, the Basque Country and Catalonia in Spain, and more recently the United Kingdom itself within the EU. 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. Indeed, 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 one observes whether there are winners or losers.

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 study the effects of changes in non-transport related costs on the location of firms across countries without considering the spatial configuration of the transportation network. An exception to this are Behrens et al. (2007b), Behrens et al. (2009) and Barbero et al. (2015), who allow for different network topologies of the trading network between countries. On the other hand, to characterize the spatial implications of falling transport costs within countries the literature 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 (2016).

While the NTT and NEG theoretical frameworks share a common framework in terms of preferences, firms' characteristics, and market structure, with equivalent centripetal and centrifugal forces at work, the main difference between models is the assumption about inputs mobility, Particularly, the role it plays 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 clears 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 of the literature dealing with multiple countries and multiple regions models 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) and Behrens et al. (2007a). 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, although 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, at the same time, in a context of imperfect competition and scale economies, trade openness yields global gains from international trade specialization, giving firms the opportunity of serving larger markets, which in turn make more profitable the location near the foreign new markets; particularly, if there are competitive advantages in the form of higher productivities and lower costs. Thus, the balance of centripetal and centrifugal forces before the 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 location, supplying the whole domestic market (i.e., the internal/central regions). However, once this economy starts a trade liberalization process and in accordance with the centripetal and centrifugal forcers one can think of two extreme scenarios: Scenario 1, where the locations that agglomerate the economic activity reinforce their privileged position (centripetal forces based on lower prices, home market effects and scale economies are reinforced). An example of this are the counties that formed the manufacturing belt region of U.S., which, after U.S. signed the North American Free Trade Agreement (NAFTA) with Canada and Mexico in 1994, experimented a growth in terms of employment and wage (Logan, 2008); and Scenario 2, where frontier locations start becoming attractive to firms and start to agglomerate (dispersion forces based on relatively lower transport cost for these regions 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 production was initially concentrated and, in this case, the whole reallocation process may result in lower regional inequality. Following the previous example, we also find some empirical evidences for the case of U.S. after the NAFTA, where the agglomeration effect was specially clear in neighboring states to Mexico (Hanson, 1998, 2001). However, it was much more significant this effect on Mexico after the 1985 Mexican Trade Reform and after the NAFTA, when the manufacturing sector left Mexico DF to relocate in U.S. border.

Here we formulate a proposal based on this NEG/NTT structure that allows for the traditional regional agglomeration and dispersion forces and include the effect of international trade, and whose main contributions can be summarized as follows: i) It models a multi-country multi-regional setting that can accommodate any configuration of the internal (regional) and external (world) network topologies. Therefore most models in the literature may be considered as special cases of this generalization; ii) It considers both transport and non-transport (e.g., tariffs) related trade costs 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, which include sector specific elasticities and transports costs—even if symmetry in the parameters will be assumed normally, as we focus on the effect of trade openness.

As a consequence of these generalizations it is virtually impossible to derive closed form solutions and analytical results for our model, but it is more flexible and realistic with respect to spatial topologies and sectoral characteristics, while it can be solved computationally to perform suitable simulations that allow us to address the research hypotheses for the specific parameters and topologies of interest, and test under what condition would trade liberalization increase or reduce within-country spatial inequalities (section 3). The main results suggest that, in general, trade openness tends to favor the new bordering regions, but this effect is not granted as both the world and internal topology of the countries, as well as the initial location of the economic activity, play important roles. Indeed, its is 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 the greatest accessibility–centrality, retains its prominent status as economic core even in a context of full integration.

In sum, we proposed a multi-country and multi-regional model that addresses the issue of evaluating the effects of trade openness in the internal distribution of economic activity across regions within countries. It 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 with centripetal and centrifugal forces, but instead of considering a domestic economy characterized by an internal and external homogeneous topology, and whose regions are equally located respect to each other and respect to the rest of the world. Secondly, taking then as reference Alonso-Villar (1999) we formulate 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 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). In comparison with Alonso-Villar (1999), who consider two economies fully integrated in terms of international trade (i.e., non-transport related costs are zero), our model allows for a progressive evaluation of the trade openness effects at different levels of tariff costs. Thirdly, as in Davis (1998) and Fujita et al. (1999) and we adopt a general model with two sectors differentiated in several ways, from the degree of product substitutability, individual transport costs, and technological characteristics, but under an international context and richer topologies.

The structure of the paper is organized as follows. Section 2 introduces the model assumptions, the general notation for any network topology representing the world and national economies, and the spatial conditions characterizing the so-called instantaneous equilibrium. Section 3 relevant 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 4 concludes.

## 2 Model

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 are of the iceberg form and include both 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 $i$ 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).

### 2.1 Preferences

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

$$U_{jl} = D_{1jl}^{\mu_1} D_{2jl}^{\mu_2}, \tag{1}$$

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) subutility function

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

where $d_{s(ik,jl)}(\phi)$ is the individual consumption in region $j$ of country $l$ of sector-$s$ variety $\phi$ produced in region $i$ situated in country $k$ including that to which $i$ belongs; and $\Omega_{si}$ 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 $\phi$ 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:

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

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

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

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

## 2.2 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 $\phi$ 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 $l_{1ik} = F + cx_{1ik}$.[1] 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. Davis (1998) proved that the home market effect depends on the relative size of transport costs in the differentiated and homogeneous 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. 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 transport costs, shipping goods between regions of different countries is normally subject to *non-transport frictions*. These 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 $\delta_{s(ik,ik)} = 1$.[2]

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

[1] 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.

