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Location of R&D and High-Tech Production by Vertically Integrated Multinationals

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Location of R&D and High-Tech Production by Vertically Integrated Multinationals*

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Abstract

This paper presents evidence that, in Europe, production of high-tech goods is attracted to large markets, while R&D activities tend to be located away from them. In order to explain this phenomenon, we develop a two-country general equilibrium model where firms make separate choices about the location of R&D and high-tech production. There are two agglomeration forces: R&D spillovers and a home-market effect creating incentives for firms to locate production in the relatively large market. We show that, for relatively weak R&D spillovers and intermediate trade costs, the smaller economy tends to specialize in R&D. We also discuss the welfare consequences of different outcomes with respect to the location of R&D, showing that while skilled labor may gain from hosting an agglomeration of R&D activities, unskilled labor will lose.

Keywords: monopolistic competition, R&D, high-tech production, agglomeration economies
JEL classification: F12, F23

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1 Introduction

The increased globalization of the economy has generated concerns about the location of industries, especially those where firms seem to be able to shift around production on a global scale. For policy-makers, these concerns are primarily related to the potential loss of jobs from a relocation of industries and its effect on unemployment. However, as has been emphasized in the recent literature on trade and location, there are also concerns about potential welfare losses from a relocation of activities generating positive externalities (e.g. Krugman, 1991a). In particular, the location of high-tech industries characterized by the importance of research and development (R&D) for generating new and improved products, may be of importance for national welfare. Since the available empirical evidence suggests that R&D activities generate positive spillovers that are geographically limited in scope (e.g. Griliches, 1992 and Jaffe et al., 1993), regions that are successful in attracting R&D activities may improve their welfare.

In most economic models, R&D is simply assumed to be located with the rest of the firm's activities.[1] For instance, models analyzing industry location in an endogenous growth setting allow for R&D spillovers, that may be either localized or global, but assume that firms' private knowledge capital is internationally immobile; that is, it is assumed that the firm generating new technology by investing in R&D has to exploit the new technology in the country in which it is developed (see Martin and Ottaviano, 1999, and Baldwin et al., 2001). An implication of this would be that R&D investing firms carry out R&D-intensive production in the same country. In this paper, we will argue that while this is a fair description of the location pattern of the activities of many R&D-investing firms, there are important deviations from this pattern. In particular, if there are low costs involved in transferring technology within firms, we would expect that multinational firms may end up carrying out production activities in other countries than where their R&D facilities are located. The reason for this is that a country which is an attractive location for R&D activities is not necessarily an attractive location for production of R&D-intensive goods. A country with a large market potential may be considered an attractive location for the production of final products, while this is unlikely to be an important aspect when deciding on the location of R&D activities.

In Europe, in particular, there is a tendency that small, peripheral countries, such as

[1] Notable exceptions in this respect are papers analyzing vertically integrated multinational firms, meaning firms locating different stages of their production process in different countries (see Helpman, 1984, Markusen, 1997, 2002).

Sweden and Finland, are home countries of highly R&D-intensive multinationals, which carry out production in other locations. This phenomenon is at odds with the standard assumption that R&D and production take place in the same country. We will present empirical evidence suggesting that the European countries' R&D activities exhibit a very different relationship with respect to the countries' market potential compared to high-tech production. While there is a positive relationship between a country's market potential and its specialization in high-tech production, there is a negative relationship between its market potential and the extent to which R&D is carried out in the country. Based on this evidence, we argue that an appropriate analysis of the location choice of high-tech firms should allow for a geographical separation of these activities.

The purpose of this paper is to develop a model where firms may choose to locate their R&D activities and their production plants in different countries, and to use this model to analyze how the location outcome depends on a number of crucial parameters. We allow for two different sources of agglomeration economies: knowledge spillovers associated with R&D activities (as in the previously cited studies by Martin and Ottaviano, 1999, and Baldwin et al., 2001) and linkages between firms carrying out production of final goods. The linkages, which arise from the combination of increasing returns to scale in production and transaction costs associated with cross-border trade, create a so-called "home-market" effect, whereby a region with a relatively large market has an advantage in attracting production of final goods. This aspect of the model is similar to recent models within the so-called "new economic geography" (see Fujita, Krugman and Venables, 1999).

Our model thus involves two different mechanisms creating incentives for the concentration of activities, and, with respect to the home-market effect, incentives for the concentration of these activities in a large market. However, counteracting these two centripetal forces is the effect on the return to scarce factors when R&D activities and the production of high-tech goods compete for resources. We assume that both these activities use inputs of skilled labor. The outcome in terms of the firms' location choices then depends on the interplay between the advantages of concentrating activities in order to benefit from externalities and being close final consumers and the disadvantages of locating skill-intensive activities where skilled labor is relatively expensive.

In the paper, we focus on the case where there is an asymmetry between countries in terms of their sizes. We analyze how the location choices of high-tech firms are affected by the strength of externalities generated by R&D activities and the strength of a home-market effect generated by the combination of plant-level scale economies and trade costs.

The analysis is related to work by Markusen (1997, 2002), which shows that a small country may end up headquartering vertically integrated multinationals with production in the larger country when the smaller country is relatively skill-abundant and trade costs relatively low. A crucial difference between this analysis and that by Markusen, however, is that agglomeration economies may not only affect the location of production activities, but also that of non-production activities.

The rest of the paper is organized as follows: In section 2, we first present empirical evidence motivating our analysis. In section 3, we discuss the related literature and the contribution of the analysis. Section 4 presents and discusses the model, while section 5 analyzes the location choice by high-tech firms on different assumptions about the strength of the different sources of agglomeration economies. It also examines the consequences for welfare. Finally, section 6 concludes.

2 Market Size and High-Tech Activities

Figure 1 shows a plot diagram of business expenditures on R&D per capita, and the share of high-tech goods in total manufacturing exports for OECD countries. As predicted by standard theory, there is a positive correlation between these two variables (the solid line shows the fitted line from an OLS regression). However, there are some interesting outliers. For instance, Sweden, which is the country that after Japan has the highest R&D expenditures per capita, does not belong to the countries with the highest share of high-tech goods in their exports. On the opposite side, Ireland has the highest share of high-tech goods in their exports, but does not belong to the countries with the highest ratio between R&D expenditures and GDP. A common feature of these two economies is the important role of multinational enterprises (MNEs); Sweden being the home country of several large MNEs and Ireland being the host country of many MNEs originating in the US and Japan, as well as other European countries.

{Figure 1: R&D expenditures per capita and the share of high-tech exports in total manufacturing exports (2000).}

An immediately obvious potential explanation for these two outliers is that they reflect the tendency of MNEs to concentrate their R&D activities in the parent firm in their home countries while producing R&D intensive goods closer to large markets.[2] This tendency is often taken to be the main explanation why certain small countries, such as Sweden, with large R&D expenditures in relation to GDP do not export high-tech goods to the extent motivated by their R&D expenditures.

In order to examine the relationship between market size, on the one hand, and high-tech production and R&D activities, on the other, we carry out a regression analysis based on data for the Western European countries. Production of high-tech goods and R&D spending are likely to be jointly determined by variables such as relative factor endowments and market potential. However, since costs associated with transferring technology may lead to a tendency for co-location of high-tech production and R&D activities, their separate effect on one another should be controlled for. We therefore control for the extent of R&D activities in our regression of a measure of a country's specialization in high-tech production, and we control for the specialization in high-tech production in our regression of a measure of the extent of R&D activities.

We run the following regressions: A country's share of high-tech exports in total manufacturing exports ($HTexp$) is regressed on its market potential (MP), relative skill endowment ($Skill$) and real business expenditures on R&D per capita ($R\&D$). A country's real business expenditure on R&D per capita is regressed on its market potential, relative skill endowment, and its share of high-tech exports in total manufacturing exports. Our measure of market potential takes the form developed by Harris (1954) and is based on data on real gross domestic income.[3] Relative skill endowments, are measured as the share of population with tertiary education.[4] Data on high-tech exports in total manufacturing exports have been collected from the World Bank (2003),[5] while data on

[2] This explanation for the case of Sweden is discussed in Hansson and Lundberg (1995).

[3] Country i's market potential is measures as:

$$MP_i = \sum \frac{x_j}{d_{ij}}$$

where x_j is measure of the market size of country j and d_{ij} a measure of the geographical distance between i and j. We have measured x_j d_{ij} as the greater circle distance between capitals when $j \neq i$ and as two thirds of the ratio of i's area and π when $j = i$. (The data have been collected from Penn World Tables 6.)

[4] Data have been collected from OECD's publication *Education at a Glance: OECD indicators* (various issues). The share of population 25 to 64 years of age that has attained university education (tertiary type A).

[5] High-technology goods are goods produced by industries (based on U.S. industries) that rank in the top 10 according to R&D expenditures. Manufactured exports are the commodities in the SITC, revision 1, sections 5-9 (chemicals and related products, basic manufactures, manufactured articles, machinery and transport equipment, and other manufactured articles and goods not elsewhere classified), excluding

business expenditures on R&D per capita have been collected from OECD (2003).[6] Our data cover the period 1990-2000 and include most countries in the European Union, Norway and Switzerland.[7] Due to the co-location of high-tech production and R&D activities, and the endogeneity problem it may cause, we also instrument high-tech exports in total manufacturing exports ($HTexp$) and business expenditures on R&D per capita ($R\&D$) as they are regressed on one another. As instruments for $R\&D$ we use the number of researchers in higher education as a share of the population (RHE),[8] R&D expenditures in higher education as a share of GDP ($HERD$) and GDP per capita ($GDPcap$) and as an instrument for $HTexp$ we use trade as a share of GDP.[9] The chosen variables fulfill the desired properties of instrument variables (for a correlation table, see Appendix B).

Table 1 presents the results obtained from carrying out fixed-effect estimation and 2SLS within estimation. We analyze the results for the 2SLS within estimations. As expected, there is a strong and positive relationship between a country's R&D expenditures and high-tech exports; the elasticity of high-tech exports with respect to R&D expenditures is 0.44 and the elasticity of R&D expenditures with respect to high-tech exports is 1.36. Conditional on the level of high-tech exports, relative endowments of skilled labor have a positive effect on the share of high-tech exports. The estimated effect of relative endowments of skilled labor on R&D expenditure per capita, on the other hand, is negative (although insignificant). This suggests that R&D activities may be dependent on inputs of more specific skills than those measured by our skill variable.

The important result emerging from the analysis is, however, that the estimated coefficients of market potential have different signs in the two regressions. The effect of market potential is positive on high-tech exports, but negative on R&D expenditure. The estimated coefficients are both statistically significant at the one percent level. The point estimates translate into relatively large elasticities with respect to market potential, with a positive elasticity of 3.76 for the share of high-tech exports and a negative elasticity of -3.90 for R&D expenditure per capita.[10]

division 68 (nonferrous metals).

[6] The series have been deflated using the GDP deflator.

[7] The estimations make use of data for 11 years and 16 countries (Austria and Luxemburg are excluded because of lack of data). Observations for several of the variables are only available for certain years, implying that the panel is unbalanced.

