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Home market effects with endogenous costs of production

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ABSTRACT

In a standard imperfect competition model, we endogenize the costs of production of firms in the increasing returns sector (IRS) via process R&D. We show that firms in the larger region in terms of demand invest more in R&D (i.e.: they are bigger in size and have lower marginal costs) than firms in the smaller region, since the former exploit larger economies of scale in production to pay for the costs of R&D. As a result, when the return on R&D is high, the larger region does not employ disproportionately more labor nor attracts a disproportionately larger share of firms in the IRS in relation to share of demand it hosts, i.e.: negative home market effects (HMEs) in employment and in the number of firms. When this occurs, only partial agglomeration of the IRS in the larger region is sustainable in equilibrium. Even so, the larger region always runs trade surplus in the IRS, i.e.: HME in trade patterns.

1. Introduction

In 2008, Paul Krugman won the Nobel Memorial Prize in Economics for his contributions to the "new" trade theory and to the "new" economic geography (Krugman, 1980, 1991). Central to both of these theories are the so-called "home market effects" (HMEs). In a two-region economy, the HMEs predict that the larger region in terms of demand, in comparison to the smaller region: (i) attracts a disproportionately higher share of firms in the increasing returns sector (IRS) in relation to the share of demand it hosts (HME in the number of firms); (ii) uses disproportionately more factors of production in the IRS in relation to the share of demand it hosts (HME in employment); and (iii) runs trade surplus in the IRS (HME in trade patterns).

A central assumption in Krugman (1980) is that the costs of production are exogenous.[1] We check the robustness of Krugman (1980) HMEs when the costs of production are endogenous. Costs of production are endogenized via process R&D investment that reduces marginal costs but increases fixed costs. In this set-up, we show that when the return on R&D is high, the larger region, relatively to the smaller region, does not disproportionately employs more labor nor attracts a disproportionately larger share of firms in the IRS in relation to share of demand it hosts (negative HMEs in the number of firms and in employment), but even so it always runs a trade surplus in the IRS (HME in trade patterns). In other words, while we continue to have a HME in trade patterns, we find negative HMEs in the number of firms and in employment, given that an increase in the market size of the larger region triggers a less than proportional increase in the number of local firms and factor employment.

Our paper then contributes to the theoretical and the empirical literature on HMEs. We contribute to the theoretical literature on HMEs, since we check the robustness of one of the assumptions in Krugman (1980): exogenous costs of production. Standard imperfect competition models (Krugman, 1980; Brander, 1981 and Ottaviano et al., 2002) assume exogenous costs of production for analytical convenience. However, as we all know, the empirical evidence demonstrates that the costs of production are endogenous (Gustavsson et al., 1999; Aw et al., 2008; Glaeser et al., 2010). But further than just adding more realism to

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[1] In Krugman (1980) there are two countries (home and foreign), two sectors (increasing returns and constant returns to scale) and one factor of production (labor). The constant returns sector (CRS) produces a homogeneous good under perfect competition. The IRS produces a set of differentiated goods under monopolistic competition. The IRS goods are subject to iceberg trade costs, while the CRS good is freely traded across countries. Preferences are Cobb–Douglas across the two goods. For the IRS goods, preferences are of the CES type and each variety enters symmetrically in the utility function of a representative consumer. Firms in the IRS incur marginal and fixed costs of production, which are constant, exogenous and equal across countries.

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trade-geography models, our results point out that the assumption of exogenous costs of production is not innocuous.

In this way, we follow the theoretical literature on the robustness of HMEs. For instance, Head et al. (2002) show that HMEs are robust to market structure and preferences (see also Feenstra et al., 2001; Helpman, 1990; Yu, 2005).[2] However, HMEs can be canceled if the constant returns good is also subject to trade costs (Davis, 1998; Crozet and Trionfetti, 2008), if there are many regions in the world economy with very similar factor endowments (Behrens et al., 2009), and if the IRS consists of non-traded goods (Behrens, 2005).

We also contribute to the empirical literature on HMEs, since our results provide some guidelines for the empirical tests on HMEs. In fact, the empirical literature on HMEs is inconclusive in what respects the existence of HMEs. For example, while Lundbäck and Torstensson (1998), Davis and Weinstein (1999, 2003), and Brülhart and Trionfetti (2009) find support for HMEs; the contrary occurs in Davis and Weinstein (1996), Feenstra et al. (2001), and Head and Ries (2001).

Our paper sheds light on these conflicting results. To see this, note that the reason why in our set-up HMEs in the number of firms and in employment do not necessarily emerge, while the same is not the case with HME in trade patterns, is that when the costs of production are endogenous, firms become endogenously asymmetric across regions. When firms in one region have lower marginal costs and are bigger in size than firms in the other region, the number of firms and the employment of factors of production in the former are reduced. Though, firms from this region still export more than foreign rivals, due to their higher cost competitiveness, i.e.: in a set-up with endogenous costs of production there is no direct link between the three HMEs.

In standard trade models, on the contrary, there is a direct link between the three HMEs, since firms are symmetric in cost competitiveness and size. In other words, if a region hosts more firms, it also employs more factors of production and runs a trade surplus in the IRSs. Due to this direct link between the three HMEs when the costs of production are exogenous, the empirical literature on HMEs just focus in one type of HME, in particular, in either the number of local firms (Davis and Weinstein, 1996, 1999, 2003) or in the balance of trade in IRSs (Lundbäck and Torstensson, 1998; Feenstra et al., 2001).[3]

Our paper then indicates that to focus in only one HME can be misleading, since the direct link between the three HMEs does not necessarily always arise. When this is the case, the existence of one HME might not translate into the existence of the others. For example, an empirical paper that fails to find HME in the number of firms can end up dismissing HMEs in general, when in fact the HME in trade patterns are present. In this sense, our results point out that the empirical literature on HMEs needs to develop tests that simultaneously check for the three HMEs and to take into account cost competitiveness and size asymmetries between firms in different regions.[4]

An interesting aspect of the asymmetries between firms generated in our model endogenously is that they result from a spatial dimension that is absent in standard imperfect competition models. In fact, when the costs of production are endogenous, outputs and prices depend not only on the spatial distribution of firms (as in standard imperfect competition models), but also on the spatial distribution of demand.[5] In particular, firms located in larger markets invest more in R&D and therefore achieve lower marginal costs than firms in smaller markets.

In addition, the relationship between R&D and the number of local firms is non-monotonic: while an increase in the number of firms in a market with a small industry promotes local firms' R&D, the contrary occurs in a market with a large industry. In this way, our paper is in accordance with the empirical work of Aghion et al. (2005, 2009). They show that innovation is shaped by the number of local firms and that the relation is non-linear.

The consequence of the spatial dimension in our model is that the location equilibrium involves stable partial agglomeration equilibriums when the return on R&D is high, even when a region hosts a relatively higher share of the world demand. In standard imperfect competition models when regions differ greatly in market size, partial agglomeration equilibriums are unstable and total agglomeration always emerges as the only stable equilibrium (see Krugman, 1991). This is an interesting result, given that, as argued by Baldwin et al. (2003), partial agglomeration configurations are more realistic than total agglomeration ones. In this sense, we also introduce a new motive for partial agglomeration: endogenous costs of production.[6]

The remainder of the paper is organized as follows: In Section 2, we present an imperfect competition trade model that encompasses both the exogenous and the endogenous costs of production cases. In Section 3 and 4, we analyze the exogenous and the endogenous costs of production cases in terms of HMEs and spatial equilibrium. In Section 5, we conclude.

2. The model

We adopt the framework in Krugman (1980), which is the standard set-up for deriving HMEs. The objective is to make our model as similar as possible to those in the literature on the HMEs.

2.1. Basic structure

The model considers one factor of production, two regions, and two sectors. The sectors are the constant returns sector (*CRS*) and the increasing returns sector (*IRS*). The two regions are home (H) and foreign (F). Preferences and underlying technologies are the same in both regions. The only factor of production is labor, which is internationally immobile. We denote M as the world endowment of labor and w_H and w_F as the labor wages at H and F, respectively. In turn, r represents the share of the world endowment of M located at home (with $r \in (0,1)$). Therefore, r is the home share of the world expenditure and $rM = m_H$ is the number of consumers at home (and for the foreign country $(1-r)M = m_F$). Since the model is symmetric, in the following, we concentrate our attention in the home region. Equations for foreign apply by symmetry.

The *CRS* produces a homogenous good under perfect competition. The *CRS* -good is freely traded between regions. The *CRS* is kept in the background and its role is to represent the "rest of

[2] In particular, HMEs are also present in oligopolist models, like Brander (1981), or in monopolistic competition models with linear demand, such as Ottaviano et al. (2002). Since Krugman (1980), Brander (1981), and Ottaviano et al. (2002) are then very similar in terms of HMEs, we label them as standard imperfect competition models.

[3] To the best of our knowledge, we are not aware of any paper that tests for HMEs in employment. This is in part due to data limitations and reverse causation issues.

[4] With the exception of Davis and Weinstein (1996, 1999, 2003), the empirical papers develop different measures of HMEs. This makes it difficult to evaluate the different contributions. However if, as we suggest, the empirical literature derives tests that encompass the three HMEs, the comparison between the different contributions becomes more direct.