[2] Therefore, our transport cost metric $\delta$ corresponds to an exponential network metric as in Behrens (2005), Behrens et al. (2007b) or Barbero and Zofio (2016).

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 of 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 is defined by the following symmetric matrix $T_s$ where each element represents trade frictions between a specific pair of regions.

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

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 $\delta_{sij}$ of the trade frictions matrix $T_s$, while the non-transport related costs have no relationship whatsoever with the topology.

## 2.3 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 $l$.

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

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

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

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 following constant-markup pricing rule:

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

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:

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

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

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 $p_{2(ik,jl)} = w_{2ik}\tau_{2(ik,jl)}$.

### 2.3.1 *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 $\lambda_{1ik}$ 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 system of equations including the income, $y_i$, price equations, $g_{si}$, and nominal wage, $w_{si}$, which are complemented with the real wage equations, $\omega_{si}$. 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 $\lambda_{1ik}$ 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 $\rho_{sij}$ 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.

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

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

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

$$g_{2ik} = \left( \lambda_{2ik}\, w_{2ik}{}^{1-\sigma_2} + \sum_{j \neq i}^{n-1} \lambda_{2jk} \Big( w_{2jk}\, \delta_{2(jk,ik)} \Big)^{1-\sigma_2} + \right. \tag{13}$$

$$\left. + \sum_{j=1}^{n} \sum_{l \neq k}^{m} \lambda_{2jl} \Big( w_{2jl}\, \tau_{2(jl,ik)} \Big)^{1-\sigma_2} \right)^{1/(1-\sigma_2)}, \quad i = 1, ..., n, \quad k = 1, ..., m$$

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

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

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

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

Finally, from the price and wage equations one obtains real salaries as the cornerstone of the model driving the migration of the workers of the first sector across regions in a country:

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

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 borders.

As argued before, no general results for the multi-region multi-country setting can be obtained, 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 particulary 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..

## 2.4 From autarky to trade openness: short-run and long-run equilibria

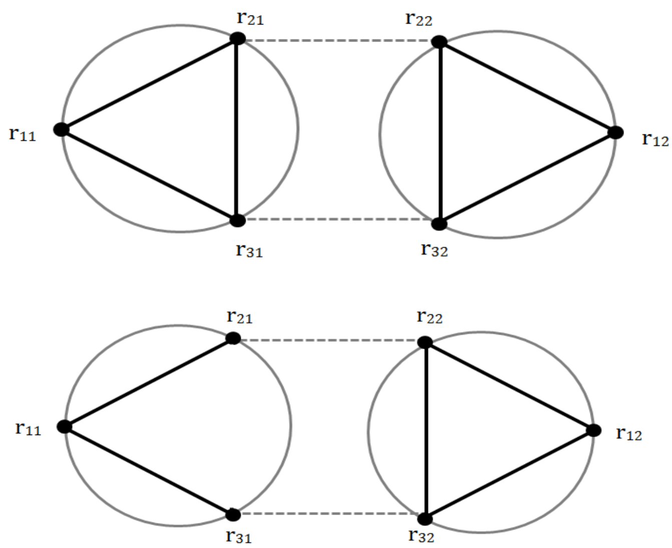
The research strategy is as follows. First, we study the standard NEG results within single country, and determine the long run-equilibria of economic activity in its regions by way of the bifurcation diagram (tomahawk) summarizing the locational patterns of economic activity. This is equivalent to study 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 benchmark country two different topologies that are completely opposed; namely a homogenous (ring) 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—network). 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 (2016). The main results refer to the usual critical values 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.

# 3 The effects of trade openness on a closed economy: Homogenous (ring) vs. Heterogenous (star) space

Figure 1 [$a, b$] shows the two alternative topologies for our benchmark (first) country, and their associated distance matrices. The second country presents the same topology in both cases so the source of variation in the equilibria as a result of trade openess can be ascribed to changes in the topology of the first country only. Considering initially the first world network with two symmetric countries—Figure 1 [$a$], a trade opening process reflects a change from two independent homogeneous topologies where no region has accessibility advantages, 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. For the second world topology—Figure 1 [$b$], the initial situation is different as 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 if trade openness takes place.[3] However, in autarky this topology gives a locational advantage to the central region $(r_{11})$. In both world topologies the reference countries are connected through the regions situated at their shared border (at the same distance as that between the regions of each country).[4] To ease comparison of results, we assume initially that the labor force in both

[3] This resembles the situation of Landlocked Developing Countries (LLDCs); i.e., $r_{11}$ could 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/.