[8] Measured as full-time equivalent researchers per 1000 population.

[9] Data on the researchers and R&D expenditures in higher education have been collected from OECD's *Main Science and Technology Indicators*, while data on trade as a share of GDP have been collected from *World Development Indicators* (World Bank). Data on GDP per capita are from *SourceOECD*.

[10] We have run regressions using measures of market potential based on real GDP and real consumption

The findings suggests that market potential in itself has a differential impact on the location of high-tech production and R&D activities in Europe. In *ceteris paribus* terms, increased market potential attracts high-tech production, while it deters R&D activities. That production activities in the high-tech sector are attracted by market potential is consistent with predictions from trade and location models, assuming that high-tech production is characterized by increasing returns to scale and trade costs. The negative impact of market potential on R&D activities, however, is not so easy to interpret on the basis of existing theory. We posit in this paper that it is negative because R&D gets crowded out as activities for which market access is more important move in. In the presence of advantages from being located in proximity to other R&D labs, this crowding-out effect may be especially strong.

3 Related Literature

In an early paper, Krugman (1980) showed that the combination of increasing returns to scale and transaction costs associated with cross-border trade may generate a so-called home-market effect; a tendency for large countries to host a disproportionately large share of production. The presence of scale economies generates an incentive for firms to concentrate production in one single location and, by locating production in a large market, firms get better access to consumers. This home-market effect serves as the basis for more recent theorizing within the so-called new economic geography framework (see Fujita et al., 1999, Baldwin et al., 2003).

In related work, multinational enterprises (MNEs) have been incorporated in trade-theoretic models by adding the assumption that there exist joint inputs such as management, marketing and R&D, which create multi-plant economies of scale (e.g. Markusen 1984, Horstmann and Markusen, 1992, Brainard 1993, Markusen and Venables, 2000). In these models, the location choices of MNEs crucially depend on the trade-off between the benefits from concentrating production in one location and those stemming from locating in proximity to the consumers, thereby avoiding trade costs. The MNEs arising in these models can be characterized as horizontal in the sense of producing the same final good

as well. Using these two measures leads to essentially the same results and elasticities of the same magnitude as those presented in Table 1. We have also run regressions with GDP replacing the market potential variable. The estimated elasticity of *HTexp* with respect to GDP is 1.37 (significant at the ten percent level) and the estimated elasticity of *R&D* with respect to GDP -1.63 (significant at the one percent level).

in more than one country. However, MNEs may also be vertical in the sense of carrying out different stages of the production process in different countries. Vertical MNEs have been analyzed by Helpman (1984) using a trade model with monopolistic competition, but without any trade costs. In Helpman's analysis, a skilled-labor abundant country may end up being net exporter of headquarters services because skill-intensive headquarters activities tend to be located there, while less skill-intensive production takes place elsewhere.

More recently, Markusen (1997, 2002) has developed a model incorporating horizontal as well as vertical MNEs. As in the analysis by Helpman (1984), vertical MNEs arise when there are advantages in fragmenting the production process into skill-intensive headquarters activities and less skill-intensive production of the final good. However, in Markusen's analysis, the equilibrium production structure is not only determined by differences in factor proportions but also by the level of trade costs. This is important since it may be especially advantageous to locate final-goods production in a large market when trade costs create benefits from producing in proximity to the consumer.

Ekholm and Forslid (2001) show in a one-factor model how vertically integrated MNEs may arise as final goods production is agglomerated in a large market while headquarters activities remain where labor costs are relatively low. A similar idea has been pursued by Gao (1999), who also analyzed a model of vertical MNEs in which agglomeration forces create a factor-cost reason for firms to locate part of their activities in the periphery, where wages are lower. In Gao's analysis, labor is the only factor input, while both headquarters activities and final production require differentiated intermediate inputs that are traded at a cost. Because headquarter activities are assumed to be more intensive in intermediate inputs, agglomeration forces are stronger for headquarters compared to final production. This implies that it is the headquarters activities that end up being located in the core, while final goods production takes place in the periphery.

Neither of these papers allow for the possibility that headquarters activities generate externalities. In the presence of such externalities, e.g. knowledge spillovers from R&D activities, the location of headquarters might be important from a welfare point of view. Knowledge spillovers may arise because firms learn from each other, for example through cooperation, by reverse-engineering each others' products or as a consequence of the turnover of highly specialized labor. Several studies have found evidence of such knowledge spillovers (e.g. Jaffe et al., 1993, Acs et al., 1992, 1994, Feldman, 1994, and Audretsch and Feldman, 1996).

A few papers have analyzed industrial location in the presence of knowledge spillovers, but without allowing for the emergence of vertical MNEs. These papers build on the endogenous growth literature (Martin and Ottaviano, 1999, Baldwin et al., 2001) and assume that technological spillovers may diffuse either globally and locally. With global spillovers, the part of knowledge capital that is not private to firms is perfectly transmitted to firms in other regions. With purely local spillovers, it is transmitted only to firms located in the same region. When spillovers fade away with distance, they generate a localized externality, which creates an additional agglomeration force. As mentioned in the introduction, firms' private knowledge capital is assumed to be completely immobile between regions in these models.

In our model, we assume localized knowledge spillovers generated by R&D activities. If they were global in scope, there would be no particular benefits from local R&D activities. In fact, if technological knowledge very easily diffused across countries, it may even be beneficial to free-ride on the rest of the world by cutting back investments in R&D. However, the fact that R&D activities tend to be geographically concentrated suggests that the knowledge spillovers may be geographically limited in scope. For instance, Feldman and Audretsch (1996) find that, controlling for the degree of geographical concentration of production, innovative activity tends to cluster more in industries where knowledge spillovers play a decisive role. Moreover, Jaffe et al. (1993) provide direct evidence of geographically limited knowledge spillovers from R&D activities.[11]

Our model adds knowledge spillovers associated with R&D activities to an analysis of the location choice of firms, which are potentially vertical MNEs in the sense of being able to geographically separate their R&D activities from their production of final goods. The analysis contributes to the previous literature by allowing for both knowledge spillovers and a geographical separation of the firm's activities. Knowledge spillovers may interact with agglomeration forces based on a home-market effect in a mutually reinforcing way. However, at the same time, if final production and R&D activities draw on the same type of resources, as is reasonable to expect when it comes to high-tech production, it may also be the case that the concentration of one type of activity raises the prices of these resources so much that the other type of activity will be located elsewhere.[12] It is the

[11] See also work by Jacobs (1969), Ciccione and Hall (1996), Coe and Helpman (1995), Coe et al. (1997) and Keller (2002).

[12] A somewhat related analysis can be found in Ekholm and Torstensson (1997), where the possibility of expanding high-tech production by means of production and R&D subsidies is analyzed assuming that both R&D and the production of high-tech goods require inputs of skilled labor.

interaction between these forces that is the focus of the present analysis.

Because we allow firms to choose to locate their R&D activities in proximity to other R&D labs in order to benefit from knowledge spillovers, the analysis is related to the literature on technology sourcing and so-called "centres of excellence". It has been argued that MNEs locate R&D in "centres of excellence" in order to source the available technology (Kogut and Chang, 1991, Neven and Siotis, 1996). Our analysis shows under what circumstances such technology sourcing emerges and under what circumstances it takes place in a small rather than in a large country. Moreover it addresses the issue whether hosting a "centre of excellence" is likely to improve national welfare.

4 The Model

We assume a two-country, two-factor and two-good model to analyze the location choice by firms operating in a high-tech industry. There are two countries, Home (H) and Foreign (F), two factors of production, skilled labor (S) and unskilled labor (L), and two final goods, a homogeneous good, Y, produced with constant returns to scale in a perfectly competitive sector and a differentiated high-tech good, X, produced with economies of scale and sold in markets characterized by monopolistic competition. The supply of skilled and unskilled labor is given. Both factors of production are perfectly mobile between sectors but completely immobile between countries. The technology for producing the homogeneous good, Y, is linear and one unit of L produces one unit of Y. Production of X requires inputs of technological knowledge (R). It is assumed that firms internalize the creation of private knowledge capital and exploit it themselves rather than selling or leasing it to other firms.[13] The firm-specific technological knowledge is created by R&D labs that may be located in a different country than production. Firms choosing to produce R and X in the same country become national enterprises, while firms choosing to separate R&D from production become multinational enterprises with a vertical production structure. We use n to superscript variables associated with national firms and m to superscript variables associated with multinational firms.

[13]The motivation for this assumption is that information asymmetries create problems with adverse selection.

4.1 Technology

R&D labs produce an input transferrable across national borders but not tradable in the sense that it can be sold at arm's length to any firm. R is assumed to be directly supplied to the production plant within the same firm. A motivation for this assumption is that asymmetric information and incomplete contracting may create strong incentives to internalize R&D within the firm. However, at the same time, we assume the firms to be unable to completely internalize the benefits from their R&D. We assume the firm-specific knowledge produced by individual firms to spill over to all firms conducting R&D in the same country. More specifically, we assume the cost of inventing additional varieties in terms of inputs of skilled labor to decrease with the amount of R&D conducted in the country. The production function of a representative R&D lab is specified as follows:

$$R_{ij} = \frac{1}{\rho^g} S_{Rij}(1 + \delta \overline{R_j}), \quad \overline{R}_j = \left(\sum_{h \neq i} R_{hj} \right), \quad g = n, m, \tag{1}$$

where R_{ij} is the amount of R&D produced by firm i in country j, the sum $\overline{R}_j$ is aggregate R&D conducted in country j, and S_{Rij} the amount of skilled labor employed by firm i to carry out R&D in country j. Parameter $\rho^g \geq 1$ denotes a cost for geographically separating the production of R and X.[14] We assume that $\rho^n = 1$ and $\rho^m > 1$, which implies that there is no additional cost incurred by national firms, only by multinational firms. An intuitive interpretation of ρ is that it reflects the costs of transmitting knowledge capital from R&D labs to production facilities abroad. With a high value of ρ^m, there will be no multinational firms.[15] With a value of ρ^m equal to one, the type of firm does not matter and we cannot distinguish a situation in which there is one national firm operating in each country from the situation in which there is one vertical MNE carrying out R&D in Home and production in Foreign and another MNE carrying out R&D in Foreign and production in Home. Such a case could be analyzed assuming a setting were R&D results are sold in a market, focusing entirely on outcomes in terms of specialization patterns, leaving issues about the configuration of firms to the side. In our model, however, the configuration of firms is an important aspect. It is therefore assumed that $\rho^m \in (1, \overline{\rho})$, where $\overline{\rho}$ is the level at which the cost of transferring technological knowledge becomes

[14] Our specification in (1) implies that transferring R from one country to another involves an "iceberg" type of cost so that $\rho^g \geq 1$ units must be shipped from the R&D lab for one unit of R to arrive at the production plant located abroad.

[15] This would correspond to the case analyzed by Martin and Ottaviano (1999) and Baldwin et al. (2001).

prohibitively high and prevents the existence of multinational firms.