[5] The empirical literature on agglomeration and efficiency support our results in that they highlight the importance of both the local levels of demand and of competition on firms' productivity. See for instance Mitra (1999), Paul and Siegel (1999), Henderson (2003), Cohen and Paul (2005), and Andersson and Lööf (2011).

[6] Other reasons pointed out for partial agglomeration are: non-traded goods (Helpman, 1998); decreasing returns (Puga, 1999); limited factor mobility (Ludema and Wooton, 1999); and the absence of income effects (Pflüger, 2004).

the economy" and to correct for trade imbalances that can occur in the *IRS*.

Firms in the *IRS* compete in an oligopolistic imperfect competitive setting to produce a homogenous good.[7] Contrary to the *CRS*-good, the *IRS*-good is subject to trade costs (t) when exchanged between regions. Resources of the sending region are used to pay for the trade costs of the *IRS*-good. The number of firms in the world economy is $N = n_H + n_F$. Where $1_H, 2_H, \ldots, n_H$ is the number of firms located at home and $1_F, 2_F, \ldots, n_F$ is the number of firms located at foreign. Then $s \in (0,1)$ is the share of firms at home, i.e.: home hosts $sN = n_H$ firms in the *IRS*, while foreign $(1-s)N = n_F$. There is free entry and exit and in the long run equilibrium the number of firms in each region is determined by the zero profit condition.

Both the *CRS* and the *IRS* use labor as only input. This implies that due to perfect competition in the *CRS* and no trade costs in the *CRS*-good, this good is the *numéraire*. Furthermore, since labor is used in both sectors, then, as long as the *CRS* produces positive output, the economy wide wages are fixed relatively to the price of the *CRS*-good. Thus, nominal wages in both regions and sectors can be normalized to one.[8]

2.2. Preferences

We assume that the preferences of a representative home consumer are quasi-linear in the *CRS*-good and in the *IRS*-good, with a quadratic sub-utility in the latter:

$$\max_{q_{0H}>0, q_{iH}>0} U_H(q_{0H}, q_{iH}) = q_{0H} + a\left(\sum_{i=1_H}^{n_H} q_{iH} + \sum_{j=1_F}^{n_F} q_{jH}\right) - \frac{b}{2}\left(\sum_{i=1_H}^{n_H} q_{iH} + \sum_{j=1_F}^{n_F} q_{jH}\right)^2, \quad (1)$$

where q_{0H} is the quantity of the *CRS*-good consumed at home and $q_{iH}$is the sales of the home firm i to each consumer in the home market (with $i = 1_H, 2_H, \ldots, n_H$) and q_{jH} is the exports of the foreign firm j to each consumer in the home market (with $j = 1_F, 2_F, \ldots, n_F$). Also, $n_H + n_F = N$ (number of firms in the *IRS* in the world economy). We assume that the *CRS*-good is the *numé raire* and therefore its price can be normalized to $P_0 = 1$.

Utility is maximized subject to the budget constraint:

$$\sum_{i=1_H}^{n_H} P_{iH} q_{iH} + \sum_{j=1_F}^{n_F} P_{jH} q_{jH} + q_{0H} \leqslant I, \quad (2)$$

where P_{iH} is the price charged by firm i for the *IRS*-good at home, with $i = 1_H, 2_H, \ldots n_H$ (and a similar interpretation for P_{jH}). In turn, I is the income of a representative consumer. Income equals labor returns that, as we have seen, are $w_H = w_F = 1$.

2.3. Firms and technology

We assume a linear cost function for the *IRS*. In particular, firms incur marginal and fixed costs of production. For the home firm i (with $i = 1_H, 2_H, \ldots n_H$) these are C_i and G_i, respectively. The total costs of producing $q_{iH} + q_{iF}$ units for the home firm i are then:

$$TC_i = G_i + C_i(q_{iH} + q_{iF}). \quad (3)$$

We consider two types of costs of production: exogenous and endogenous. In the endogenous costs of production case, costs of production are endogenized via R&D investment. As in Krugman (1984), firms choose outputs and R&D levels simultaneously. We therefore do not take into account strategic R&D investment (see the appendix for the implications of strategic investment). The objective of this assumption is to demonstrate that our results are not driven by strategic behavior on R&D, but are only due to the endogeneity of the costs of production. We choose a standard functional form for the marginal and the fixed costs of production with R&D. To be more precise, we follow Leahy and Neary (1997) in assuming process R&D investment.[9] Denoting $k_i \geqslant 0$ as R&D by the home firm i, we have:

$$C_i = c - \theta k_i$$
$$G_i = g + \frac{\gamma k_i^2}{2}, \quad (4)$$

where $c > 0$ and $g > 0$ are the marginal and the fixed costs without R&D. In turn, $\theta > 0$ is the cost-reducing effect of R&D and $\gamma > 0$ is the cost of R&D. Note that not only do all firms in a location have the same cost parameters (i.e.: $\theta_i = \theta_H, \gamma_i = \gamma_H$, $g_i = g_H$ and $c_i = c_H$ for $i = 1_H, 2_H, \ldots n_H$), but the same also occurs for firms located in different regions (i.e.: $\theta_H = \theta_F = \theta, \gamma_H = \gamma_F = \gamma, g_H = g_F = g$ and $c_H = c_F = c$). This is assumed in order to make sure that asymmetries between firms only arise endogenously.

The only difference between the endogenous and the exogenous costs of production case is the cost function. In particular, the cost function when the costs of production are exogenous is a special case of Eq. (4) with $k_i = 0$, i.e.: the endogenous costs of production model encompasses the exogenous costs of production model. When $k_i = 0$, costs are exogenous because they cannot be changed by the firm, i.e.: $C_i = c$ and $G_i = g$. Furthermore, the costs of production are the same across regions, i.e.: $C_H = C_F = c$ and $G_H = G_F = g$. In this sense, the exogenous costs of production case is similar to the oligopoly trade model of Brander (1981).[10]

In the endogenous cost of production case, Eq. (4) shows that process R&D reduces marginal costs, but increases fixed costs ($\frac{\partial G_H}{\partial k_i} > 0and\frac{\partial C_H}{\partial k_i} < 0$).[11] Therefore, when firms choose R&D they face a trade-off between lower marginal costs and higher fixed costs (and *vice versa*). In addition, the assumption of quadratic fixed costs of R&D, $\frac{\gamma(k_i)^2}{2}$, implies diminishing returns to scale in R&D.[12] In spite of diminishing returns to scale in R&D, we shall see that firms can still explore economies of scale in production in order to invest more in R&D and to pay for the extra fixed costs.[13] In this way, firms located in larger markets can invest more in R&D, and as a result, achieve lower marginal costs than firms in smaller markets.

Following Brander (1981), firms set outputs taking as given the outputs of the rivals. Furthermore, due to trade costs, markets are segmented. This implies that firms can price discriminate between locations, i.e.: firms choose the quantities to ship to each market independently, and therefore the export price (net of transport

[7] We choose an oligopoly model, since the type of R&D investment considered in this paper is usually employed in this set-up. To justify this choice we use the result in Head et al. (2002) that standard imperfect competition models with exogenous costs of production, oligopoly or monopolistic competition, are equivalent in terms of HMEs.

[8] Combes et al. (2008) provide empirical evidence on the spatial behavior of wages. See also Gerlach et al. (2009), Combes and Duranton (2006) on the role of labor markets on innovation and the location of industry.

[9] The alternative to process R&D is product innovation R&D. For the relation between the two see Callois (2008).

[10] For a more recent exposition of trade models under oligopoly see Neary (2010).

[11] As discussed by Neary (2010), then, k_i does not need to be interpreted only as R&D investment, but can be thought of as any other strategic variable that firms use to affect their costs of production (such as capital stock and quality or distribution channels).

[12] There is no consensus in the empirical literature of whether R&D exhibits constant, increasing or diminishing returns to scale, although there seems to be more support for the diminishing returns hypothesis (see Fung, 2002).

[13] The importance of fixed costs and scale economies for R&D is confirmed by the empirical studies of Gustavsson et al. (1999), Aw et al. (2008). In turn, increasing returns are the hallmark of the "new" trade theory (Krugman, 1980) and the empirical evidence shows its centrality in international trade (see Antweiler and Trefler, 2002).

costs) needs not be equal to the price charged to domestic consumers.[14] We then have that, as in Brander (1981): $q_{iH} = q_{HH}, q_{iF} = q_{HF}, k_i = k_H, C_i = C_H$ and $G_i = G_H$ for $i = 1_H, 2_H, \ldots n_H$, and the same for foreign firms. However, in the endogenous costs of production case, due to trade costs, market size differences, increasing returns and R&D investment is possible to have $k_H \neq k_F$ and as such, differently from standard imperfect competition models with exogenous costs of production, $C_H \neq C_F$ and $G_H \neq G_F$. Below, we prove this endogenous asymmetry property.

2.4. Demand

As shown in Appendix, given that the price conditions for home and foreign products at home are similar, they also face the same price, so $P_{iH} = P_{jH} = P_H$. From the maximization problem in Eq. (1), subject to the restriction in Eq. (2), we can then demonstrate that the demand for the *IRS*-good equals (see Appendix):

$$P_H = a - bQ_H, \tag{5}$$

where $Q_H = \sum_{i=1_H}^{n_H} q_{iH} + \sum_{j=1_F}^{n_F} q_{jH}$. From Eq. (5) we have that the demand for the *IRS*-good is independent of income. In this formulation all income effects are captured by the *numéraire* good. This is so because we use a quasi-linear utility function that abstracts from general equilibrium income effects. In this way, our model is similar to the monopolistic competition models with linear demands of Ottaviano et al. (2002) and Melitz and Ottaviano (2008). However, as we prove in Appendix, results in our model do not depend on the relative size of the manufacturing sector.