[4] 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




[$a$]

$$r_{(ik,jl)} = \left[\begin{array}{ccc|ccc} 0&1&1&3&2&2\\ 1&0&1&2&1&2\\ 1&1&0&2&2&1\\ \hline 3&2&2&0&1&1\\ 2&1&2&1&0&1\\ 2&2&1&1&1&0 \end{array}\right]$$

[$b$]

$$r_{(ik,jl)} = \left[\begin{array}{ccc|ccc} 0&1&1&3&2&2\\ 1&0&2&2&1&2\\ 1&2&0&2&2&1\\ \hline 3&2&2&0&1&1\\ 2&1&2&1&0&1\\ 2&2&1&1&1&0 \end{array}\right]$$

**Fig. 1** [$a$] Graphical representation of two countries characterized by a homogenous topology and the equivalent matrix of distances (within and between countries). [$b$] 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).

sectors is also evenly distributed in the second country: $\lambda_{sj2} = 1/3$, $s = 1, 2$, $j = 1, 2, 3$, and the values of the rest of parameters considered henceforth, unless indicated otherwise, correspond to those normally adopted in the literature–e.g., Fujita et al. (1999): $\mu = 0.4$, $\sigma_1 = 5$, $\sigma_2 = 10$, $t_2 = 1.275$.[5]

Figure 2 [$a, b$] presents the *tomahawk* bifurcation diagrams for the autarkic equilibria for the first region $(r_{11})$ in the reference country according to both world topologies and with respect to the transport costs of sector 1 (mobile sector) comprised between 1 and 2.

The differences between equilibria for the homogenous (ring) and heterogenous (star) topologies are stark. In the former case–Figure 2 [$a$], results show that at relatively low levels, and from relatively high levels of transport costs, the symmetric equilibrium is stable; i.e., each region holds an equal share of manufacturing activity and associated population: $\lambda_{1i1} = 1/3$, $i = 1, 2, 3$. However, for intermediate values of transport costs, agglomeration

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. Similarly in Italy with the Lazio (Rome) and the northern regions.

5 The location of the first sector activity in the second country: $\lambda_{1l2}$, 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: $\lambda_{1i1}$. 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.

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 the 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 break-point values (which breaks up the stable symmetric equilibrium) and sustain-point values (at which the core-periphery equilibrium becomes unstable).

For the latter case corresponding to the star topology–Figure 2 [$b$], the privileged position of the central region secures its core role in the economy, which is always a feasible long-term solution–except for unrealistically low transportation costs. Additionally, the alternative equilibrium corresponding to the symmetric distribution of firms and workers in the two peripheral regions, leaving the central location without manufacturing sector (green hollows), is only feasible for a very narrow range of transport costs. Consequently, the central region ($r_{11}$) 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. We now turn to analyze the effects of trade liberalization, identifying which regions gain/lose from the opening up process.

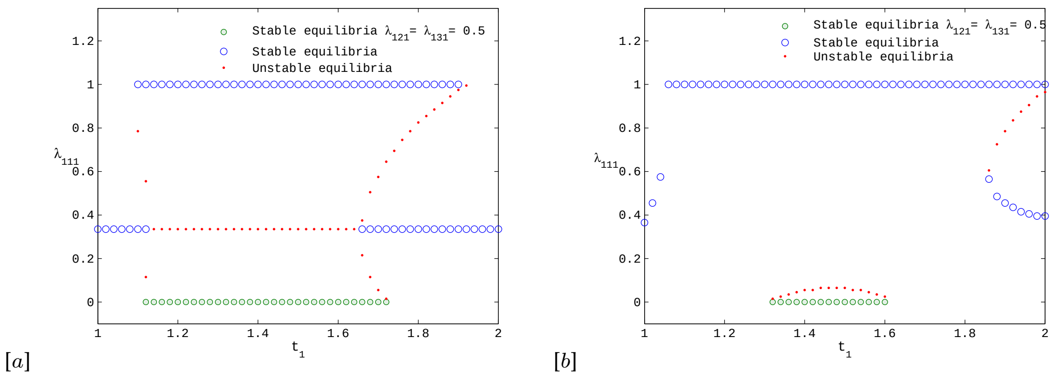



**Fig. 2** Bifurcation with two differentiated sectors, $t_2 = 1.275$. Autarky economy composed of 3 regions, $\rho_{s(ik,jl)} = \infty$. [$a$] Ring or triangle topology and [$b$] star or line topology.

## 3.1 How trade openness favours bordering regions by changing the trade network topology.

To study the break-points in both world topologies: ring and star, Figure 3 [panels $a, b$] plots the variation in the difference in real wages between workers of sector 1 across regions of the same country ($k$ = 1) when a marginal change in population takes place: $\delta\lambda_{1i1} > 0$, both under autarky: $\rho_{s(ik,jl)} = \infty$, and under complete trade openness: $\rho_{s(ik,jl)} = 0$—for comparison purposes, the solid lines recall the break point results of the previous section for the autarkic case (closed economy). 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 $[a, b]$, 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. 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.