The production function specified in (1) has the property of augmenting the productivity of skilled labor in a constant proportion to the number of firms conducting R&D in the country. We have thus assumed that the R&D spillovers obtained from an additional firm conducting R&D in the country is independent of the initial size of the R&D sector. Alternative assumptions could be made, i.e., increasing or decreasing productivity spillovers in the R&D sector. However, since we have no information about the specific nature of R&D spillovers, we have simply chosen to model them as being constant.

A cost-minimizing firm chooses S_{Ri}, taking the level of $\overline{R}$ as given, in order to produce the technological knowledge required to produce a variety of the high-tech product. That is, we assume that the firm takes potential knowledge spillovers into account in its location decision. For a firm to enter the market with a new variety, it must generate one unit of R. This implies the following demand for skilled labor stemming from an R&D lab located in country j:

$$S_{Rij}\left(n_j^n, n_k^m \mid R_i = 1\right) = \rho^g \left(1 - \delta + \delta(n_j^n + n_k^m)\right)^{-1} \tag{2}$$

where n_j^n is the number of national enterprises in country j and n_k^m the number of multinational enterprises conducting R&D in country j and producing in country k (note that country subscripts denote the country where the firm locates its production plant). A firm deciding to conduct its R&D in the country with a larger total number of R&D labs needs to use a smaller amount of skilled labor in order to produce its own single unit of R.

The high-tech firms then employ unskilled labor (L) and skilled labor (S) to produce their final products. There are fixed costs in production, creating an incentive for concentrating final production to one country. More specifically, we assume the following cost function of a representative high-tech firm producing in region j:

$$c\left(w_{Sj}, w_{Lj}, X_{ij} \mid R_i = 1\right) = w_{Sj}^{\alpha} w_{Lj}^{1-\alpha}(\beta + \gamma X_{ij}) \tag{3}$$

where w_{Sj} and w_{Lj} are the returns to skilled and unskilled labor, respectively, X_{ij} is the level of output of the representative firm i, $\alpha \in [0, 1]$, and β and γ are positive constants.

4.2 Preferences

In modelling consumer preferences, we use the Dixit-Stiglitz specification of preferences for variety (Dixit and Stiglitz, 1977). A representative consumer has the following utility function:

$$U = (C_X)^{\mu} (C_Y)^{1-\mu}, \qquad C_X = \sum_{i=1}^{n^w} \left(c_i^{1-\frac{1}{\sigma}} \right)^{\sigma/(\sigma-1)}, \tag{4}$$

where C_X is a sub-utility function capturing utility derived from the consumption of different varieties of high-tech goods; c_i denotes the consumption of each available variety, $\mu \in [0,1]$, and $n^w = n^n + n^m$ is the total number of varieties produced.[16]

It is well-known that a two-stage budgeting procedure generates the following expression for demand for an individual variety i (see e.g. Fujita et al., 1999, section 4.1):

$$c_i = \frac{p_i^{-\sigma} \mu E}{P^{1-\sigma}}, \tag{5}$$

where $P \equiv \left(\sum_{j \neq i} p_j^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$ is a CES price index of manufacturing products and E total expenditures.

Letting Y be numeraire, we get the following demand for Y:

$$C_Y = (1-\mu) E. \tag{6}$$

4.3 Profit Maximization of Firms

With symmetric firms operating in the two countries, H and F, the price index in a region j reduces to:

$$P_j = \left[\sum_g n_j^g (p_j)^{1-\sigma} + \sum_g n_k^g (\tau p_k)^{1-\sigma} \right]^{1/(1-\sigma)}, \; j = H, F, \; k = H, F, \; j \neq k, \; g = n, m \tag{7}$$

where n_j^g is the number of high-tech producing firms in country j (superscript g denotes national or multinational). Trade in X is assumed to involve an iceberg type of transaction

[16] Following e.g. Neary (2001), we assume a finite number of varieties instead of defining the subutility function C_X over a continuum of varieties. This requires a sufficiently large number of firms for us to be able to approximate the elasticity of demand by σ (see Helpman and Krugman, 1985, Chapter 6).

cost denoted by $\tau \geq 1$ (for one unit to arrive, τ units must be shipped).

First-order conditions for profit maximizing by a firm producing in country j are given by:

$$p_j \left(1 - \frac{1}{\sigma}\right) = \gamma w_{Sj}^{\alpha} w_{Lj}^{1-\alpha} \tag{8}$$

where σ is the price elasticity of demand. Free entry and exit and a continuous number of firms imply that in equilibrium, all active firms make zero profits. At the same time, these assumptions imply that a type of firm that is not active in equilibrium, must make negative profits. This means that we have the following complementary slackness condition:

$$\Pi_j^g \leq 0 \qquad n_j^g \geq 0 \qquad \text{and} \qquad \Pi_j^g n_j^g = 0. \tag{9}$$

Given the pricing condition (8), the profits of a national enterprise in country j are:

$$\Pi_j^n = \left(p_j - \gamma w_{Sj}^{\alpha} w_{Lj}^{1-\alpha}\right)\left(X_{jj} + \tau X_{jk}\right) - w_{Sj}^{\alpha} w_{Lj}^{1-\alpha}\beta - w_{Sj}\left(1 - \delta + \delta(n_j^n + n_k^m)\right)^{-1}, \tag{10}$$

where the first subscript of X_{jj} denotes the location of the production plant and the second the market where the final good is sold. The second term in (10) represents the fixed costs in production and the third term the cost of producing one unit of R. Profits of a multinational enterprise locating production in country j but R&D in country k are given by:

$$\Pi_j^m = \left(p_j - \gamma w_{Sj}^{\alpha} w_{Lj}^{1-\alpha}\right)\left(X_{jj} + \tau X_{jk}\right) - w_{Sj}^{\alpha} w_{Lj}^{1-\alpha}\beta - w_{Sk}\rho^m\left(1 - \delta + \delta(n_k^n + n_j^m)\right)^{-1}.$$

4.4 Equilibrium

The equilibrium conditions used to solve the model are first-order conditions, zero profit conditions (in complementary slackness form) and conditions for the clearing of factor and goods markets. To solve for the equilibrium, we use the following system of equations for $j = H, F$, $k = H, F$, $j \neq k$

$$P_j = \left[\left(n_j^n + n_j^m\right) p_j^{1-\sigma} + \left(n_k^n + n_k^m\right)\left(p_k \tau\right)^{1-\sigma}\right]^{1/(1-\sigma)} \tag{P_j}$$

$$E_j = \left(w_{Sj} S_j + w_{Lj} L_j\right) \tag{E_j}$$

$$X_{jj} = \frac{p_j^{-\sigma} \mu E_j}{P_j^{1-\sigma}} \tag{X_{jj}}$$

$$X_{jk} = \frac{(p_j \tau)^{-\sigma} \mu E_k}{P_k^{1-\sigma}} \tag{X_{jk}}$$

$$\gamma \left(w_{Sj}^{\alpha} w_{Lj}^{1-\alpha} \right) = p_j \left(1 - \frac{1}{\sigma} \right) \tag{p_j}$$

$$w_{Sj} \left(1 - \delta + \delta (n_j^n + n_k^m) \right)^{-1} + \left(w_{Sj}^{\alpha} w_{Lj}^{1-\alpha} \right) \left(\gamma \left(X_{jj} + \tau X_{jk} \right) + \beta \right) \geq p_j \left(X_{jj} + \tau X_{jk} \right) \tag{n_j^n}$$

$$w_{Sk} \left(1 - \delta + \delta (n_k^n + n_j^m) \right)^{-1} \rho^m + \left(w_{Sj}^{\alpha} w_{Lj}^{1-\alpha} \right) \left(\gamma \left(X_{jj} + \tau X_{jk} \right) + \beta \right) \geq p_j \left(X_{jj} + \tau X_{jk} \right) \tag{n_j^m}$$

$$L_j = \left(n_j^n + n_j^m \right) (1 - \alpha) \left(\frac{w_{Sj}}{w_{Lj}} \right)^{\alpha} \left(\gamma \left(X_{jj} + \tau X_{jk} \right) + \beta \right) + Y_j \tag{w_{Lj}}$$

$$\begin{aligned} S_j &= \left(n_j^n + n_k^m \rho^m \right) \left(1 - \delta + \delta (n_j^n + n_k^m) \right)^{-1} \\ &\quad + \alpha \left(\frac{w_{Lj}}{w_{Sj}} \right)^{1-\alpha} \left(n_j^n + n_j^m \right) \left(\gamma \left(X_{jj} + \tau X_{jk} \right) + \beta \right) \end{aligned} \tag{w_{Sj}}$$

$$w_{Lj} \geq 1. \tag{Y_j}$$

The associated variables are given in parenthesis after each equilibrium condition. In total, this is a system of 20 equations solving for the 20 unknowns P_H, P_F, n_H^n, n_F^n, n_H^m, n_F^m, p_H, p_F, E_H, E_F, w_{SH}, w_{SF}, w_{LH}, w_{LF}, X_{HH}, X_{HF}, X_{FF}, X_{FH}, Y_H, and Y_F.

5 Analysis

In this model, the combination of increasing returns to scale and trade costs creates a home-market effect leading to a tendency for the larger country to attract the final production of the differentiated good. As in new economic-geography models with intersectorally mobile, but regionally immobile, factors, the advantages of locating increasing returns to scale production in the larger market are strongest for intermediate levels of trade costs.[17]

Because of the tendency for the final goods production of X to become concentrated in the large country, the small country may end up having an advantage in producing R&D. That is, it may be cheaper to produce R&D in the small country because skilled labor is relatively expensive in the large country where most of the skill-intensive high-tech production takes place. However, it may still be the case that R&D becomes concentrated in the large country, since there are agglomeration economies working in the R&D sector as well.

5.1 Stability of Different Equilibria

To begin with, note that in equilibrium, there will never be multinational firms originating in both countries. If there are incentives for firms producing in country j to conduct R&D in country k, there cannot simultaneously be incentives for firms producing in country k to conduct R&D in country j.[18]

Suppose we start from a situation with only national firms. A firm producing in H (F) has no incentive to relocate its R&D activities to F (H) if the cost of separating R&D from production geographically is greater than a potential lowering of costs for R&D by locating these activities in the other country. Using the expressions for the costs of carrying out R&D activities given by the zero profit conditions, we find that this is the case if and only if the following condition holds:

$$\frac{1}{\rho^m} \leq \frac{w_{SH}}{w_{SF}} \frac{(1-\delta+\delta n_F^n)}{(1-\delta+\delta n_H^n)} \leq \rho^m. \tag{11}$$

[17] See e.g. Krugman and Venables (1995), and Venables (1996).

[18] Formally, if firms producing in H have incentives to locate R&D in F, the following condition must hold:

$$\frac{w_{SH}}{w_{SF}} \geq \rho^m \varphi,$$

where $\varphi \equiv \left(1-\delta+\delta(n_H^n+n_F^m)\right) / \left(1-\delta+\delta(n_F^n+n_H^m)\right)$. If firms producing in F have incentives to locate R&D in H, the following condition holds:

$$\frac{w_{SH}}{w_{SF}} \leq \frac{\varphi}{\rho^m}.$$

Since $1/\rho^m < \rho^m$, both conditions cannot hold simultaneously.