2.5. Firms' profits

From the above, we have that the maximization problem for a representative home firm, in both the exogenous and endogenous cost of production case, can then be stated as:

$$\max_{q_{HH} \geqslant 0, q_{HF} \geqslant 0, k_H \geqslant 0} \Pi_H(q_{HH}, q_{HF}) = (P_H - C_H)m_H q_{HH} + (P_F - C_H - t)m_F q_{HF} - G_H, \tag{6}$$

where t represents the trade costs. Following the trade literature, we assume that: firms in different regions incur the same trade costs to export products, i.e.: $t = t^*$; and that the trade costs are not à *priori* prohibitive, i.e.: $0 < t < a - c$. Note, however, that the latter assumption is not sufficient to assure that it is profitable for a firm to export. Below, we derive the conditions for trade to arise in equilibrium for the exogenous and the endogenous costs of production cases.

In the next sections, we analyze the HMEs in the exogenous and endogenous costs of production cases. We start by defining HMEs and then apply this to the exogenous and the endogenous costs of production cases.

3. Home market effects

As mentioned in the introduction, in the context of a standard imperfect competition model with exogenous costs of production, there are three types of HMEs: in the number of firms, in employment and in trade patterns. We start with HME in the number of firms and then turn to the other two.

3.1. HME in the number of firms

The point of departure for the HME in the number of firms is the free entry condition. We assume that firms enter the industry until all profit opportunities are exhausted. The free entry conditions therefore imply that:

$$\Pi_H = \Pi_F = 0 \Rightarrow \Delta\Pi = \Pi_H - \Pi_F = 0, \tag{7}$$

where $\Delta\Pi$ is the profit differential between locating at home or at foreign. Totally differentiating $\Delta\Pi$ with respect to s and r, we obtain:

$$d\Delta\Pi = \frac{\partial\Delta\Pi}{\partial s}ds + \frac{\partial\Delta\Pi}{\partial r}dr. \tag{8}$$

From Eq. (8), we have:

$$\frac{ds}{dr} = \frac{\frac{\partial\Delta\Pi}{\partial r}}{-\frac{\partial\Delta\Pi}{\partial s}}. \tag{9}$$

In the literature on HMEs, $\frac{\partial\Delta\Pi}{\partial r}$ is usually denoted as the "demand effect" and $\frac{\partial\Delta\Pi}{\partial s}$ as the "crowding-out effect". The demand effect measures the change in profits of domestic firms as a result of changes in local market size. The crowding-out effect looks at the change in profits of domestic firms as a consequence of changes in the number of local firms.

When home is the larger region, the HME in the number of firms arise if home hosts a disproportionately larger share of the world's firms than of the world's demand, i.e.: $\frac{ds}{dr} > 1$ (see Head et al., 2002). This is so if:

$$\frac{ds}{dr} > 1 \Rightarrow \frac{\partial\Delta\Pi}{\partial r} + \frac{\partial\Delta\Pi}{\partial s} > 0. \tag{10}$$

The following proposition can then be stated.

Proposition 1. *The HME in the number of firms emerges in the larger region if the sum of the "demand effect" and the "crowding-out effect" is positive.*

3.2. HMEs in employment and trade patterns

The HME in employment is derived from the full employment condition. Note that the full employment condition at home implies that:

$$m_H = n_H(C_H q_H + \Gamma_H) + q_{0H} \Rightarrow \frac{n_H(C_H q_H + \Gamma_H)}{m_H} = 1 - \frac{q_{0H}}{m_H}, \tag{11}$$

where $q_H = q_{HH} + q_{HF}$. If home is the larger region, the HME in employment emerges if, in relation to the share of world demand it hosts, home employs relatively more labor in the *IRS* than does foreign:

$$\frac{n_H(C_H q_H + \Gamma_H)}{m_H} > \frac{n_F(C_F q_F + \Gamma_F)}{m_F} \Rightarrow \frac{s}{r}\frac{(1-r)}{(1-s)} > \frac{C_F q_F + \Gamma_F}{C_H q_H + \Gamma_H}. \tag{12}$$

For the HME in trade patterns, we have to start from the trade balance for the *IRS*, which equals:

$$B_H = m_F n_H q_{HF} P_F - m_H n_F q_{FH} P_H. \tag{13}$$

If home is the larger region, the HME in trade patterns arises if home runs a trade surplus in the *IRS*, i.e.: $B_H > 0$. This occurs when:

$$B_H > 0 \Rightarrow \frac{s}{r}\frac{1-r}{1-s} > \frac{q_{FH}P_H}{q_{HF}P_F}. \tag{14}$$

The expressions for HMEs in employment and in trade patterns are then similar, since the left hand side of Eqs. (12) and (14) is the same. Furthermore, $\frac{s}{r}\frac{(1-r)}{(1-s)}$ is associated with the HME in the number of firms, because it relates the share of firms at home with the share of firms at foreign weighted by the share of demand at foreign to the share of demand at home. In fact, if home is the larger region and hosts a disproportionately larger share of the world's firms than of the world's demand (HME in the number of firms),

[14] As shown by Brander and Krugman (1983) this occurs because Cournot rivalry leads to reciprocal dumping.

$\frac{s}{r}\frac{1-r}{1-s} > 1$. Otherwise, with negative HME in the number of firms, $\frac{s}{r}\frac{1-r}{1-s} < 1$. In this way, it can be notice that HMEs in employment and in trade patterns are present when the same occurs with the HME in the number of firms.

The above results are summarized in the next proposition.

Proposition 2. *The HME in employment arises when the share of firms and demand in the larger region relatively to the smaller region is larger than factor employment for a representative firm in the smaller region relatively to factor employment for a representative firm in the larger region. The HME in trade patterns emerges when the share of firms and demand in the larger region relatively to the smaller region is larger than exports for a representative firm in the smaller region relatively to exports for a representative firm in the larger region.*

In the next two sub-sections, we look at the HMEs through the two cases considered in this paper: exogenous and endogenous costs of production.

4. Exogenous costs of production

In this section, we analyze the exogenous costs of production case, i.e.: with $k_H = k_F = 0$. We start with the production equilibrium, then turn to HMEs in the number of firms, employment and trade patterns and close with the spatial equilibrium.

4.1. Production equilibrium

To find the production equilibrium, we need to derive the first order conditions (FOCs) for outputs per consumer. It can be shown that from the maximization problem in Eq. (6), we obtain:

$$q_{ii} = \frac{(a - c + n_j t)}{b(N+1)}$$
$$q_{ij} = \frac{(a - c - t(n_j + 1))}{b(N+1)}, \text{with } i,j = H,F \quad \text{and} \quad i \neq j. \tag{15}$$

Remember that $n_H = sN$ and $n_F = (1-s)N$. Solving for prices from Eq. (5), we arrive at:

$$P_i = c + \frac{a - c + n_j t}{N+1}, \text{ with } i,j = H,F \text{ and } i \neq j. \tag{16}$$

Eqs. (15) and (16) show two important features of standard imperfect competition models with exogenous costs of production (like Krugman, 1980; Brander, 1981; Ottaviano et al., 2002). In first place:

$$\frac{dq_{HH}}{ds} = -\frac{tN}{b(N+1)} < 0$$
$$\frac{dq_{HF}}{ds} = \frac{tN}{b(N+1)} > 0 \tag{17}$$
$$\frac{dP_H}{ds} = -\frac{tN}{(N+1)} < 0.$$

In other words, sales per consumer and prices depend on the spatial distribution of firms. In particular, as the number of firms increases at home, home prices decrease, home firms' output per consumer in the home market decreases and home firms' output per consumer in the foreign market increases. However, and in second place:

$$\frac{dq_{HH}}{dr} = \frac{dq_{HF}}{dr} = \frac{dP_H}{dr} = 0. \tag{18}$$

Sales per consumer and prices therefore do not depend on the spatial distribution of demand. Then, in a standard imperfect competition model with exogenous costs of production there is no spatial price discrimination in relation to demand patterns, only with respect to industrial location patterns. As we shall see, the same is not the case when the costs of production are endogenous, and this difference has important implications for the crowding-out effects, the demand effects, the HMEs and the spatial equilibrium.

Before turning to the HMEs, note that it only makes sense to talk about HMEs when trade between regions is possible. In other words, at the base of the analysis of HMEs is to know whether international trade can contribute to the emergence of HMEs. This issue does not occur with monopolistic competition models with CES demand (like Krugman, 1980) since, independently of parameter values, firms always export. However, when demand is linear, as in this paper, for very high trade costs firms do not export (see also Ottaviano et al., 2002; Head et al., 2002). Therefore, we need to derive the threshold level of trade costs below which it is profitable for firms to export, i.e.: the trade condition. The trade condition is obtained by making $q_{HF} = 0$ and $q_{FH} = 0$ and solving for t (see Appendix):

$$t < \bar{t}_H = \bar{t}_F \equiv \frac{a-c}{N+1}. \tag{19}$$

In this way, in a standard imperfect competition model with exogenous costs of production, the trade condition is the same for the home and the foreign firms and does not depend on the international distribution of demand (r) or industry (s).