Focusing first on the ring topology for the benchmark country, note that since space is homogenous the initial autarchy results be independent of which two regions are chosen for the break-point analysis. 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 $[a]$ 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 homogeneous space is unstable is greater when the incoming or receiving region has a

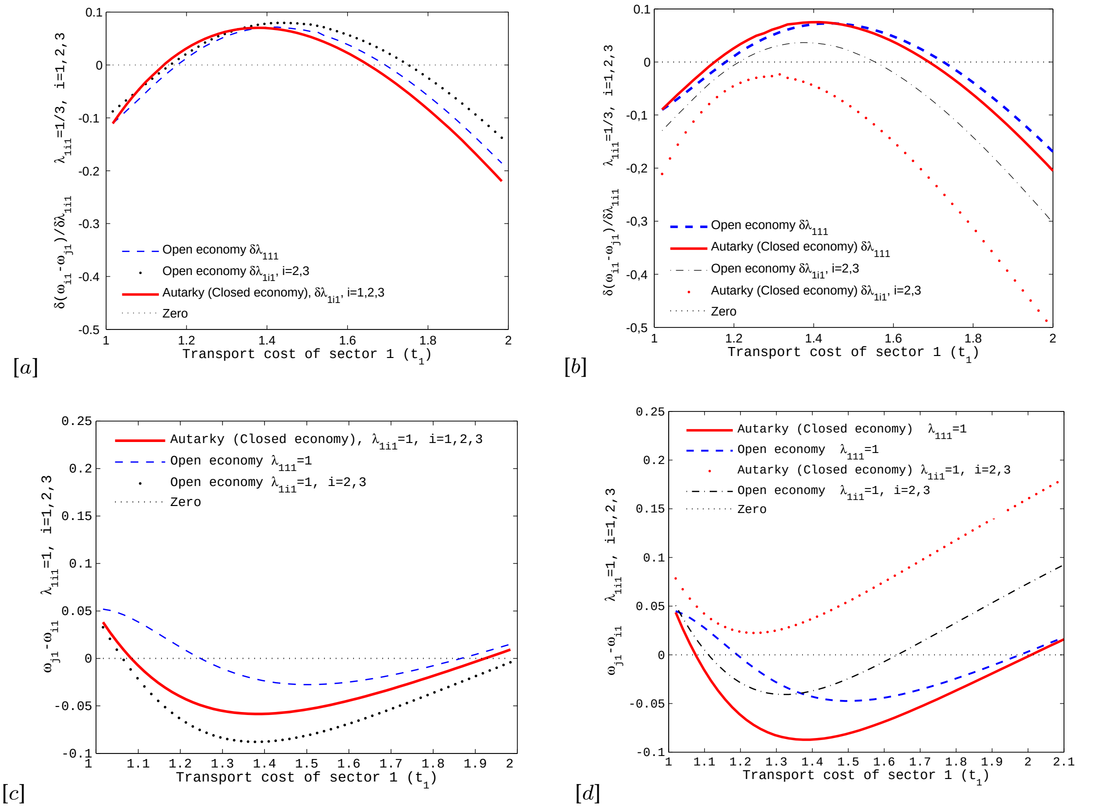



**Fig. 3** Break points [$a$] and [$b$] in region 1 and region 2 (or 3) in country 1 before and after the openness of the economy,where in panel [$a$] both countries have a ring topology and in panel [$b$] the country of interest has the star topology. Sustain Points [$c$] and [$d$] in region 1 and region 2 (or 3) in country 1 before and after the openness of the economy,where in panel [$c$] both countries have a ring topology and in panel [$d$] the country of interest has the star topology. In all cases $t_2 = 1.275$, $\lambda_{1ik} = 1/3$, $i = 1, 2, 3$ and $k = 1,\ 2$.

locational advantage in an open economy, since it is more probable that it generates a self-reinforcing agglomeration effect.

Figure 3 [$b$] shows equivalent analysis of the stability of the symmetric equilibrium in the mobile sector 1, considering the star topology in the benchmark country. With respect to Figure 3 [$a$], the starting autarky scenario shows the privileged locational advantage of the central region ($r_{11}$), as the other regions ($r_{21}$ or $r_{31}$) must ship their products through it. Therefore, space is no longer neutral, and 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. 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. 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 [$a$] (ring 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 which receives 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 homogeneous space, being at intermediate values of transport costs when the symmetric equilibrium ceases to be stable, thereby triggering a process of agglomeration.

Given the world trade network in Figure 1 [$b$], 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 homogeneous equilibrium, for higher transport costs. This suggests that for this network, although trade liberalization favors the border regions, the internal uneven topology weighs considerably. Nevertheless, these results are against those in Figure 3 [$a$], 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* $r_{11}$.

## 3.2 The resilience of agglomerating central regions to trade openness: Ring and star topologies

Figure 3 [$c$] shows the levels of transport cost in sector 1 where one of the regions in the ring topology agglomerates all the economic activity in a stable way, i.e., a sustain-point exercise. As for the break- points in the previous case, we take as reference two extreme scenarios: a closed economy: $\rho_{s(ik,jl)} = \infty$ (solid line), and the 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 [$a$] 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 homogeneous 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 intermediated 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.