If this condition is satisfied, an equilibrium with only national firms is stable with respect to the potential relocation of activities.

There are three factors affecting whether (11) holds: the relative return to skilled labor in the two countries, the relative number of firms, the strength of R&D externalities as captured by δ, and the size of the separation cost, ρ^m. If follows directly from (11) that the higher the return to skilled labor in H relative to F and the larger the number of firms in F relative to H, the less likely that firms from F have incentive to relocate R&D to H, but the more likely that firms from H have incentive to relocate R&D to F. As long as $n_F^n > n_H^n$, a higher value of δ will have an effect in the same direction (i.e. making it less likely that firms have incentive to relocate R&D to H, but more likely that they have incentive to relocate R&D to F). An increase in the value of ρ^m will expand the parameter space for which an equilibrium with only national firms is stable. In order for multinational firms to arise for some parameter values, ρ^m cannot be too high.

Suppose that we start from a situation with R&D concentrated in F. In this case there are national firms from F and multinational firms carrying out R&D in F and production in H. This will constitute a stable equilibrium if a multinational firm has no incentive to relocate R&D to H. Once more, we use the expressions for the cost of carrying out R&D given by the zero profit condition to show that this will be the case if and only if:

$$\rho^m \leq \frac{w_{SH}}{w_{SF}} \frac{(1 - \delta + \delta(n_F^n + n_H^m))}{(1 - \delta)}. \tag{12}$$

Similarly, if we start from a situation with R&D concentrated in H; implying that there are national firms in H and multinational firms carrying out R&D in H and production in F; this will be a stable equilibrium if a multinational firm has no incentive to relocate R&D to F. This will be the case if and only if:

$$\frac{w_{SH}}{w_{SF}} \frac{(1 - \delta)}{(1 - \delta + (n_H^n + n_F^m))} \leq \frac{1}{\rho^m}. \tag{13}$$

With only national firms operating, the difference in country size will, through its effect on the relative size of the R&D sector, always be a factor pulling R&D labs in the direction of the larger country. However, since the presence of a home-market effect should put upward pressure on the return to skilled labor in the larger country, there may also be a counteracting force stemming from differences in factor prices, pulling R&D labs in the direction of the smaller country. Whether this force is sufficiently strong to outweigh the one related to a difference in the size of the R&D sector depends on the strength of the home market effect, which in turn depends on the level of trade costs. In the following, we shall analyze how the relative return to skilled labor in the small country varies with the level of trade costs. This analysis is done in order to bring out under what circumstances the net effect of the two opposing forces might be such that R&D labs are pulled in the direction of the small country.

Assume that both countries produce Y so that $w_{LH} = w_{LF} = 1$ and that there are only national firms operating in the high-tech sector. Using the zero-profit condition for national firms in H in the factor-market clearing condition for skilled workers, we get the following equilibrium condition:

$$S_H = n_H^n \left[\xi_H (1 + \alpha (\sigma - 1)) + \alpha \beta \sigma w_{SH}^{\alpha - 1} \right], \tag{14}$$

where $\xi_H \equiv (1 - \delta + \delta n_H^n)^{-1}$.[19]

This condition gives us the combinations of n_H^n and w_{SH} for which the demand for skilled labor equals the fixed supply. The resulting relationship between n_H^n and w_{SH} is positive (see Appendix). It is shown in Figure 2 as the upward sloping broken curve.[20]. The curve is upward sloping since a larger number of high-tech firms leads to a larger demand for skilled labor and therefore a higher return to skilled labor. The level of δ affects the location of this curve so that a higher level of δ shifts the curve to right (i.e. reduces the demand for skilled labor for a given number of firms).

{Figure 2: Stability of equilibrium with national firms only}

In order to find the equilibrium value of n_H^n and w_{SH}, we need to ensure that goods markets clear as well. Combining the zero-profit condition with supply equals demand for a representative national firm producing high-tech goods in Home gives us the following

[19] See the Appendix for the derivation of the condition.

[20] The following parameter values have been used to plot the curve: $S_H = 20$, $\delta = 0.05$, $\alpha = 0.5$, $\beta = 0.1$, $\mu = 0.7$, and $\sigma = 7.5$.

equilibrium condition:[21]

$$\frac{\sigma w_{SH}^{\alpha\sigma}\left[w_{SH}^{1-\alpha}\xi_H+\beta\right]}{\mu} = \frac{(w_{SH}S_H+L_H)}{\left[n_H^n w_{SH}^{\alpha(1-\sigma)}+n_F^n\left(w_{SF}^{\alpha}\tau\right)^{1-\sigma}\right]} + \frac{\tau^{1-\sigma}(w_{SF}S_F+L_F)}{\left[n_F^n w_{SF}^{\alpha(1-\sigma)}+n_H^n\left(w_{SH}^{\alpha}\tau\right)^{1-\sigma}\right]}. \quad (15)$$

This condition gives us the combinations of n_H^n and w_{SH} for which supply equals demand for a given number of firms and return to skilled workers in Foreign. Because of the complexity of this condition, we are unable to find closed-form solutions for n_H^n and w_{SH}, which is why we present numerical simulations in the next section.

The relationship between n_H^n and w_{SH} implicit in condition (15) may very well be a non-monotonic one (see Appendix), indicating the possibility of multiple equilibria. The ambiguity of the relationship arises for the following reason: An increase in n_H^n has two effects; a decrease in R&D costs, which implies that output per firm has to decrease in order to maintain zero profits, and a decrease in the demand for each product. It is possible that these two effects exactly net out so that market clearing is maintained without any change in w_{SH}. If the two effects do not net out, however, implying that firms are making either positive or negative profits at the given level of demand, w_{SH} has to change in order for profits to be zero when firms are selling their equilibrium level of output. Changes in w_{SH} affect demand differently depending on whether trade costs are high or low. An increase in w_{SH} close to free trade will reduce the demand for domestically produced products, since they become relatively more expensive compared to foreign ones. An increase in w_{SH} close to autarky, on the other hand, will increase the demand for domestically produced products, since it leads to an increase in income and there is only weak competition for foreign produced varieties. Whether an increase or a decrease in w_{SH} is required to maintain equilibrium in the goods market therefore depends on the level of trade costs.

It is important to note that the relationship between n_H^n and w_{SH} implicit in condition (15) depends on the level of trade costs. In Figure 2, there are three curves plotting this condition: one for free trade ($\tau = 1.0$), one for an intermediate level of trade costs ($\tau = 1.25$) and one for a high level of trade costs ($\tau = 2.0$).[22] The curvature changes from

[21] See the Appendix for the derivation of the condition.

[22] The following values of the additional parameters have been used: $\delta = 0.01$, $\alpha = 0.5$, $\beta = 0.1$,

an essentially horizontal line at free trade to more and more negatively sloped curves for higher trade costs. However, more importantly, the location of the curves differs depending on the level of τ. When the home-market effect is strong, i.e. the trade cost is at an intermediate level, the return to skilled labor consistent with goods market clearing is lower for a given number of firms compared to when it is weak, i.e. the trade cost is either low or high.

The implied equilibrium values of n_H^n and w_{SH} are such that for low and high levels of trade costs, the equilibrium price of skilled workers and the number of firms is higher than for an intermediate level of the trade cost. A low w_{SH} creates an advantage for Home in carrying out R&D activities that has to be weighed against the disadvantage of having relatively small R&D externalities.

In Figure 2, we have also drawn two thin lines showing the combinations of n_H^n and w_{SH} that make firms indifferent between being national and multinational firms for a given value of the cost for separating R&D and production; here taken to be relatively small.[23] The first line; the one furthest down of the diagram; is derived from the following equality:

$$\frac{1}{\rho^m} = \frac{w_{SH}\left(1-\delta+\delta n_F^n\right)}{w_{SF}\left(1-\delta+\delta n_H^n\right)}. \tag{16}$$

Above this line, high-tech firms operating in Foreign have no incentive to relocate R&D activities, whereas below the line they have incentive to relocate R&D to Home.

The other line; the one furthest up in the diagram; is derived from the following equality:

$$\rho^m = \frac{w_{SH}\left(1-\delta+\delta n_F^n\right)}{w_{SF}\left(1-\delta+\delta n_H^n\right)}. \tag{17}$$

Below this line, firms producing in Home have no incentive to relocate R&D activities, whereas above the line they have incentive to relocate R&D to Foreign. The value of ρ^m has been set sufficiently low for an equilibrium with only national firms to be unstable for all three levels of τ. However, whereas firms in Home have incentives to relocate R&D to Foreign for low and high levels of trade costs, it is the firms in Foreign that have incentive to relocate R&D to Home for intermediate levels of trade costs. That is, when the home-

$\mu = 0.7$, $\sigma = 7.5$, $\gamma = 1$, $S_H = 20$, $L_H = 20$, $S_F = 40$, $L_F = 40, n_F^n = 9.09$, and $w_{SF} = 0.645$. The values of n_F^n and w_{SF} have been chosen so as to be consistent with a free trade equilibrium.

[23] The lines are drawn for $\rho^m = 1.015$.

market effect is strong, there will be a tendency for firms to concentrate R&D activities in the small country.

With a higher level of ρ^m, the firms would lack incentive to relocate R&D activities for a wider range of values of w_{SH}, implying that for a sufficiently high cost of separating R&D and production, an equilibrium with only national firms would be stable irrespective of trade costs. However, the case shown in Figure 2 tells us that for small separation costs, we may get very different location outcomes depending on the level of trade costs.

5.2 Numerical Simulations

The previous section showed that, for given production costs and number of firms in Foreign, Home may end up specializing in R&D activities for a certain range of trade costs. Whereas the analysis shows the possibility of such an outcome, however, it does not establish that an equilibrium with Home specializing in R&D activities will occur when wages and number of firms in Foreign are allowed to be determined endogenously. In order to solve the full model, we rely on numerical simulations.[24] The values of crucial parameters have been chosen so that they are consistent with the previous empirical and theoretical literature.[25] The parameter ρ^m may be interpreted as the cost of transmitting technological knowledge within an MNE. The empirical literature on such costs is scarce. Teece (1977) is among the very few that provide empirical estimates on the costs of transferring technology within MNEs. He found transfer costs averaging 19 percent of the total project costs, with a considerable variation ranging from 2 to 59 percent.[26] We set $\rho^m = 1.1$, implying that separating production from R&D increases the costs involved in creating firm-specific knowledge with 10 percent. This number is somewhat arbitrarily chosen, but for the purpose of our analysis, the important aspect is that it is not so high that firms never have incentives to become MNEs, at the same time as it is greater than one, the point at which the model becomes degenerate with respect to determining firm configuration.