With outputs per consumer and prices, in the next subsections we are ready to focus on the HMEs and on the spatial equilibrium.

4.2. HME in the number of firms

As we have seen, in order to calculate the HME in the number of firms, we have to analyze the free entry-exit condition, Eq. (7). With exogenous costs of production, $\Delta\Pi$ simplifies to:

$$\Delta\Pi = 2\left((2D - t)\left(r - \frac{1}{2}\right) - Nt\left(s - \frac{1}{2}\right)\right)\left(\frac{Mt}{(N+1)b}\right) = 0. \tag{20}$$

From Eq. (20), we can investigate two important relations in the model. First, the existence of crowding-out and demand effects. Second, the equilibrium number of firms in each location. We start with the crowding-out and demand effects, which equal, respectively:

$$\frac{\partial\Delta\Pi}{\partial s} = -\frac{2t^2 NM}{(N+1)b} < 0$$
$$\frac{\partial\Delta\Pi}{\partial r} = \frac{2Mt(2D-t)}{(N+1)b} > 0. \tag{21}$$

In a standard imperfect competition trade model with exogenous costs of production, then, the demand effect is positive (profits of local firms increase with the size of the domestic market) and the crowding-out effect is negative (profits of local firms decrease with number of domestic firms).

In turn, the equilibrium number of firms in each location, $\hat{s}$, can be found by solving $\Delta\Pi = 0$ for s:

$$\hat{s} = \frac{1}{2} + \frac{2\left(a - c - \frac{t}{2}\right)}{Nt}\left(r - \frac{1}{2}\right). \tag{22}$$

Eq. (22) shows that:

$$r = \frac{1}{2} \Rightarrow \hat{s} = \frac{1}{2}$$
$$r > \frac{1}{2} \Rightarrow \frac{1}{2} < \hat{s} \leqslant 1 \tag{23}$$
$$r < \frac{1}{2} \Rightarrow 0 \leqslant \hat{s} < \frac{1}{2}.$$

In equilibrium, then, the larger region always hosts more firms than the smaller region.

We can now study whether the larger market not only hosts more firms, as shown in Eq. (22), but also hosts a disproportionately higher share of the world's firms than of the world's demand (i.e.: HME in the number of firms). We have seen above that HME in the number of firms arise if Eq. (10) is satisfied. Inserting Eq. (21) in Eq. (10), we find:

$$\frac{\partial \Delta \Pi}{\partial r}+\frac{\partial \Delta \Pi}{\partial s}=\frac{2(2D-t(N+1))Mt}{(N+1)b}>0. \tag{24}$$

In this sense, as long as trade is possible, i.e.: Eq. (19) is satisfied, the larger region hosts a disproportionately higher share of the world's industry than of the world's demand. Therefore, in a standard imperfect competition model, HME in the number of firms always arise.

4.3. HMEs in employment and trade patterns

In what relates to HMEs in employment and trade patterns, remember that HMEs in employment and trade patterns depend on the relation $\frac{s}{r}\frac{(1-r)}{(1-s)}$, see Eqs. (12) and (14). Assume without loss of generality that home is the larger region (results apply by symmetry if foreign is the larger region). From equations (22) and (24), we have that:

$$r>\frac{1}{2} \Longleftrightarrow \hat{s}>r>\frac{1}{2} \Longleftrightarrow \frac{s}{r}\frac{(1-r)}{(1-s)}>1. \tag{25}$$

We can then apply this relation to HMEs in employment and in trade patterns. Start with the HME in employment. Note that from Eq. (15) that $q_H = q_F$. It then follows:

$$\frac{s}{r}\frac{(1-r)}{(1-s)}>1>\frac{cq_F+g}{cq_H+g}=1. \tag{26}$$

As such, the existence of the HME in employment follows.

Turn now to HME in trade patterns. It can be shown that (see Appendix):

$$\frac{q_{FH}P_H}{q_{HF}P_F}=\frac{(a+(c+t(1-s))N)}{(a+(c+st)N)}\frac{(a-c-t(1+sN))}{(a-c-t(1+(1-s)N))}<1 < \frac{s}{r}\frac{1-r}{1-s}. \tag{27}$$

As a result, in a standard imperfect competition model, HME in trade patterns also always emerge.

4.4. Spatial equilibrium

Eqs. (22) and (23) demonstrate that the larger region hosts more firms. We would then like to investigate when the larger region attracts all industry. It can be shown that for $r>\frac{1}{2}$ agglomeration at home arises if trade costs are below a threshold level of trade costs, $\bar{t}_{CP}$ (see Ottaviano et al., 2002). To obtain the threshold level for agglomeration, we just need to make $\hat{s}\geqslant 1$ in Eq. (22) and solve for t:

$$t<\bar{t}_{CP}\equiv\frac{4(a-c)}{N+2(r-\frac{1}{2})}\left(r-\frac{1}{2}\right). \tag{28}$$

As long as the trade condition holds, Eq. (19), Eq. (28) is satisfied the higher the home region market size (i.e.: as the share of demand at home, r, approaches one). Conversely, Eq. (28) is not satisfied the more symmetric the two regions are in terms of market size (i.e.: as the share of demand at home approaches one-half).

Fig. 1 depicts the spatial equilibrium of the exogenous costs of production case. The horizontal axis represents the home share of demand (r) and the vertical axis the home share of firms in the *IRS* (s). In Fig. 1, the points *A*, *B* and *C* stand for stable spatial equilibriums. The lines r', r'', r''' represent different spatial distributions of demand (with $r'''>r''>r'=1/2$). The arrows in these lines illustrate the direction of the spatial movements of the firms. The line s' shows the values of s that make $\Delta\Pi = 0$.

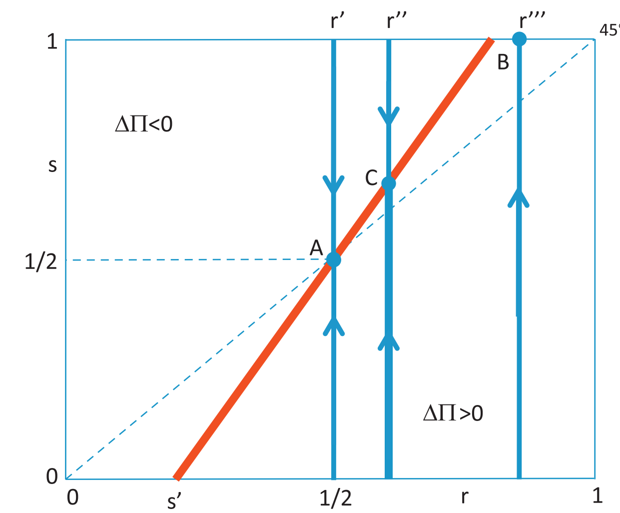

Fig. 1. Spatial equilibrium with exogenous costs of production.

As can be seen from Fig. 1, we observe the spatial equilibriums from models with exogenous costs of production (Head et al., 2002): symmetry for $r=\frac{1}{2}$; agglomeration at home as r tends to one (or at foreign as r tends to zero); and partial agglomeration as r tends to one-half. Therefore, in standard imperfect competition models with exogenous costs of production three stable spatial equilibriums emerge: symmetric dispersion; agglomeration; and partial agglomeration (in Fig. 1 points *A*, *B* and *C*, respectively).

In the next section, we shall see that the spatial equilibrium with endogenous costs of production encompasses other configurations, since firms in different locations differ in the costs of production.

5. Endogenous costs of production

In this section, we analyze the endogenous costs of production case, i.e.: with $k_H \geqslant 0$ and $k_F \geqslant 0$. We start with the production equilibrium and then turn to HMEs in the number of firms, employment and trade patterns and close with the spatial equilibrium.

5.1. Production equilibrium

In order to find outputs per consumer and R&D levels, we need to derive the respective FOCs. From the FOCs for outputs per consumer, we obtain:

$$q_{ii}=\frac{(a-C_i(1+n_j)+C_jn_j+tn_j)}{b(N+1)}$$
$$q_{ij}=\frac{(a-C_i(n_j+1)+C_jn_j-t(n_j+1))}{b(N+1)}, \text{with } i,j=H,F \text{ and } i\neq j. \tag{29}$$

Remember that $n_H = sN$ and $n_F = (1-s)N$. In turn, from the FOCs for R&D, we have:

$$k_i=\frac{\theta}{\gamma}(m_iq_{ii}+m_jq_{ij}), \text{with } i,j=H,F \text{ and } i\neq j. \tag{30}$$

Noting also that $m_H = rM$ and $m_F = (1-r)M$. When the costs of production are endogenous, then, the spatial patterns of demand (r) affect investment in R&D across regions. As we shall see, this has important consequences for the endogenous costs of production case. First, differently from standard imperfect competition models, prices and outputs per consumer also depend on market size. Second, and as a result, the crowding-out effects, the demand effects, the HMEs and the spatial equilibrium in the endogenous costs of production case differ from the exogenous costs of production case. In this subsection, we focus on the first point and turn to the second one in the next subsections.