We now study the sustain points corresponding to the opposite star topology–Figure 3 [$d$]. As in Figure 3 [$b$] for the heterogenous space, and even in the case of autarky, we need to study separately the stability of the core-periphery results when it is a peripheral region ($r_{21}$ or $r_{31}$) or the central region ($r_{11}$) those agglomerating. Connecting with the results portrayed in Figure 2 [$b$] in autarky, peripheral regions *never* agglomerate regardless the transport cost level (i.e., for $\lambda_{1i1} = 1, \; i = 2, 3$ , the curves are always above zero: $\omega_{j1} - \omega_{i1} > 0, j = 1$). At the other extreme, $\lambda_{111} = 1$, with the most central region agglomerating the entire labor force of sector 1, is stable 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 the ring 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 the autarkic situation appears for lower values of 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 agglomerating earlier.

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 in the domestic network is the one maintaining its hegemony. In the homogeneous space, trade liberalization gave a clear advantage to the border regions. With the introduction of a heterogeneous domestic topology, where the network favors the furthest region to the foreign market, 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 the transport costs range 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 $r_{31}$.

## 3.3 Trade openness and long-run equilibria

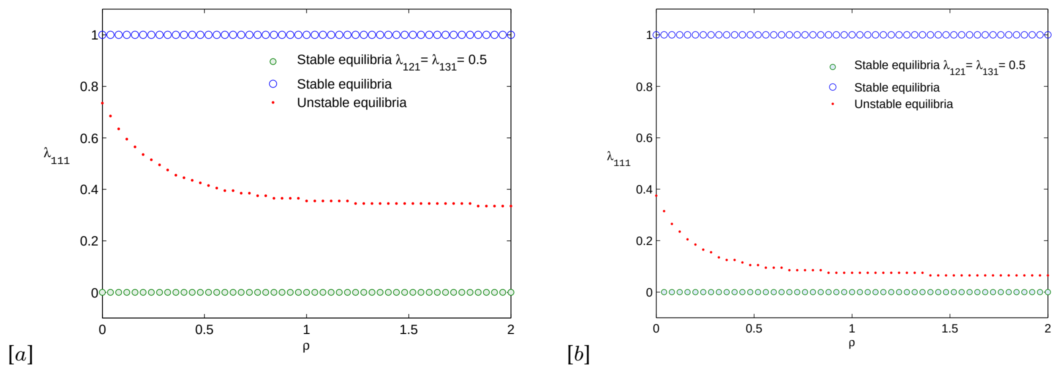



**Fig. 4** Bifurcation for region 1 in country 1 with respect to the degree of openness of the economy, $t_1 = 1.4$ and $t_2 = 1.275$. Where $\lambda_{1i2} = 1/3$, $i = 1,2,3$. [$a$]Triangle topology in both countries and [$b$] star and triangle topologies, respectively.

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 $\rho$. Figure 4 [$a$,$b$] shows the distribution patterns of the mobile sector that represent an equilibrium, for relevant ranges of openness: $\rho = [0,2]$, with $\rho \simeq 2$ being equivalent to a closed economy given our numerical results. As in Figure 2 [$a$,$b$] , 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, and regardless the ring (triangle) and star (line) topologies, 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 confirms the persistence of the agglomerated equilibrium–although shared by the border regions. Indeed, when the economy is an autarky; i.e., $\rho$ tends to infinitum, 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 (2016); i.e. graphically the red dots). However, when an opening process starts ($\rho$ 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, narrowing the range of values for which full agglomeration in the new periphery 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 in the unlikely event that 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, through the model's centripetal forces.

One can corroborate how agglomerating forces are at work in favor of the farthest region $r_{11}$ in the star topology by looking at the short-run equilibrium shares of economic activity for all levels of trade openness–red dots, which are lower than those corresponding to the neutral ring topology. Indeed, for relatively large values of trade barriers $\rho > 0.5$, a share of about 10% of the industrial activity in sector 1 is enough to reach real wages at the same level that in the bordering regions, holding the remaining 90% between the two–Figure 4 [$b$]. While this share between 30% and 40% for the triangle topology–Figure 4 [$a$]. However, when a relevant level of trade opening is reached: $\rho < 0.5$, only those combinations in which the farthest region to the external market $r_{11}$ progressively increases its population, are equilibria, being always the required share of industrial activity in setor 1 lower than 40% for the star topology; otherwise a process of relocation will begin toward the other regions. In any event, it is remarkable how low are the levels of economic activity necessary for the short run unstable equilibria to hold in comparison with the triangle configuration; i.e., the level for which the centripetal forces are able to counterbalance the centripetal forces associated to the new network topology.

### 3.4 Trade openness and welfare

Finally, the set of graphics in Figure 5 illustrate a detailed analysis of the indirect utility of individuals (hereafter real wages) in each region under both world topologies and the two traditional spatial distributions studied for the mobile sector: core-periphery and full dispersion configurations.[6] Therefore, real wages can then be considered as measures of welfare, and how they vary in absolute and relative values with trade openness, give insights on whether it is welfare increasing or detrimental and its effects on regional equality.

This analysis complements those that took place when searching for the break points Figure 3 [$a, b$], and sustain points Figure 3 [$c, d$]. In those Figures the comparative statics analyses between 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 $\rho \simeq 2$, which leads to the autarky scenario). Here we analyze simultaneously the salaries for the three regions and we do it for all values of $\rho$ comprised in the selected range. Given the selected bounds of transport costs for sector 1, a rich range of equilibria emerges. Moreover, as the range of real wages in the $y$-axis is the similar, we can compare the three cases analyzed both by world topologies and distribution of economic activity. Figure 5 [panels $a, c, e$] corresponds to the ring topology under full dispersion, agglomeration in region 1, and agglomeration in one of the regions closely located to the other country, while Figure 5 [panels $b, d, f$] correspond to its star counterpart under the same distributional patterns.