We are mainly interested in examining how the R&D externalities and the home-market effect interact in determining the outcome. The strength of the home-market effect depends on four different parameters: the trade cost, τ, the share of high-tech goods

[24]We use GAMS (general algebraic modeling system) (Rutherford 1995, 1999) to solve the model.

[25]In the simulations discussed below we have used the following parameter values: $\mu = 0.7$, $\alpha = 0.5$, $\beta = 0.1, \gamma = 1$, $\sigma = 7.5$, $S_H = 20$, $L_H = 20$, $S_F = 80$ and $L_F = 80$.

[26]The sample consisted of 26 projects in the manufacturing sector.

in consumption, μ, the elasticity of substitution, σ, and the relative size of countries, S^F/S^H.[27] Holding any three of these constant, variations in the fourth will affect the strength of the home-market effect. It has previously been shown that the higher the value of μ and the lower the value of σ, the greater the advantages of locating in a large region (see Krugman, 1991b). It also seems straightforward that the larger the relative size of Foreign, i.e. the higher the value of S^F/S^H (or L^F/L^H), the greater the advantages of locating in that country. However, the relative size of the countries may generate more subtle effects as well; if S^F/S^H is very high, Home's supply of skilled labor may be too small for R&D to concentrate in that region.

Our strategy is to fix the levels of μ, σ, and S^F/S^H, and then carry out the analysis of the effect of variations in the strength of the home-market effect solely in terms of changes in τ. An obvious reason for focusing on τ is that this parameter is the one most closely related to changes in policy, such as efforts to liberalize trade and integrate markets. The value of μ is set to 0.7 and of σ to 7.5. The implied budget share of high-tech goods is substantially higher than the actual share of such goods in overall consumption. However, μ should be interpreted as the share of consumption of traded goods, which may not be so far from 0.7. The value of σ is consistent with empirical estimations.[28] For the main part of the analysis, we will assume that Foreign is four times as large as Home, but we will also address the issue how the outcomes depend on the relative size of countries.

The parameter δ captures the strength of R&D externalities. With weak R&D externalities, there are weak incentives for firms to concentrate R&D activities in one of the countries. However, it makes sense to put some restrictions on how large R&D externalities can be. A natural restriction is to require that entry of an additional R&D lab leads to a positive net effect on the R&D sector's demand for skilled labor. A sufficient condition for this restriction to hold is that δ is less than the inverse of the amount of skilled labor employed in the R&D sector (see appendix). This condition holds in all the simulations presented.

[27] Note that, in this type of model, the elasticity of substitution determines the degree of scale economies, implying that choosing a particular value of σ put restrictions on possible values of the parameters in the cost function.

[28] For instance, using US data, Hanson (1998) estimated the elasticity of substitution between manufactured goods to range between about 5 and 11 based on a version of the Krugman model (1980).

5.2.1 Location of Production and R&D

Different equilibria are characterized by the different types of firms that are active, by the pattern of specialization and the concentration of R&D activities in each of the two countries. We first analyze a benchmark case with no externalities in the R&D sector, that is $\delta = 0$. This case corresponds to one of the cases analyzed by Markusen (1997); the case where countries of different size have identical relative factor endowments and trade costs are moderately high; and one of the cases analyzed by Ekholm and Forslid (2001) in a one-factor model with inter-regional factor mobility. Figure 3 shows Home's share of the total number of R&D labs and its share of total high-tech production. At free trade and high levels of trade costs, Home's share of total R&D and total high-tech production is proportional to its relative size, thereby implying that there is no specialization in either high-tech production or R&D and only national firms are active. However, at an intermediate level of trade costs, the home-market effect is relatively strong, inducing a relatively large share of firms to locate their high-tech production in the large country (F). This will tend to reduce demand for skilled labor in the small country (H), leading to a relatively low price of skilled labor. The relatively low price of skilled labor creates a factor market reason for high-tech firms to locate R&D activities in H. Hence, for intermediate levels of trade costs, there are, in equilibrium, multinational firms producing high-tech goods in the large country, while carrying out R&D in the small country. Within this range of trade costs, the large country specializes in the production of high-tech goods, while the small country specializes in R&D.[29]

{Figure 3: Benchmark case with no R&D externalities}

Another benchmark case is one where there are R&D externalities, but no trade costs. In this case, the R&D externalities create incentives for firms to locate their R&D activities in the same country. Figures 4 and 5 show that for levels of δ close to zero, both R&D activities and production activities are spread out between the countries in proportion to their size. However, beyond a certain threshold level of δ, R&D activities tend to become concentrated in one of the countries. For the distribution of overall resources assumed in Figure 4, activities agglomerate in either of the countries beyond this threshold

[29] With the size differences chosen in Figure 4, both countries produce the high-tech good for all levels of τ. However, with larger size differences between Home and Foreign, high-tech production may become completely concentrated in the large country.

level, although we cannot determine in which. With larger size differences, however, a concentration of R&D activities in the large country would be the only stable equilibrium for relatively low levels of δ, since in that case, the amount of skilled labor available in the small country would not be sufficient to support the entire R&D sector. There is also an unstable equilibrium where R&D activities are conducted in both countries. It is unstable in the sense of a small perturbation of the equilibrium creating incentives for firms of different types to exit and enter, so that we end up in one of the equilibria with total concentration of R&D activities.[30]

{Figure 4: Home's share of R&D activities in a benchmark case with free trade}

{Figure 5: Home's share of high-tech production in a benchmark case with free trade}

In order to analyze how R&D externalities and a home-market effect interact in determining the location structure, we look at cases where δ is greater than zero and τ varies from the free trade level to close to autarky. Figure 6 shows a case where R&D externalities are relatively weak ($\delta = 0.01$). As seen in this Figure, at relatively low levels of trade costs, R&D may end up being concentrated in either country. These equilibria are stable. In addition, there is an unstable equilibrium, marked by a dashed line, where R&D activities are spread out between the countries. For a range of intermediate trade costs, concentration of R&D activities in the large country is not a possible equilibrium. In this case, both concentration of R&D in the small country and dispersion of R&D are stable equilibria. For relatively high trade costs, dispersion is the only stable equilibrium. When trade costs are high, each country's share of production becomes close to its share of overall income, since firms are then mainly producing for the domestic market. This limits the scope for concentrating R&D activities since it puts restrictions on how much resources are available for carrying out R&D in each country. As a result, there are no incentives for firms to separate their R&D activities from their production activities, and all firms become purely national ones.

{Figure 6: Home's share of R&D activities for moderate R&D externalities ($\delta = 0.01$)}

[30]The issue of stability has been analyzed by examining whether the total costs for conducting R&D would increase or decrease for a firm moving its R&D activities from one country to another, keeping the location of production fixed.

In Figures 7 and 8, we show a case with stronger R&D externalities ($\delta = 0.03$). In this case, R&D externalities are sufficiently strong for making the dispersed outcome either unfeasible, or unstable. For trade costs below a certain threshold level, R&D becomes concentrated in either country, while for trade costs above that threshold level, it becomes concentrated in Foreign. Figure 8 shows Home's share of high-tech production corresponding to the distribution of R&D activities shown in Figure 7. In the equilibrium where R&D is concentrated in Foreign, Home's share of high-tech production corresponds roughly to its relative size (a little more than that close to free trade since Home will then be net exporter of high-tech products), while in the equilibrium where R&D is concentrated in Home, its share of high-tech production is much lower. Irrespective of which equilibrium we end up in, there is going to be coexistence of national firms and multinational firms carrying out their R&D activities where there is an agglomeration of R&D; or, put differently, where there is a "center of excellence".

{Figure 7: Home's share of R&D for stronger R&D externalities ($\delta = 0.03$)}

{Figure 8: Home's share of high-tech production for stronger R&D externalities ($\delta = 0.03$)}

Ultimately, we want to trace out the location outcome for all possible values of δ and τ. Figure 9 shows which types of stable equilibria exist for different combinations of values of δ and τ. For weak externalities, R&D never becomes concentrated and the only type of equilibrium that exists is one in which R&D is dispersed. For stronger externalities, there are more possibilities. For high δ and low to moderate trade costs, there are two stable equilibria where R&D concentrates in either country. For high δ and moderate to high trade costs, R&D becomes concentrated in Foreign. Moreover, within a certain range of parameter values where neither δ nor τ are too high, R&D either becomes spread out or concentrated in the small country. As externalities become stronger, the range of trade costs for which an equilibrium with a concentration of R&D in the small country can appear increases. The main conclusion emerging from this is that the combination of low trade costs and large R&D externalities create the preconditions for when a concentration of R&D activities in the small country becomes a stable equilibrium. Note, however, that it is only when R&D externalities are neither too small nor too large that the equilibrium in which R&D is concentrated in the small country is the only possible agglomerated equilibrium.

{Figure 9: Equilibrium regimes for different values of δ and τ}

5.2.2 Welfare

The Dixit-Stiglitz specification of preferences implies that a higher degree of product variation reduces the price index and the cost of attaining a given level of utility. Welfare thus increases with the number of varieties produced. The price index is also affected by the level of trade costs; both directly and through the effect on the share of imported goods. Due to the effect of the share of imports on the price index, the per capita utility tends to be higher in the large country (except in the limiting case where trade is completely costless). This effect may be even stronger when there are R&D externalities if R&D agglomerates in the small country, since the share of imports of high-tech goods from the large country will then be even higher.

The effect on welfare can be assessed by calculating per-capita utility according to the following expression:

$$u_j = \Lambda \frac{(S_j w_{Sj} + L_j w_{Lj})}{P_j^{\mu}}. \tag{18}$$

where $\Lambda = \mu^{\mu}(1-\mu)^{(1-\mu)}/(S_j+L_j)$. This expression shows that changes in welfare are due to changes in the real return to skilled and unskilled labor. In order to assess the welfare implications of ending up in an equilibrium with an agglomeration of R&D activities, we first analyze how the CES price index differ in different equilibria.

When there are R&D externalities, the degree of product variation will depend on the location of R&D activities. Product variation tends to be larger when R&D is agglomerated than when it is dispersed, since the former situation leads to larger R&D externalities. It also tends to be larger when it is agglomerated in the large country than when it is agglomerated in the small economy, the reason being that the R&D sector tends to be larger in the economy with more skilled labor. The exception to this is when the home-market effect is strong, since the large demand for skilled labor for final goods production then tends to bid up the price of skilled labor, resulting in an R&D sector that may be smaller than the one an equilibrium with R&D concentrated in the small country would generate.

Figure 10 shows the CES price index in the two countries when R&D externalities are sufficiently strong for agglomeration of R&D activities to occur even when trade costs are high ($\delta = 0.03$). As is clear from this figure, the equilibrium with R&D concentrated in Home is associated with a relatively high price index in Home, especially as trade costs become relatively high. Foreign has a lower price index, partly because it is larger and is able to produce a larger share of the goods domestically, partly because all its resources are used for final goods production. The concentration of R&D activities in Home leads to a relatively high return to skilled labor, which feeds into the price indices through the effect on prices of domestically produced varieties in Home and on prices of imported varieties in Foreign.[31] Since the prices of domestically produced varieties tend to have a relatively high weight in the CES price index, especially for high trade costs, this may also contribute to the difference in the price indices of Home and Foreign. In the equilibrium with R&D concentrated in Foreign, Home still has a higher price index than Foreign, but the difference is much smaller. Home now uses all its resources for domestic final goods production, while it is Foreign that devote part of its resources to R&D. Moreover, the return to skilled labor now tends to be lower in Home than in Foreign.