To find outputs and R&D, solve simultaneously Eqs. (29) and (30):

$$q_{ii} = \frac{(N+1)M\big((1-\eta)(a-c)+n_j t\big) - m_j \eta t\big(2n_j(N+2-\eta)+(1-\eta)\big)}{bM((N+1)-\eta)(1-\eta)(N+1)}$$
$$q_{ij} = \frac{(N+1)M\big((1-\eta)(a-c-t)-n_j t\big) + m_i \eta t\big(2n_j(N+2-\eta)+(1-\eta)\big)}{bM((N+1)-\eta)(1-\eta)(N+1)}$$
$$k_i = \theta\frac{(1-\eta)\big((a-c)M-m_j t\big)+n_j t(2m_i - M)}{\gamma b((N+1)-\eta)(1-\eta)}, \text{with } i,j=H,F \text{ and } i\neq j, \tag{31}$$

where like in Leahy and Neary (1997), $\eta = \frac{\theta^2 M}{b\gamma}$ represents the "relative return on R&D". A high η represents a large relative return on R&D, since the cost-reducing effect of R&D (θ) is high relatively to the cost of R&D (γ). In other words, for high η, firms reap larger benefits from investment in R&D in terms of cost reduction, and *vice versa*.

As we shall see, similar to what occurs in other process R&D models (like Leahy and Neary, 1997), η is central to the solution of the endogenous costs of production case. For the moment, start by noticing that from the second order conditions (SOCs) for R&D we need that $0 < \eta < 1$ (see Appendix). This means that the relative return on R&D (η) cannot be extremely high, otherwise the trade-off that a firm faces when investing in R&D (lower marginal costs versus higher fixed costs) is not binding.

Turn now to prices by substituting Eq. (31) in the indirect demand, Eq. (5), to obtain:

$$P_i = \frac{(N+1)M\big(a-c+n_j t\big) - \big(\eta(a-c)(N+1)M - m_j\eta t(2n_i - N)\big)}{M((N+1)-\eta)(N+1)}, \text{with } i,j = H,F \text{ and } i\neq j. \tag{32}$$

It can be shown that the relation between outputs and prices of the home firms and the share of firms at home equals:

$$\frac{dq_{HH}}{ds} = \frac{(2(1-r)\eta(N+2-\eta)-(N+1))Nt}{b((N+1)-\eta)(1-\eta)(N+1)} \gtrless 0$$
$$\frac{dq_{HF}}{ds} = -\frac{(2r\eta(N+2-\eta)-(N+1))Nt}{b((N+1)-\eta)(1-\eta)(N+1)} \gtrless 0 \tag{33}$$
$$\frac{dP_H}{ds} = -\frac{(N+1-2\eta(1-r))Nt}{((N+1)-\eta)(N+1)} < 0.$$

In turn, the relation between outputs and prices of the home firms and the share of demand at home is as follows:

$$\frac{dq_{HH}}{dr} = \frac{dq_{HF}}{dr} = \frac{\eta t(2(1-s)N(N+2-\eta)+(1-\eta))}{b((N+1)-\eta)(1-\eta)(N+1)} > 0$$
$$\frac{dP_H}{dr} = -\frac{2(s-\frac{1}{2})Nt\eta}{((N+1)-\eta)(N+1)} \gtrless 0. \tag{34}$$

In other words, in the endogenous costs of production case, outputs per consumer and prices are affected not only by the number of firms in each location (s) as in standard new trade theory models with exogenous costs of production (see Head et al., 2002, and Eqs. (15)–(18)), but also by market size (r). In this way, with endogenous costs of production, firms spatial price discriminate not only in relation to the number of local firms but also to the level of local demand.

In particular, we have that as in the exogenous costs of production case, home prices decrease with the number of firms located at home. However, differently from the exogenous costs of production case, home firms' output per consumer in the home and in the foreign markets can either increase or decrease as the number of home firms increases. Furthermore, we have now that as market size at home increases, home firms' output per consumer in the home and in the foreign regions also increases. In turn, prices in the home market only decrease with the share of demand at home if home hosts more firms than foreign.

To understand these results, we need to investigate how R&D behaves in relation to changes in the share of local demand (r) and the share of local firms (s). We have that $\frac{dk_H}{dr}$ equals:

$$\frac{dk_H}{dr} = \frac{(2(1-s)N+(1-\eta))Mt\theta}{(N+1-\eta)(1-\eta)b\gamma} > 0. \tag{35}$$

Eq. (35) is unambiguously positive, as long as $0 < \eta < 1$ holds. Then, home firms' R&D investment increases with the local share of demand. The rationale for this outcome follows from the R&D trade-off: lower marginal costs versus higher fixed costs. As we have seen, when firms invest more in R&D they reduce marginal costs at the expense of higher fixed costs. The capacity of firms to pay for the extra fixed costs associated with more innovation, though, increases with market size. This is so, since in larger markets firms have higher sales and therefore larger economies of scale in production, which can be used to finance R&D.

In turn, $\frac{dk_H}{ds}$ simplifies to:

$$\frac{dk_H}{ds} = -\frac{2(r-\frac{1}{2})MNt\theta}{(N+1-\eta)(1-\eta)b\gamma} \lesseqgtr 0. \tag{36}$$

Eq. (36) is positive for $r < \frac{1}{2}$ and negative for $r > \frac{1}{2}$. Therefore, firms located in the larger region are penalized with respect to R&D when the number of local firms increases. The contrary occurs in the smaller region. The reason for this follows from the fact that firms in the smaller market are limited by the small size of the local market which is reflected in lower sales and in a lower capacity to invest in R&D (Eq. (35)). As a result, firms in the smaller market increase R&D expenditures in order not to exit the market and to deter further entry. The opposite occurs in the larger market, where firms have room to try to accommodate an increase in the number of local firms by reducing R&D investment.

A larger market size has then three effects. First, it increases local firms' revenues, since R&D is higher (and marginal costs lower) on the larger market, Eq. (35). Second, it depresses local firms' revenues when the number of firms increase in the larger market, because this conduces to a reduction in R&D (and as such an increase in marginal costs), Eq. (36). Third, it makes firms endogenously asymmetric across regions, given that firms' R&D behavior is determined by the spatial distribution of demand. Note that this is never the case in standard imperfect competition models, where firms are always symmetric in costs (Krugman, 1980; Brander, 1981; Ottaviano et al., 2002). As we shall show below, these market size effects have important implications in terms of market access, HMEs and the spatial equilibrium.

Start with the effects on market access (we analyze the effects on HMEs and on the spatial equilibrium in the next subsections). As in the model with exogenous costs of production, the trade conditions are obtained by solving q_{HF} and q_{FH} for t:

$$t < \bar{t}_i \equiv \frac{(1-\eta)(N+1)M(a-c)}{(N+1)M(n_j+1-\eta)-\eta m_i(2n_j(N+2-\eta)+1-\eta)}, \text{with } i,j = H,F \text{ and } i\neq j. \tag{37}$$

Differently from standard imperfect competition models, where all firms (either from home or foreign) have the same trade conditions (see Eq. (19)), in the model with endogenous costs of production, firms from different regions have different levels of access to international markets. This is so because firms across regions are asymmetric.

We are now ready to analyze the consequences for the HMEs of the endogenous costs of production and the endogenous asymmetries between firms that follow. We first look at the HME in the number of firms and then turn to the HMEs in trade patterns and employment.

5.2. HME in the number of firms

To derive the HME in the number of firms, we use the same strategy as in the exogenous costs of production case. We then analyze the free entry-exit condition (Eq. (7)). With endogenous costs of production, $\Delta\Pi = 0$ simplifies to:

$$\Delta\Pi = \frac{(2-\eta)\left(a-c-\frac{t}{2}\right)\left(r-\frac{1}{2}\right)}{(2tM)^{-1}b(1-\eta)((N+1)-\eta)} + \frac{Nt\left((1-\eta)\left(4\eta r(1-r)\left(1+\frac{1-\eta}{N+1}\right)-1\right)-2\eta\left(r-\frac{1}{2}\right)^2\right)\left(s-\frac{1}{2}\right)}{(2tM)^{-1}b(1-\eta)^2((N+1)-\eta)} = 0. \tag{38}$$

As in the standard imperfect competition model, from the profit differential expression, we can analyze the existence of crowding-out and demand effects and the equilibrium number of firms at home and at foreign. We start with the crowding-out and the demand effects, which equal, respectively:

$$\frac{\partial\Delta\Pi}{\partial s} = -\frac{(1-\eta)\left(1-4\eta r(1-r)\left(1+\frac{1-\eta}{N+1}\right)\right)+2\eta\left(r-\frac{1}{2}\right)^2}{\left(2MNt^2\right)^{-1}(N+1-\eta)(1-\eta)^2 b} < 0$$
$$\frac{\partial\Delta\Pi}{\partial r} = \frac{(1-\eta)(2-\eta)\left(a-c-\frac{t}{2}\right)(N+1)-4Nt\eta\left(s-\frac{1}{2}\right)\left(r-\frac{1}{2}\right)((2(1-\eta)(N+2-\eta)+N+1))}{(2tM)^{-1}(N+1-\eta)(N+1)(1-\eta)^2 b}. \tag{39}$$

It can be proved that the crowding-out effect is unambiguously negative (see Appendix). Then, like in standard imperfect competition models, a higher number of local firms always depress profits. In turn, the demand effect can either be positive or negative (see Appendix). We have that when the larger region also hosts more firms $\left(r > \frac{1}{2} \text{and} s > \frac{1}{2}\right)$ the demand effect is weaker when R&D is very efficient (high η), and the opposite when η is small. The mechanism is the following. When η is high, the importance of the demand effect is reduced, given that firms are less dependent on domestic demand in order to be efficient on R&D and sales. Furthermore, as shown in Eq. (36), firms in the larger market reduce R&D expenditures as a response to an increase in the number of local firms, conducing to lower revenues. As we shall see, the behavior of the demand effect in relation to η plays an important role in the existence of HMEs.