Starting clockwise from Figure 5 [$a, b$], it depicts the case in which economic activity is equally distributed across the three domestic regions ($\lambda_{1i1} = 1/3$, $i = 1, 2, 3$). For high values of $\rho \simeq 2$ we get the same results to those obtained under the symmetric network economy in autarky–Figure 2 [$a$]. With the opening up process; i.e., the smaller is the level of tariffs $\rho$, a significant increase in real wages in the bordering regions $r_{21}$ and $r_{31}$ is observed. However,

[6] 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).

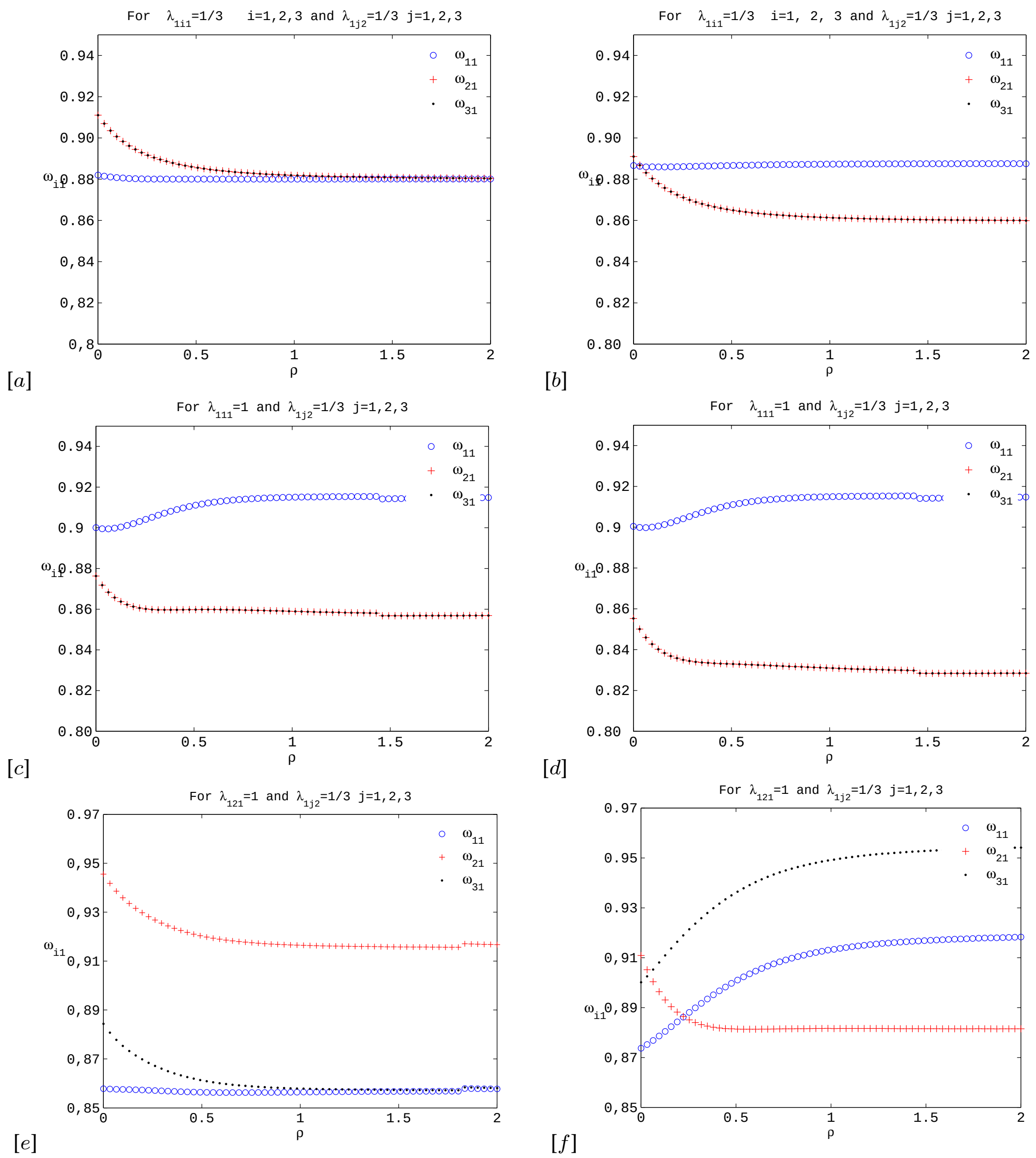



**Fig. 5** Real wage in each domestic region for different degrees of openness $\rho \in [0, 2]$, $t_1 = 1.4$ and $t_2 = 1.275$. $[a, c, e]$Triangle topology in both countries and $[b, d, f]$ star and triangle topologies, respectively.

while for the ring topology real wages in the border regions are *always* above that of the inner region $r_{11}$, so trade liberalization is welfare enhancing in the bordering regions, driving firms and workers in the long run, for the star topology wages at the border *never* surpass those of the inner region except for the case of zero tariffs. Indeed, 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 brought about by increases in real wages in the border regions. However, only when $\rho$ 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.