{Figure 10: Price indices in different equilibria ($\delta = 0.03$).}

The concentration of R&D activities in one country frees up resources for high-tech production in the other country, thereby leading to a relatively low import share and lower consumer prices. The country that carries out all the R&D activities, on the other hand, suffers from being able to produce less domestic varieties of the high-tech good, thereby having a relatively high import share and high consumer prices. Hence, being the host of an agglomeration of R&D activities has a negative effect on the price level, and will therefore lead to a lower real return to unskilled labor. However, it seems evident that skilled labor potentially might benefit from having a concentration of R&D activities, since it will increase the demand for skilled labor and put upward pressure on the return

[31] With an agglomeration of R&D activities in Home, the return to skilled labor has to be higher in Home than in Foreign with free trade. There is co-existence of national firms in Home and multinational firms with R&D activities in Home. Since the fixed costs for conducting R&D are higher for the multinational firms than for the national firms (because of the separation cost ρ^m), the operating profits of the multinationals must also be higher in order for the zero profit conditions for both types of firms to be satisfied. This requires that the return to skilled labor in Foreign is lower than in Home. In autarky, it also seems likely that the return to skilled labor will be higher in the country hosting an agglomeration of R&D activities. However, for intermediate trade costs, because of the effect on the demand for skilled labor of the home-market effect, the return to skilled labor may be higher in Foreign.

to skilled labor.

Figure 11 shows the real return to skilled labor in the case corresponding to Figure 10, i.e. $\delta = 0.03$. For all levels of τ in between the free trade level and the level at which an equilibrium with R&D concentrated in Home is no longer feasible, the real return to skilled labor is higher in a country if that country is the host of an agglomeration of R&D activities. For both countries, the difference is especially large for relatively high trade costs, indicating that the higher price index when hosting an agglomeration is more than compensated for by the higher return to skilled labor.

{Figure 11: The real return to skilled labor in different equilibria ($\delta = 0.03$)}

In the equilibrium with an agglomeration of R&D activities in Home, the real return to skilled labor is higher in Foreign than in Home for intermediate trade costs, whereas it is higher in Home than in Foreign for low and high trade costs. This again reflects the impact of the home-market effect, which tends to increase the return to skilled labor through its effect on demand for skilled labor in final goods production, and to lower the price index through its effect on the share of domestically produced varieties.

From this analysis, which shows the outcome in what we believe is an interesting and relevant case, we thus conclude that while skilled labor may benefit from having an agglomeration of R&D activities, unskilled labor loses because it tends to make final goods more expensive. If unskilled labor receive a relatively high weight in overall welfare, it is possible that the overall welfare effect of hosting an R&D agglomeration is negative. This welfare loss would occur even though the externality associated with R&D activities has been assumed to be purely national in scope in the sense of one firm's R&D activities only affecting other firms with R&D located in the same country. It is the interaction with the home-market effect that generates this result. Since there are two activities generating externalities at the same time as they are competing for resources, the outcome in terms of welfare depends on the relative strength of the welfare improving effects generated by the two types of externalities. Part of the benefit from R&D spillovers is global since they generate increased product variety, benefitting both countries. The effect that is purely national is to raise wages of skilled labor in the country where R&D concentrates. This then has to be weighed against the effect on consumer prices stemming from producing a smaller share of the high-tech products domestically.

5.2.3 Relative Size

The relative size of countries may affect the results obtained above. As already mentioned, the strength of the home-market effect will depend on the relative size of countries. At the same time, whether R&D can become concentrated in the smaller country will depend on whether the supply of skilled labor is sufficiently large to support the entire R&D sector.

In order to analyze how the location pattern is affected by changes in relative size, we solve the model by varying Home's share of a fixed total supply of S and L and keeping the level of trade costs and externalities constant. Figure 12 shows the case with a strong home-market effect ($\tau = 1.2$) and moderate externalities ($\delta = 0.01$). We find the same type of equilibria as shown in Figure 6. Within an interval where Home's share of overall resources is between around 0.2 and 0.4, there are three equilibria: one in which the share of R&D activities is equal to relative country size, one in which R&D tends to concentrate in the smaller country, and one (unstable) in which R&D activities are spread out disproportionately between the countries. When Home's share of overall resources is lower than 0.2, we find that the only stable equilibrium is the first one; the one in which the share of R&D activities corresponds to relative country size. Within this interval, Home is not sufficiently large to host all R&D activities and therefore, there will not be a concentration of R&D activities, although there are incentives to locate R&D in the smaller country. When Home's share of overall resources is higher than 0.4, we find an additional unstable equilibrium in which Home's share of R&D activities is small. Throughout the range in which Home's relative size is above 0.2, an equilibrium with R&D concentrated in Home is a stable equilibrium. Thus, in order for such an equilibrium to be possible, Home cannot be too small in relation to the rest of the world.

{Figure 12: Relative country size and equilibria with moderate externalities}

5.3 Discussion

The analysis in this paper shows that, in a model with completely localized R&D spillovers and a home-market effect, an equilibrium with a concentration of R&D activities in the smaller region is stable for moderate to strong R&D spillovers and low to moderate levels of trade costs. Under these circumstances, hosting an agglomeration of R&D externalities will benefit skilled labor, being the factor used in both R&D activities and high-tech production, but will be to the detriment of unskilled labor, being the factor used in high-tech production and the rest of the economy.

There are several objections one could make about the realism about the setting in which the analysis has been carried out. To begin with, R&D spillovers might not primarily affect the productivity in the innovation sector, as it has been assumed here, but instead primarily the productivity in high-tech production. If this were the case, it would create incentives for firms to locate high-tech production in the same place as R&D takes place (similarly if the spillovers for some reason would go in the other direction; from high-tech production to R&D). This could potentially be another explanation for the observed tendency for co-location of high-tech production and R&D activities, in addition to the presence of technology transfer costs within firms. However, the notion of pure knowledge spillovers are probably best captured as a productivity effect within the knowledge creation sector itself, rather than a productivity effect across sectors.

Another potential objection to the analysis is the assumption of purely national R&D spillovers. The existing research points to substantial spillovers across national borders, even if these spillovers seem to taper off with geographical distance (e.g. Keller, 2002). The main justification for focusing on purely national spillovers is that the effect of making them less national in this case is straightforward; it simply weakens the incentives for concentration of R&D activities.

Since the location outcomes are, to a large extent, affected by differentials in the return to skilled labor, it would seem natural to consider how the possibility of skilled labor to migrate across countries would affect the outcome. The analysis of the real return to skilled labor in different types of equilibria in Figure 11 suggests that incentives for skilled labor to migrate to the country hosting the agglomeration of R&D do indeed arise. Interestingly enough, these incentives are small for certain intermediate levels of trade costs in the equilibrium in which R&D agglomerates in the small country. The relatively strong-home market effects then leads to a real return to skilled labor in the large country that is roughly the same as in the small country. The fact that the two curves cross (not only once, but twice) also suggests that market integration in the form of a reduction of trade costs would lead to very different migration incentives depending on the level from which the reduction took place. To analyze this possibility explicitly is, however, beyond the scope of this paper.

While our analysis primarily deals with the geographical separation of innovation and production, it may also be applied to address the recent phenomenon of outsourcing of skill-intensive activities such as software programming from Europe and the US to low-wage countries. Much like R&D, such activities are characterized by being upstream in relation to production of the final output and involving only small transportation costs. In the context of our model, outsourcing of such activities would arise in order for the firms to take advantage of cheap skilled labor in countries that are "small" in the sense that they only contribute to a small share of the overall demand for the final product. As in the case analyzed here, we would expect that while skilled labor might lose from the reduction in the demand for skilled labor, unskilled labor is likely to gain from lower consumer prices. Consumer prices will be lower not only because there is a reduction in production costs which is passed on to consumers, but also because the consumers end up having better access to final products, as they are supplied in closer proximity to the consumers.

6 Concluding Remarks

This paper has analyzed location choice by firms operating in a high-tech sector on the assumption that there are two sources of agglomeration economies: knowledge spillovers from R&D activities and a home-market effect based on the combination of scale economies and trade costs. These two sources of agglomeration economies affect the choice of locating R&D differently from the choice of locating high-tech production. The home-market effect creates incentives for high-tech firms to concentrate production in the larger economy, while the technological externality creates incentives for firms to locate R&D labs in proximity to other R&D labs. Because skilled labor is assumed to be used in both production and R&D, the tendency for production activities to concentrate in the large country, thereby putting upward pressure on the return to skilled labor, implies that there may be advantages associated with locating R&D in the small economy. When trade costs are such that the home-market effect is particularly strong, while the technological externality is not too weak and not too strong, we get multiple equilibria: in one equilibrium, R&D activities are completely concentrated in the smaller economy and in another, they are spread out between countries. With stronger R&D spillovers, R&D becomes concentrated in either country for low to intermediate trade costs, while it becomes concentrated in the large country for high trade costs.

We also compare welfare in an equilibrium with R&D concentrated in the small country with welfare in an equilibrium with R&D concentrated in the large country. Hosting an agglomeration of R&D activities leads to a higher price index than if R&D activities are concentrated in the other country. In the former case, there is less resources available for final goods production compared to the latter. Because the consumer price index increases with the share of imported products, this implies that the price index tends to be higher. At the same time, hosting an agglomeration of R&D activities leads to a higher return to skilled labor than if R&D activities are concentrated in the other country. The latter effect may be sufficiently strong to lead to a higher real return to skilled labor, implying that while unskilled labor loses from hosting an agglomeration of R&D activities, skilled labor gains.

We started out with the observation that market size seems to have a differential impact on the location of high-tech production and R&D activities in Europe. In our model, an outcome where the attraction of high-tech production to a large economy leads to a "crowding out" of R&D activities arises for certain parameter values; more specifically, for relatively small R&D spillovers and intermediate trade costs. Whether this is in fact an accurate description of R&D spillovers and trade costs in Europe, we do not know, but it is difficult to refrain from using the analysis to speculate about the effect of a further reduction of trade costs within Europe. According to the analysis presented, a reduction in trade costs from an intermediate level would tend to reduce the advantage of the small country in specializing in R&D activities, leading to either a more dispersed outcome in terms of the location of R&D or, for higher R&D externalities, to the possibility of an agglomeration in either country, perhaps making historical factors decisive for the outcome. The reduction in trade costs would tend to lower consumer prices, thereby having a positive effect of real income. Still, skilled labor in the small country would potentially lose, because of a possible reduction in demand for this factor.

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Table 1: Results from fixed-effect regressions.