In what concerns the equilibrium number of firms in each location, $\hat{s}$, which is obtained by solving Eq. (38) for s, we have that:

$$\hat{s} = \frac{1}{2} + \frac{(1-\eta)(2-\eta)\left(a-c-\frac{t}{2}\right)}{Nt\left(2\eta\left(r-\frac{1}{2}\right)^2-(1-\eta)\left(4\eta r(1-r)\left(1+\frac{1-\eta}{N+1}\right)-1\right)\right)}\left(r-\frac{1}{2}\right). \tag{40}$$

Start by noticing that the large fraction on the right hand side of Eq. (40) is always positive (see Appendix). Then, Eq. (40) behaves in the same way as Eqs. (22) and (23) for the exogenous cost of production case. Thus, in the endogenous costs of production case, as in the exogenous costs of production case, the larger region also hosts more firms in equilibrium. However, as we shall see below the nature of the spatial equilibrium differs in the endogenous and exogenous costs of production cases.

We can now investigate whether the larger region not only hosts more firms, as shown in Eq. (40), but also hosts a disproportionately higher share of the world's firms than of the world's demand (i.e.: HME in the number of firms). We have shown above that the HME in the number of firms arise if Eq. (10) is satisfied. Inserting Eq. (39) in Eq. (10), we obtain:

$$\frac{\partial\Delta\Pi}{\partial r} + \frac{\partial\Delta\Pi}{\partial s} = \frac{(1-\eta)\left((2-\eta)\left(a-c-\frac{t}{2}\right)-Nt\left(1-4\eta r(1-r)\left(1+\frac{1-\eta}{N+1}\right)\right)\right)}{(2tM)^{-1}(N+1-\eta)(1-\eta)^2 b} - \frac{2Nt\eta\left(r-\frac{1}{2}\right)\left(\left(r-\frac{1}{2}\right)(N+1)+2\left(s-\frac{1}{2}\right)((2(1-\eta)(N+2-\eta)+N+1))\right)}{(2tM)^{-1}(N+1-\eta)(N+1)(1-\eta)^2 b} \tag{41}$$

Note that the numerators of the two terms in Eq. (41) are always positive. So to sign Eq. (41), we just need to look at the numerator. After inspection (see Appendix), we can conclude that the sign of Eq. (41) depends on the parameter η (relative efficiency of R&D). In fact, we have that for higher values of η, HME in the number of firms do not arise, while for lower values of η, the contrary occurs. In other words, when the return on R&D is high, we have a negative HME in the number of firms, since an increase in market size in the larger region conduces to a less than proportional increase in the number of firms located there.

The rationale for this result comes from R&D investment. In effect, as we have seen, market size differences trigger endogenous asymmetries between firms in different regions, since firms in larger markets invest more in R&D. By investing more in R&D, firms in the larger market achieve lower costs than firms in the smaller market. As a result, in equilibrium the larger market does not need to host a disproportionately higher share of the world industry than of the world demand. The previous effects are magnified when the return on R&D is high.

We can illustrate this result with a simple numerically example. Consider an economy where $t = 4$, $a = 100$, $c = 50$ and $N = 10$. Start by considering that the relative return on R&D equals $\eta = 0.7$. The question we ask is what will occur to the equilibrium share of firms at home $(\hat{s})$ and the HME in the number of firms, if market size increases 10%, from say $r = 0.55$ to $r = 0.605$? The answer is that the share of firms at home will increase 25% from $\hat{s} = 0.76$ to $\hat{s} = 0.95$. In other words, we assist to the presence of the HME in the number of firms, since an increase in market size leads to a more than proportional increase in the share of firms at home.

If now, we increase the relative return on R&D to $\eta = 0.86$, what are the consequences on the share of firms at home and the HME in the number of firms? We consider again an increase of 10% in market size at home from $r = 0.55$ to $r = 0.605$. We have that the share of firms at home now increases just 7% from $\hat{s} = 0.91$ to $\hat{s} = 0.97$. In other words, the HME in the number of firms is canceled, once an increase in market size leads to a less than proportional increase in the share of firms at home.

In the previous examples, the results seem to be driven by a high value of η. However, we can also derive similar outcomes for lower values of η. For instance consider now that $t = 8$, $a = 100$, $c = 50$ and $N = 10$. Start with $\eta = 0.4$ and $r = 0.6$. We will have that an increase of 10% in market size at home from $r = 0.6$ to $r = 0.66$ results in an increase in the share of firms at home of 11%, from $\hat{s} = 0.65$ to $\hat{s} = 0.72$. In other words, we see the emergence of HME in the number of firms.

Continue now with the same scenario (i.e.: $t = 8$, $a = 100$, $c = 50$ and $N = 10$) and start again with a market size of $r = 0,6$. However, increase slightly the relative return on R&D to $\eta = 0.6$. Now an increase of 10% in market size at home from $r = 0.6$ to $r = 0.66$ conduces to an increase in the share of firms at home of just 9% from $\hat{s} = 0.69$ to $\hat{s} = 0.75$. Therefore, we stop to observe the HME in the number of firms.

The above examples show then that the parameter η does not need to be extremely high for the HME in the number of firms to be canceled. It is just necessary that η is sufficiently high in relation to remaining parameters describing the economy. This is so because η stands for the relative return on R&D (i.e.: relation between the costs and the cost-reducing effects of R&D, γ and θ, respectively, weighted by world population, M and an inverse measure of market size, b) and not for the absolute return on R&D. Remember also that the SOC for R&D also imposes that η is not bigger than one. This is in accordance with empirical estimations of Fung (2002) for the return on R&D activities. Due to all these reasons, we believe that the values of η for which the HME in the number of firms is canceled are empirically plausible.

5.3. HMEs in employment and trade patterns

We turn now to HMEs in employment and trade patterns, Eqs. (12) and (14), respectively. The starting point is again the relation $\frac{s}{r}\frac{(1-r)}{(1-s)}$, since both the HMEs in employment and in trade patterns depend on it. As in the exogenous costs of production case, due to the symmetry in the model, we just look at the case where home is the larger region.

To analyze the HMEs in employment and in trade patterns in the endogenous costs of production case, we can use the fact that $\frac{s}{r}\frac{(1-r)}{(1-s)}$ is related to the HME in the number of firms and that what determines the existence or not of the HME in the number of firms is η (relative return on R&D), Eq. (41). In fact, if home is the larger region, from Eqs. (40) and (41), we have that:

$$r > \frac{1}{2} \Rightarrow \hat{s} > \frac{1}{2} \Rightarrow \left(\frac{s}{r}\frac{(1-r)}{(1-s)}\right)_{\eta=0} > 1$$
$$r > \frac{1}{2} \Rightarrow \hat{s} > \frac{1}{2} \Rightarrow \left(\frac{s}{r}\frac{(1-r)}{(1-s)}\right)_{\eta=1} < 1. \quad (42)$$

Due to this behavior, in order to study the HMEs in employment and trade patterns in the endogenous costs of production case, we focus on these two extreme cases, i.e.: $\eta = 0$ and $\eta = 1$.

Start with the HME in employment. We have that if home is the larger region, and η tends to zero (low relative return on R&D), the right-hand side of Eq. (12) approaches Eq. (26) from the exogenous costs of production case. As a result, as η tends to zero, HME in employment arise. In turn, when η tends to one (high relative return on R&D), we have:

$$\left(\frac{C_F q_F + G_F}{C_H q_H + G_H}\right)_{\eta=1} = \frac{s^2}{(1-s)^2} > 1 > \left(\frac{s}{r}\frac{(1-r)}{(1-s)}\right)_{\eta=1}. \quad (43)$$

When η tends to one, then, the HME in employment does not emerge. Therefore, when the return on R&D is high, the *IRS* in the larger region employs a less than proportional share of labor in relation the share of demand it hosts.

In what concerns the HME in trade patterns, we again have that as η tends to zero (low relative return on R&D), the right-hand side of Eq. (14) approaches Eq. (27) from the exogenous costs of production case. Then it also follows that as η tends to zero, the HME in trade patterns arise. The question is then if, as η tends to one (high relative return on R&D), the HME in trade patterns is canceled in the same way as it occurs with the HMEs in the number of firms and employment:

$$\left(\frac{q_{FH}P_H}{q_{HF}P_F}\right)_{\eta=1} = -\frac{(c(N+1)+(1-s)Nt+t(r+s-2rs))s}{(c(N+1)+sNt+t(r+s-2rs))(1-s)} < 0 < \left(\frac{s}{r}\frac{1-r}{1-s}\right)_{\eta=1}. \quad (44)$$

As η tends to one, then, the HME in trade patterns emerges. This follows from the effects of market size on R&D. We have seen that firms in the larger market invest more in R&D (and have as such lower marginal costs) than firms in the smaller market. This implies that firms in the larger region need less labor to produce the same amount of output (no HME in employment). Larger firm size, in turn, means that relatively fewer firms arise in equilibrium in the larger market (no HME in the number of firms).[15] However, since firms in the larger market have lower marginal costs, they can export more than rivals in the smaller market and also to crowd-out foreign imports. In the end, the larger market, even in the absence of HMEs in the number of firms and employment, still runs a trade surplus in the *IRS* (HME in trade patterns).