Therefore, the model suggests that when space is highly heterogenous, with the centrality of the network favoring central regions, only full openness through free-trade agreements can bring real changes to the regional distribution of economic activity. Also, according to the results of the bifurcation diagram–Figure 4 $[a, b]$, we know that both outcomes, the full agglomeration in the central region ($\lambda_{111} = 1$) or in the border regions ($\lambda_{1i1} = 1/2, i = 2, 3$), are a stable equilibrium distribution.

The subsequent panels of Figure 5 $[c, d]$ show the scenario in which the entire population working in the mobile sector is concentrated in the furthest region to the foreign country ($\lambda_{111} = 1, \lambda_{1i1} = 0, i = 2, 3$). In the case of autarky ($\rho \simeq 2$), as expected, results in both graphs are equivalent regardless the country topology, either ring or star, with region $r_{11}$ presenting the highest wage. As trade liberalization (reduction of $\rho$) takes place, the inner region preponderance remains undisputed, even if progressively higher trade openness entails a monotonic increase in wages in the other border regions (with increased accessibility), while the new periphery ($r_{11}$, after the openness) hardly experiences any changes. In short, the impact of the home network effect, which favors region 1, dominates over the effect of trade liberalization, which favors frontier regions.[7]

The real differences between the ring and star topologies emerge when comparing panels $[e, f]$ in Figure 5, 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 this case $r_{21}$. Here, the dependency of the equilibria on the initial topology can be clearly observed. In the ring topology–Figure 5 $[e]$, this agglomerating border region sees its initial position reinforced with trade openness, with increasing real wages that are mirrored by the other frontier region $r_{31}$, while the inner region is left behind definitively, resulting in greater welfare inequalities; i.e., the gap between real wages increases significantly, and it is the largest in all studied configurations. In general, under a homogenous (ring) 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 wages, as all regions face similar price indices, its value is larger the higher is the income of the closest neighbors (lower transport costs). In the case of price indices, both for the sector 1 and 2, as nominal wages are similar across the different locations, these indices are lower the higher is the share of these sectors located 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.

On the contrary, for the star topology where the border region cannot sustain the initial agglomeration as presented in Figure 3 $[d]$, the forces associated to trade openness materialize in a reversal of real wage levels for rather low values of $\rho \simeq 0.25$–Figure 5 $[f]$; and even in this case the remaining border region $r_{31}$ exhibits higher levels. This unexpected outcome requires further elaboration by examining both nominal wages and price indices conforming the real wages in both production sectors. Indeed, for high tariff barriers the agglomerating region presents the lowest real wages, followed by the domestic hub region $r_{11}$, and being the further border region the one that collects the most attractive real wages. One of the main factors

[7] 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: $\lambda_{1j2} = 0.5, j = 2, 3$. Real wage patterns and the sign of the differences between regions are unaffected by these changes.

driving this result is the large share of income spent on sector 2 varieties, $(1 - \mu = 0.6)$[8], whose prices have a negative impact on the real wages of the benchmark region $r_{21}$ . More specifically, the mechanism at work behind 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 industry is evenly distributed across regions (1/3), immobile, and also incurring 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 and 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 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. Only with full liberalization through a free-trade area this region ends up having the highest real wages, followed by the other border region.[9].

Finally, with the case specific qualifications above, we can conclude from comparing the levels and gaps between real wages in the paired panels for both topologies, that the ring economy results in higher welfare levels and lower inequality across regions, as real wages are consistently higher than in the case of the star economy, and their difference is systematically lower. This is quite relevant from the perspective of transportation and trade policies, as reducing the centrality of the networks generally increases welfare levels, but removing trade impediments may result in opposite outcomes; i.e., larger or smaller regional inequalities as in Figure 5 $[e, f]$, corresponding to a situation where one border region agglomerates and trade openness takes place.

## 4 Conclusions

We model the effect of trade openness on the location of economic activity of the mobile (manufacturing) industry within a country in a multi-region multi-country NEG/NTT model, paying special attention to different results depending on its internal topology; i.e., ring (homogenous space) or star (heterogeneous space) networks, and its connection with 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 et al. (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

[8] 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 that 50%, we observe an inverse result. Therefore, the results are specific depending on the spending structure in each economy.

[9] 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.

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 to characterize short and long-run equilibria. Other authors (Barbero et al., 2015) study the effect of the network centrality in a world trade network, 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 favour of a central region (star). Therefore, we observe that with trade liberalization border regions profit from 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.

Although no single narrative can do justice to the many simulations that can be performed with our model, which generalizes many of the existing proposals, by changing the different model parameters and network topologies, here we focus on the distributive effects of trade openness; i.e., the regional reallocation of economic activity when transitioning from an autarkic situation to one characterized by fulling integration in a "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 homogeneous space (triangle) with respect to the star considered in this study.

ii) if the mobile industry is completely located in autarky 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 its border counterparts for a wider range of transport costs $t_1$ and trade openness $\rho$. Under a homogenous space topology, trade openness makes the dispersive effect more intense as a result of the lower centrality (in this case 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 processes are 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.