	Dep var: $HTexp$				Dep var: $R\&D$			
	Fixed effects		IV-Fixed effects		Fixed effects		IV-Fixed effects	
	Coef.	Elast.	Coef.	Elast.	Coef.	Elast.	Coef.	Elast.
MP	3.3×10^{-6}	2.39	5.3×10^{-6}	3.76	-6.3×10^{-6}	-3.50	-7.1×10^{-6}	-3.90
	(3.83)	(3.82)	(5.86)	(5.85)	(-4.32)	(-4.31)	(-3.82)	(-3.81)
$Skill$	0.215	0.145	0.230	0.149	-0.157	-0.081	-0.314	-0.162
	(1.54)	(1.54)	(1.92)	(1.92)	(-0.63)	(-0.63)	(-0.92)	(-0.92)
$R\&D$	0.414	0.54	0.358	0.44	-		-	
	(6.88)	(6.88)	(2.41)	(2.41)				
$HTexp$	-		-		1.278	0.976	1.774	1.36
					(6.88)	(6.83)	(2.60)	(2.60)
$Constant$	-33.68		-54.71		88.63		78.26	
	(-3.36)		(-5.67)		(4.64)		(4.46)	
R^2	0.80		0.83		0.68		0.63	
Number of observations	57 (16 groups)				66 (16 groups)			

Note: Figures in parenthesis are t-statistics (z-statistics for IV-estimations). Time dummies are included. Elasticities are evaluated at the mean of the independent variable. The value of R^2 is related to the within variation. As instrument for R&D we use the number of researchers in higher education as a share of the population, R&D expenditures in higher education as share of GDP and GDP per capita and as instrument for HTexp we use trade as share of GDP.

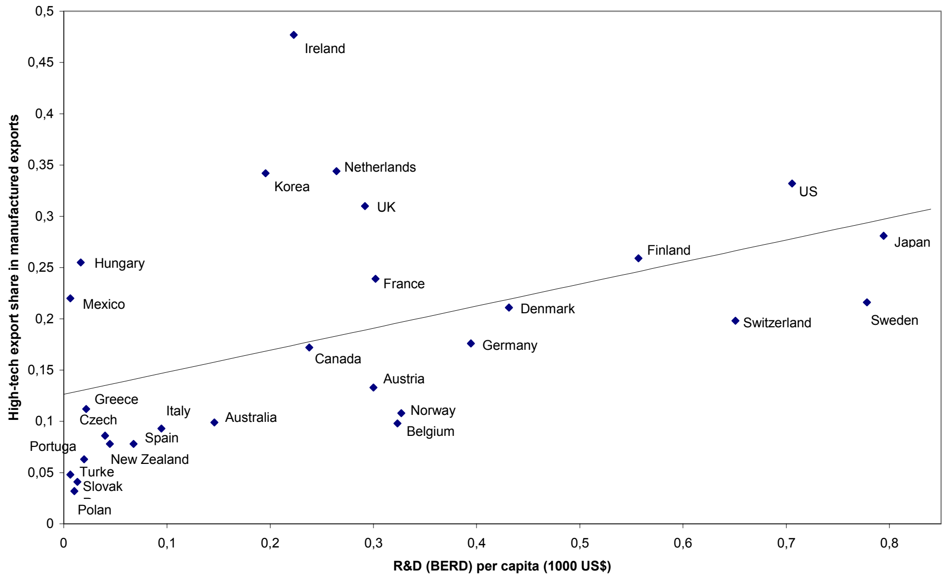

Figure 1: R&D expenditures per capita and the share of high-tech exports in total manufacturing exports 2000. [Note: The R&D figures are from 1999 for Denmark, Greece, Ireland, New Zealand, Norway, Portugal and Sweden and from 1998 for Austria. Sources: World Bank and OECD]

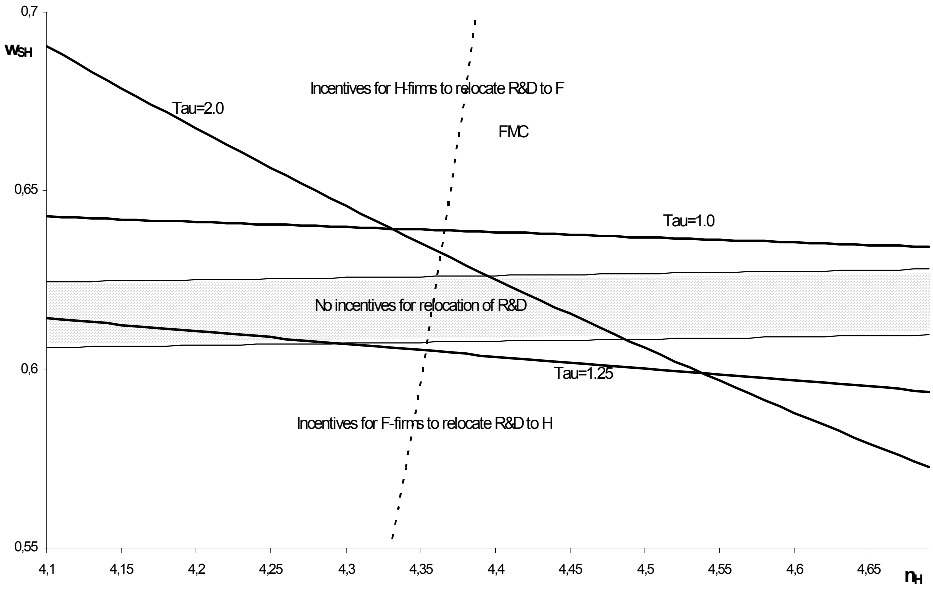

Figure 2: Stability of equilibrium with national firms.

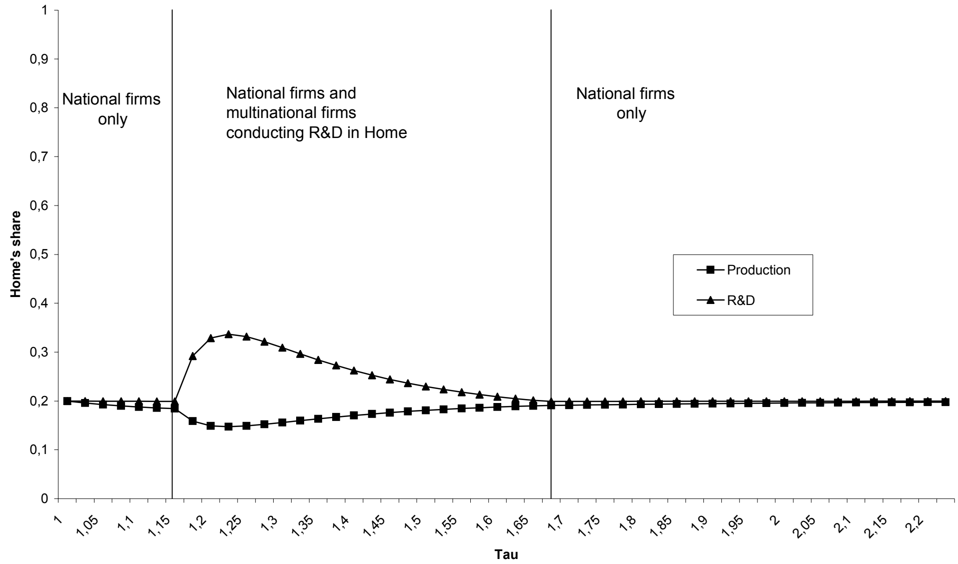

Figure 3: Benchmark case with no R&D externalities.

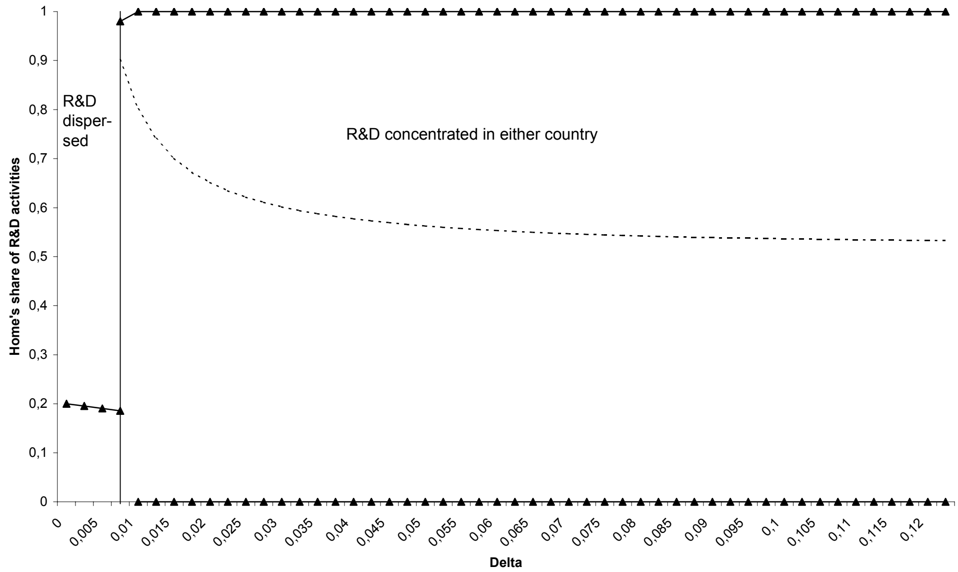

Figure 4: Home's share of R&D activities in a benchmark case with free trade.

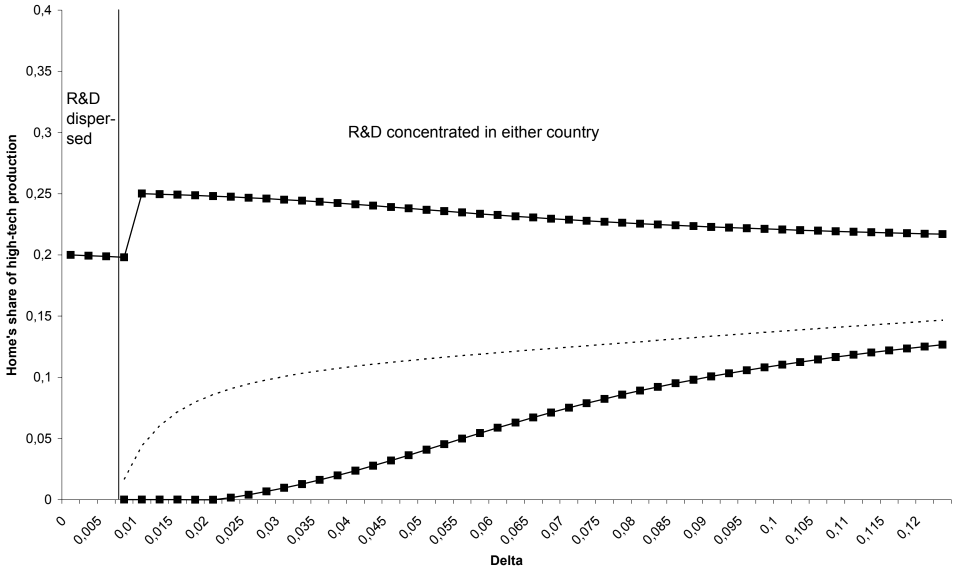

Figure 5: Home's share of high-tech production in a benchmark case with free trade.