5.4. Spatial equilibrium

From Eq. (40) we have that the larger region hosts more firms in equilibrium. In this sense, the spatial equilibriums with exogenous and endogenous costs of production look similar (Eq. (23)). This however is not totally correct, since agglomeration and dispersion follow different patterns in the endogenous costs of production case. To see this, start by noticing that for $r > \frac{1}{2}$ agglomeration at home arises if trade costs are lower than a threshold level of trade costs. As in the exogenous costs of production case, the threshold level for agglomeration can be found by making $\hat{s} \geqslant 1$ in Eq. (40) and solve for t:

$$t < \bar{t}_{CP} \equiv \frac{2(1-\eta)(2-\eta)(a-c)\left(r-\frac{1}{2}\right)}{\left((1-\eta)(2-\eta)\left(r-\frac{1}{2}\right)+N\left(2\eta\left(r-\frac{1}{2}\right)^2-(1-\eta)\left(4\eta r(1-r)\left(1+\frac{1-\eta}{N+1}\right)-1\right)\right)\right)}. \quad (45)$$

The threshold level for agglomeration again depends on η (relative return on R&D). In fact, we have that as η tends to zero (low relative return on R&D), Eq. (45) approaches Eq. (28) from the exogenous costs of production case. Therefore, as η tends to zero, Eq. (45) is satisfied (i.e.: agglomeration arises) the higher the home region market size, and is not satisfied the more symmetric the two regions are in terms of market size. In turn, as η tends to one (high relative return on R&D), we have:

$$t < (\bar{t}_{CP})_{\eta=1} \equiv 0. \quad (46)$$

As η tends to one, Eq. (45) therefore is not satisfied, given that $t > 0$. Consequently, and independently of the share of demand in each region, as η tends to one, total agglomeration never arises. In this way, as η tends to zero, the endogenous cost of production case encompasses a spatial equilibrium similar to the one in the exogenous costs of production case (see Fig. 1). However, as η tends to one, two new spatial equilibrium configurations arise (see Figs. 2 and 3).

Figs. 2 and 3 read as Fig. 1. The horizontal axis represents the home share of demand (r) and the vertical axis the home share of firms in the *IRS* (s). The points *A, B, C* and *D* stand for stable spatial equilibriums. The lines r', r'', r''' and r'''' represent different spatial distributions of demand (with $r'''' > r''' > r'' > r' = 1/2$). The arrows in these lines illustrate the direction of the spatial movements of the firms. The line s' shows the values of s that makes $\Delta\Pi = 0$.

[15] There is some evidence that more efficient firms use less labor, which can lead to a reduction in local employment. Also, in a market with more efficient firms, fewer firms survive. See for example Neumark et al. (2008) for Wal-Mart stores.

Comparing Figs. 1–3, we have the following. In Figs. 1 and 2 three stable spatial equilibriums emerge: symmetric dispersion, agglomeration and partial agglomeration (for example points *A*, *B* and *C*, respectively). In turn, in Fig. 3, only two stable spatial equilibriums arise: symmetric dispersion and partial agglomeration (points *A* and *B*, respectively). The partial agglomerated equilibriums in Figs. 2 and 3, however, differ from those in Fig. 1. In the latter, partial agglomeration only arises if the spatial distribution of demand is not very asymmetric, i.e.: as *r* tends to one-half (point *C* in Fig. 1). In the former, partial agglomeration emerges even for a very asymmetric spatial distribution of demand, i.e.: as *r* tends to one (point *D* in Fig. 2 and point *B* in Fig. 3). Furthermore, Fig. 3 shows a spatial equilibrium pattern not possible in the exogenous costs of production case, since total agglomeration never arises in equilibrium.

The reason for the differences in the spatial equilibriums in Figs. 2 and 3 is that, as we have seen above, when ηincreases (relative return on R&D increases), firms use R&D more efficiently to achieve lower costs. When this occurs, local competition in the larger market becomes very fierce. As a result, some of the firms have to exit the larger market, preventing total agglomeration to occur. Due to this, asymmetric spatial equilibriums without total agglomeration emerge in our model.

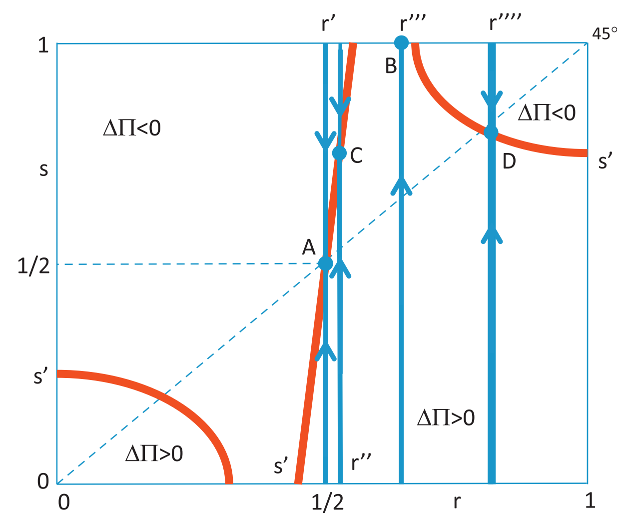

Fig. 2. Spatial equilibrium with endogenous costs of production (1).

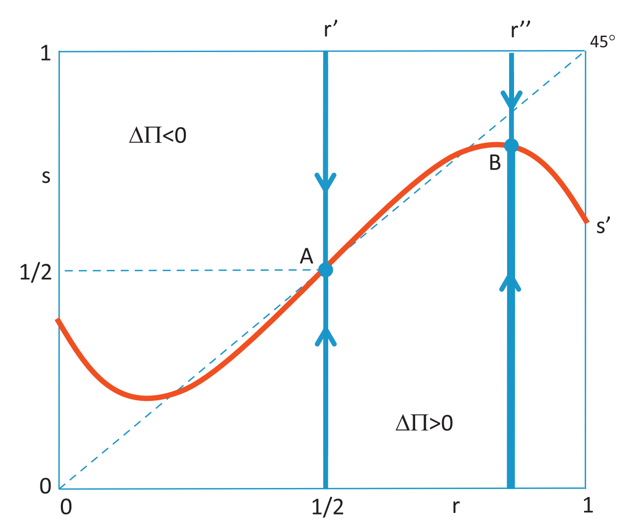

Fig. 3. Spatial equilibrium with endogenous costs of production (2).

6. Discussion

Home market effects (HMEs) are the cornerstone of the trade-geography literature. The HMEs predict that in increasing return sectors (IRSs), the larger region, relatively to the smaller region (Krugman, 1980): attracts a disproportionately larger share of firms in the IRS in relation to the share of demand it hosts (HME in the number of local firms); employs disproportionately more factors of production in relation to the share of demand it hosts (HME in factor employment); and runs a trade surplus in the IRS (HME in trade patterns). As a result, total agglomeration of the IRS emerges on the larger region when trade costs are sufficiently small (Krugman, 1991).

In this paper we have tested the robustness of home market effects (HMEs) to one of the central assumptions of standard trade-geography models (Krugman, 1980, 1991; Brander, 1981; Ottaviano et al., 2002): exogenous costs of production. In particular, we have endogenized the costs of production as a result of firms' R&D responses to market size differences.

In this set-up, we have shown that HMEs in the number of firms and employment are canceled when the return on R&D is high, i.e.: the larger region does not employ disproportionately more labor nor has a disproportionately larger share of firms in the IRS in relation to share of demand it hosts. In this way, we find negative HMEs in the number of firms and in employment, since when market size increases in the larger region it conduces to a less than proportional increase in the number of firms and in factor employment in this region. When this is the case, even when market size differences between regions are large, the only sustainable spatial equilibrium is partial agglomeration. Though, the HME in trade patterns continues to hold, i.e.: the larger region runs a trade surplus in IRSs.

The rationale for these results is that firms in the larger region invest more in R&D than firms in the smaller region, given that the former find it easier to pay for the fixed costs of innovation due to higher economies of scale in production. As a consequence, firms in the larger market are bigger in size and have higher cost competitiveness than firms in the smaller market. In this sense, since firms in the larger market are bigger in size, fewer firms survive there in equilibrium. Also, given that firms in the larger market have higher cost competitiveness, on one hand, they use resources more efficiently and therefore employ relatively less factors of production than firms with lower cost competitiveness. On the other hand, they export more than rivals in the smaller market.

Our results have implications for the empirical literature on HMEs (Davis and Weinstein, 1996, 1999, 2003; Lundbäck and Torstensson, 1998; Feenstra et al., 2001; Head and Ries, 2001; Brülhart and Trionfetti, 2009). This literature just focuses in one type of HMEs (usually either the HME in the number of firms or the HME in trade patterns). This is so, because when firms are symmetric across regions, the existence of the HME in the number of firms implies also the existence HMEs in employment and in trade patterns. Our model illustrates that when firms differ in cost competitiveness across regions this direct link between the three HMEs does not necessarily emerge. In this sense, our analysis suggests that empirical tests on HMEs should take into consideration the three HMEs simultaneously.