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* locational patterns of the economic activity and the configuration of the domestic and international networks, but the direction of these forces have been clearly identified. As the behaviour of economic agents can be anticipated, if larger regional inequalities are expected as a result of trade openness, this undesirable effect could be compensated by appropriate infrastructure investments that will counterbalance centripetal forces. Moreover, by reducing the centrality of the the transportation networks by leveling the reginal playing field, higher welfare levels are observed across the whole economy. 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 can incorporate in their decision making processes.

## References


1. Ago, T., Isono, I., Tabuchi, T. (2006). Locational disadvantage of the hub. *Annals of Regional Science*, 40, 819-848.
2. Akamatsu, T., Yuki T., Kiyohiro I. (2012). Spatial discounting, Fourier, and racetrack economy: A recipe for the analysis of spatial agglomeration models. *Journal of Economic Dynamics and Control*, 36, 1729-1775.
3. Alonso-Villar, O. (1999). Spatial distribution of production and international trade: A note. *Regional Science and Urban Economics*, 29**(3)**, 371-380.
4. Barbero, J., Behrens, K. and Zofío, J.L. (2015). Industry location and wages: The role of market size and accessibility in trading networks. CEPR discussion paper No. 10411, Centre for Economic Policy Research, London.
5. Barbero, J., and Zofío, J.L. (2016). The multiregional core-periphery model: The role of the spatial topology. *Networks and Spatial Economics*, 16(2), 469-496.
6. Behrens, K. (2005). Market size and industry location: traded vs non-traded goods. *Journal of Urban Economics* 58, 24-44.
7. Behrens, K., Gaigné, C., Ottaviano, G. I. P., Thisse, J. F. (2007a). Countries, regions and trade: On the welfare impacts of economic integration. *European Economic Review*, 51(5), 1277-1301.
8. Behrens, K., Lamorgese, A.R., Ottaviano, G.I.P. and Tabuchi, T. (2007b). Changes in transport and non-transport costs: Local vs global impacts in a spatial network. *Regional Science and Urban Economics* 37**(6)**, 625–648.
9. Behrens, K., Lamorgese, A.R., Ottaviano, G.I.P., and Tabuchi, T. (2009). Beyond the Home Market Effect: Market size and specialization in a multi-country world. *Journal of International Economics* 79**(2)**, 259–265.
10. Brülhart, M., Crozet, M., and Koenig, P. (2004). Enlargement and the EU periphery: The impact of changing market potential. *World Economy*, 27**(6)**, 853-874.
11. Castro, S.B., da Silva, J.C., and Mossay, P. (2012). The core-periphery model with three-regions and more. *Papers in Regional Science*, 91: 401-418.
12. Charlot, S., Gaigné, C. and Nicoud, F.R.(2006). Agglomeration and welfare: The core-periphery model in the light of Bentham, Kaldor, and Rawls. *Journal of Public Economics* 90, 325–347.
13. Davis D.R. (1998). The home market, trade, and industrial structure. *American Economic Review* 88**(5)**, 1264–1276.
14. Dixit, A., and Stiglitz, J.(1977). Monopolistic competition and optimum product diversity. *American Economic Review*, 67, 297–308.
15. Fujita, M., Krugman, P. and Venables, A. (1999). *The Spatial Economy: Cities, Regions, and International Trade*. MIT Press.
16. Hanson, G. H. (2001). US-Mexico integration and regional economies: evidence from border-city pairs. *Journal of Urban Economics*, 50**(2)**, 259–287.
17. Hanson, G. H. (1998). Regional adjustment to trade liberalization. *Regional Science and Urban Economics*, 28**(4)**, 419–444.
18. Helpman, E., and Krugman, P.R. (1987). *Market Structure and Foreign Trade*. Cambridge, MA: MIT Press.
19. Krugman, P.R. (1980). Scale economies, product differentiation and the pattern of trade. *American Economic Review* 70**(5)**, 950–959.
20. Krugman, P.R. (1991). Increasing returns and economic geography. *Journal of Political Economy* 99**(3)**, 483–499.
21. Krugman, P.R. (1993a). First nature, second nature, and metropolitan location. *Journal of Regional Science*. 33 **(2)**, 129–144.
22. Krugman, P.R. and Livas-Elizondo, R. (1996). Trade policy and the third world metropolis. *Journal of Development Economics*. 49**(1)**, 137-150.
23. Logan, J. (2008). Belted by NAFTA? A look at Trade's Effect on the US Manufacturing Belt. *Regional Studies*. 42**(5)**, 675–687.
24. Picard, P.M. Zeng, D-Z. (2005), Agricultural sector and industrial agglomeration. *Journal of Development Economics*, 77 **(1)**, 75–106.
25. Zofío, J.L., Condeço-Melhorado, A.M., Maroto-Sánchez, A. and Gutiérrez, J. (2014). Generalized transport costs and index numbers: A geographical analysis of economic and infrastructure fundamentals, Transportation research. Part A, Policy and practice 67, 141–157.