In terms of future work, our model would gain by being merged with other complementary approaches like Melitz (2003) and Bernard et al. (2007). In Melitz (2003) firms are heterogeneous in productivity but the distribution of productivity across regions is the same. In Bernard et al. (2007) firms are also heterogeneous in productivity like in Melitz, but they also respond asymmetrically across regions to international comparative advantages differences. In turn, in our framework firms' R&D efforts (and therefore cost competitiveness) differ between regions in reaction to market size asymmetries. With this generalization, we would be able to analyze how market size interacts with comparative advantage and with firm heterogeneity at regional and international levels.

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Appendix A

A.1. Demand

To find the demand functions for the *CRS*-good and the *IRS*-good, we need to solve the problem in Eq. (1) subject to the restriction in Eq. (2). Start with the *CRS*-good. Maximizing Eq. (1) in relation to the *CRS*-good, we have that:

$$\frac{\partial U_H}{\partial q_{0H}} - \lambda P_0 = 0 \Longleftrightarrow 1 = \lambda P_0, \tag{47}$$

where λ is the budget constraint multiplier. Since $P_0 = 1$, then $\lambda = 1$. In turn, maximizing in relation to the quantity of the *IRS* -good sold by the home firm i at home, noting that $\lambda = 1$, we obtain:

$$\frac{\partial U_H}{\partial q_{iH}} - \lambda P_{iH} = 0. \tag{48}$$

It can be checked that a similar expression applies to the foreign firms' sales at home. Eq. (5) in the main text then follows. By substituting Eq. (5) in the budget constraint, Eq. (2), it is also possible to derive the conditions that guarantee $q_{0H} > 0$:

$$I > (a - bQ_H)Q_H = Q_H P_H. \tag{49}$$

In other words, $q_{0H} > 0$ when the representative consumer's income is larger than the amount he/she consumes of the *IRS*-good. In this sense, the previous equation shows that our model does not imply that the share of the manufacturing sector must be small.

A.2. Trade condition exogenous costs of production case

Solving $q_{HF} > 0$ and $q_{FH} > 0$ for t, we have:

$$\begin{aligned} t &< \bar{t}_H \equiv \frac{a - c}{(1 - s)N + 1} \\ t &< \bar{t}_F \equiv \frac{a - c}{sN + 1}. \end{aligned} \tag{50}$$

It can be seen that $\bar{t}_H$ and $\bar{t}_F$ are stricter at $s = 0$ and $s = 1$, respectively. Therefore, we obtain Eq. (19) for both home and foreign firms.

A.3. Proofs on the signs of different equations

Eq.(27). One way to show that $\frac{q_{FH}P_H}{q_{HF}P_F} < 1$ is to note that:

$$q_{FH}P_H - q_{HF}P_F = -\left(s - \frac{1}{2}\right)\frac{2(2a - c - t + Nc)Nt}{b(N+1)^2}. \tag{51}$$

We can see that for $s > \frac{1}{2}$, then $\frac{q_{FH}P_H}{q_{HF}P_F} < 1$.

Eq.(39). In what respects $\frac{\partial \Delta \Pi}{\partial s}$, the denominator of the fraction is positive, once $0 < \eta < 1$. The numerator is also positive, given that the second term in the numerator is always positive. The same is also the case with the first term in the numerator, since even at its local minimum (at $r = \frac{1}{2}$) it is positive.

In what concerns $\frac{\partial \Delta \Pi}{\partial r}$, while the first term in the numerator is positive, the sign of the second term depends on $(r - \frac{1}{2})(s - \frac{1}{2})$. The derivative $\frac{\partial \Delta \Pi}{\partial r}$ is positive if $r > \frac{1}{2}$ and $s < \frac{1}{2}$ or $r < \frac{1}{2}$ and $s > \frac{1}{2}$, since the second term in the numerator is then positive. However, if $r > \frac{1}{2}$ and $s > \frac{1}{2}$ or $r < \frac{1}{2}$ and $s < \frac{1}{2}$, $\frac{\partial \Delta \Pi}{\partial r}$ is not necessarily positive, given that the second term is negative. In particular, when $r > \frac{1}{2}$ and $s > \frac{1}{2}$ or $r < \frac{1}{2}$ and $s < \frac{1}{2}$, $\frac{\partial \Delta \Pi}{\partial r}$ is negative for high η (and the reverse for low η). This is so, since as ηtends to one, the first term in the numerator of $\frac{\partial \Delta \Pi}{\partial r}$ approaches zero and therefore the first (positive) term in the numerator is dominated by the second (negative) one.

Eq.(40). The numerator of the large fraction in Eq. (40) is positive, since $a - c > t$ and $0 < \eta < 1$. In turn, the denominator is also positive, given that it has a local minimum at $r = \frac{1}{2}$, where it is positive.

Eq.(41). As η tends to zero, the numerators in Eq. (41) approach $2(a - c) - t(N + 1)$. Then, as η tends to zero, $\frac{\partial \Delta \Pi}{\partial r} + \frac{\partial \Delta \Pi}{\partial s} > 0$ for $t < \frac{2(a-c)}{N+1}$. If η tends to one, the numerators approach $(3 - 4s - 2r)(r - \frac{1}{2})Nt$. The previous expression is negative for $r > \frac{1}{2}$, given that for $r > \frac{1}{2} \Rightarrow \hat{s} > \frac{1}{2}$, see Eq. (40). Note also that $(3 - 4s - 2r)(r - \frac{1}{2})$ has two solutions $(\frac{3}{2} - 2s, \frac{1}{2})$ and the second derivative of the expression is negative. Therefore, when η tends to one, Eq. (41) follows an inverse U-shaped relation to r. Consequently, for $r > \frac{1}{2}$, the expression is negative.

A.4. SOC for R&D

The SOCs for R&D are:

$$\begin{aligned} \frac{d^2 \Pi_H}{d(k_H)^2} &= \gamma\left(\eta\frac{(1 - s) + 1}{2} - 1\right) < 0 \\ \frac{d^2 \Pi_F}{d(k_F)^2} &= \gamma\left(\eta\frac{s + 1}{2} - 1\right) < 0. \end{aligned} \tag{52}$$

Solving both expressions for η, we obtain: $\eta < \frac{2}{(1-s)+1}$ and $\eta < \frac{2}{s+1}$. It can be checked that: $1 < \frac{2}{(1-s)+1} < 2$ and $1 < \frac{2}{s+1} < 2$. Since $\eta > 0$, then, the SOCs for R&D are always satisfied if $0 < \eta < 1$.

A.5. Digression: strategic R&D investment

In the model in this paper, firms invest in a constrained efficient way. However, the literature on R&D investment highlights the role of strategic behavior. When firms invest strategically in R&D, we know from Fudenberg and Tirole (1984) that it matters if a firm plays Cournot (i.e.: compete in quantities) or Bertrand (i.e.: compete in prices). With Cournot behavior, firms over-invest in R&D (above the social optimum) in order to reduce rivals' outputs. With Bertrand behavior, firms under-invest in R&D, so that price competition is softened. To see this, note that when investment in R&D is strategic and firms play Cournot, the FOC for R&D for the home firms is:

$$\frac{d\Pi_H}{dk_H} = \underbrace{\frac{\partial \Pi_H}{\partial k_H}}_{\text{Non strategic motive}=0} + \underbrace{\frac{\partial \Pi_H}{\partial q_{FF}}\frac{dq_{FF}}{dk_H} + \frac{\partial \Pi_H}{\partial q_{FH}}\frac{dq_{FH}}{dk_H}}_{\text{Strategic motive}>0}. \tag{53}$$

While if the firms play Bertrand, we have instead:

$$\frac{d\Pi_H}{dk_H} = \underbrace{\frac{\partial \Pi_H}{\partial k_H}}_{\text{Non strategic motive}=0} + \underbrace{\frac{\partial \Pi_H}{\partial p_{FF}}\frac{dp_{FF}}{dk_H} + \frac{\partial \Pi_H}{\partial p_{FH}}\frac{dp_{FH}}{dk_H}}_{\text{Strategic motive}<0}, \quad (54)$$

where p_{FF} and p_{FH} are the prices foreign firms set for the foreign and the home markets, respectively. The strategic motive under Cournot is positive, because an increase in R&D investment by the home firms leads to a reduction of the outputs of foreign firms, which in turn increases the profits of the home firms. The strategic motive under Bertrand is negative, since an increase in R&D by the home firms leads to a reduction of the prices of foreign firms, which in turn decreases the profits of the home firms.

For our case, what is important from the two previous equations is that the strategic motive works symmetrically for the home and the foreign firms, independently of market size considerations. In other words, and taking the Bertrand case as example, if home firms invest more in R&D, all foreign firms reduce prices, and all home firms see a reduction in profits. In turn, the non-strategic motive is the same for home and foreign firms, and therefore, in spite of strategic investment, R&D continues to be affected by market size. In this way, even when firms under-invest in R&D, we continue to have the channel that can cancel HMEs.

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