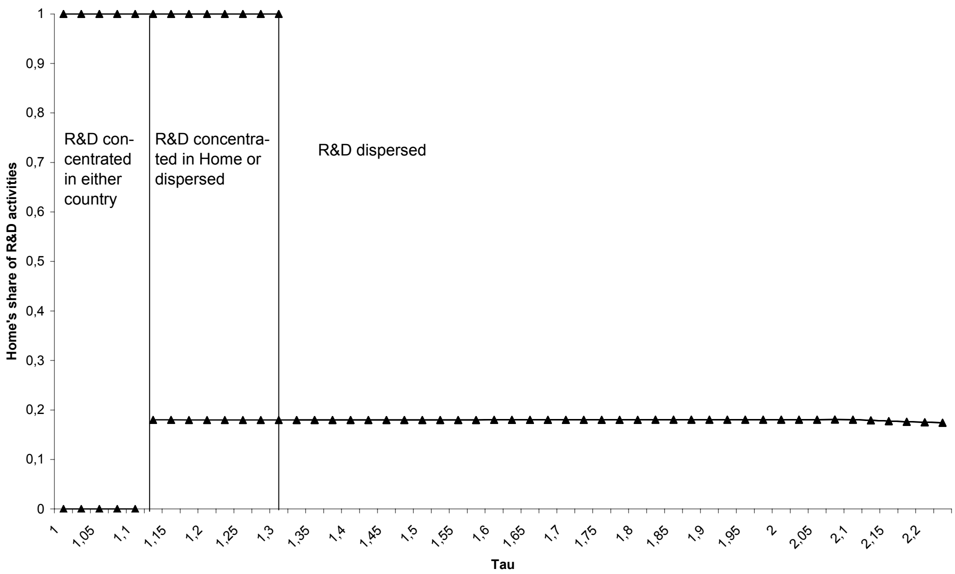

Figure 6: Home's share of R&D activities for moderate R&D externalities ($\delta = 0.01$).

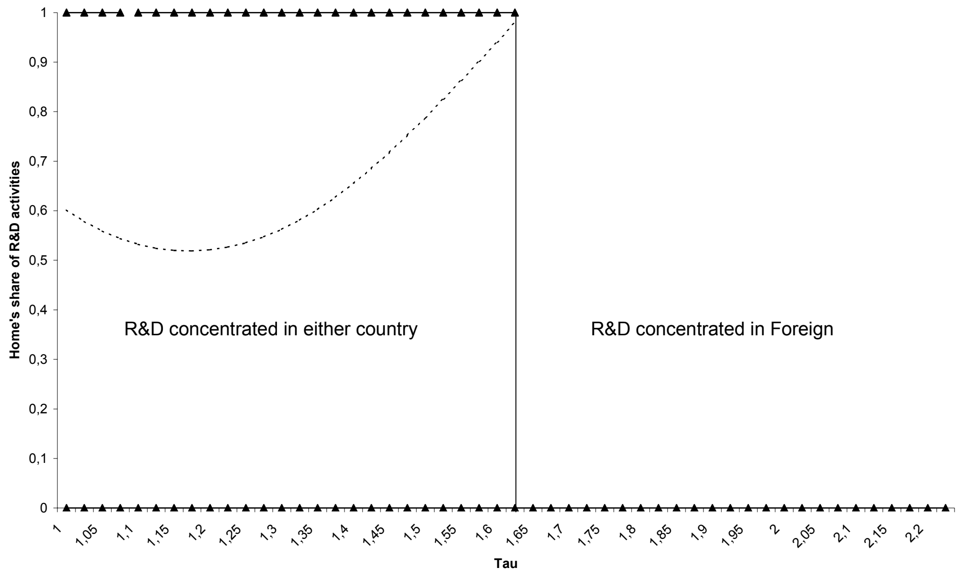

Figure 7: Home's share of R&D for stronger R&D externalities ($\delta = 0.03$).

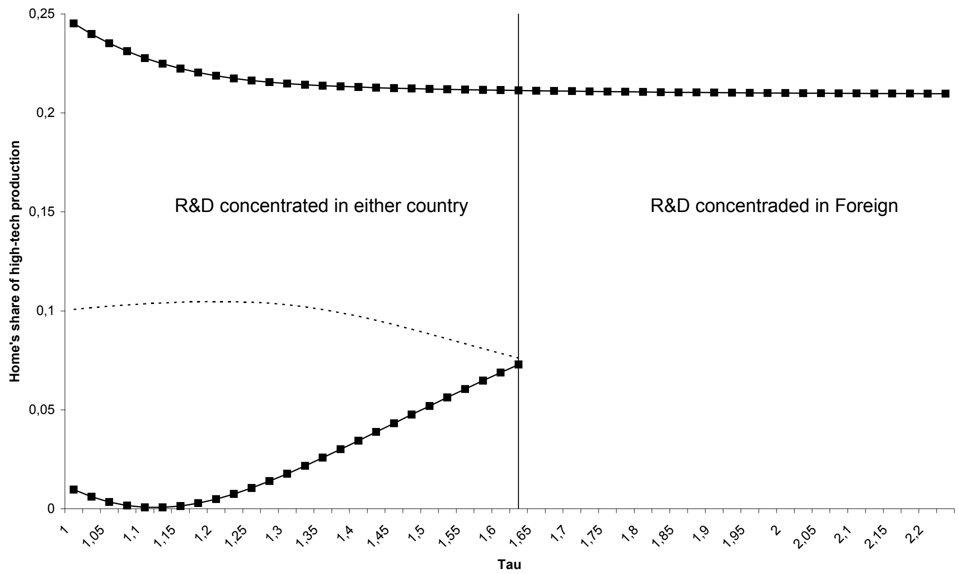

Figure 8: Home's share of high-tech production for stronger R&D externalities ($\delta = 0.03$).

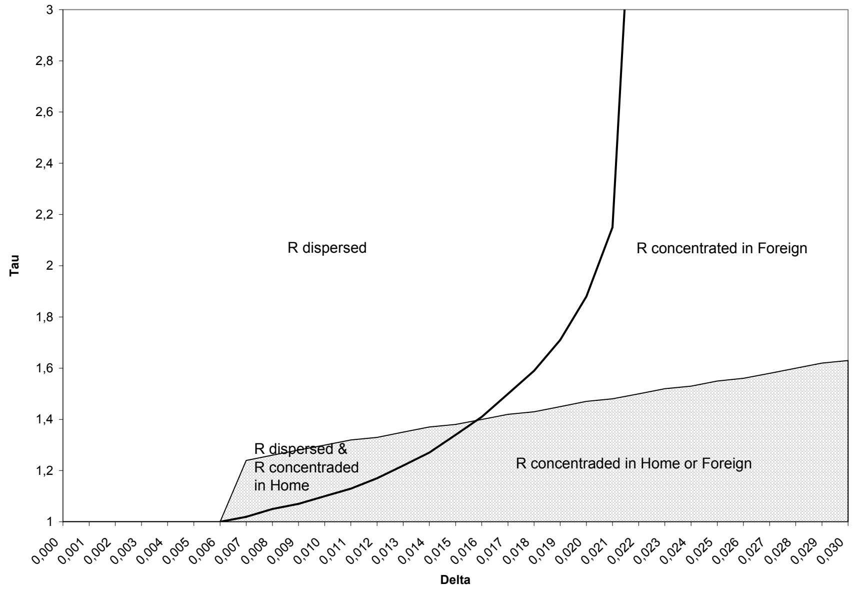

Figure 9: Equilibrium regimes for different values of δ and τ.

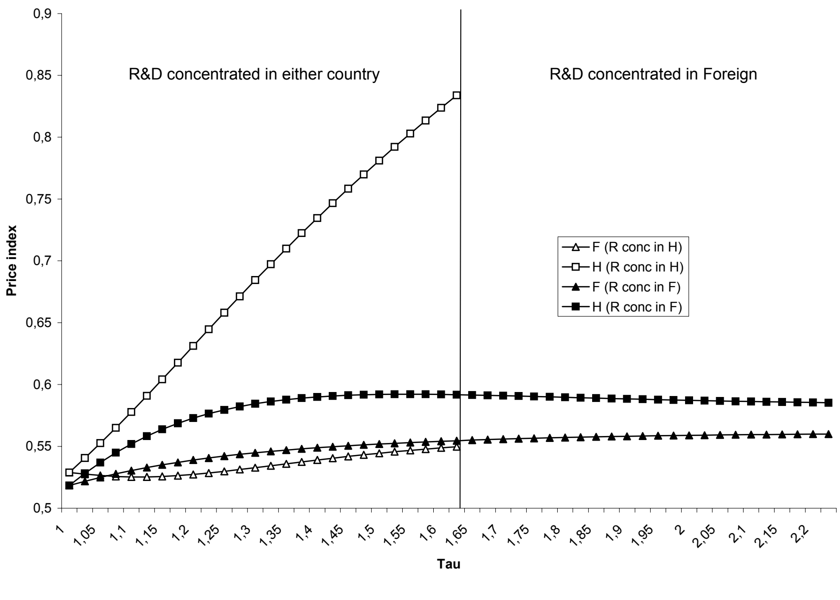

Figure 10: Price indices in different equilibria ($\delta = 0.03$).

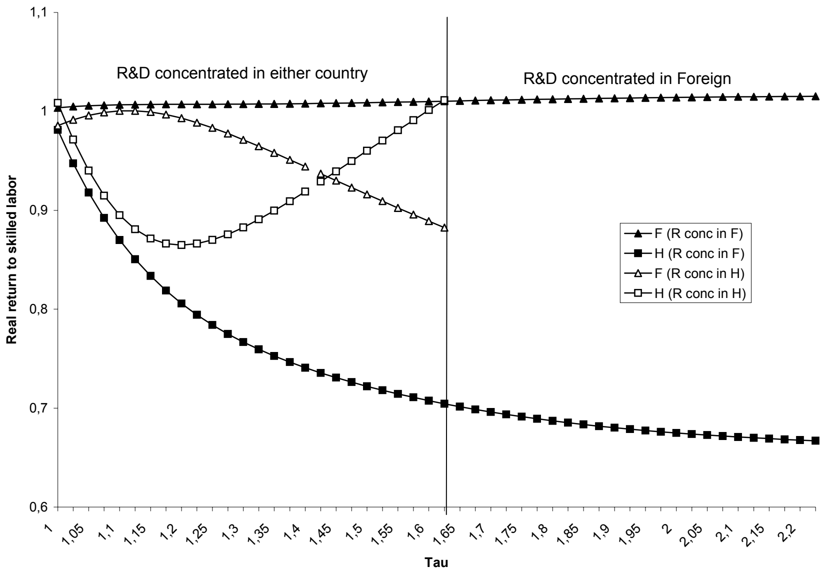

Figure 11: The real return to skilled labor in different equilibria ($\delta = 0.03$).

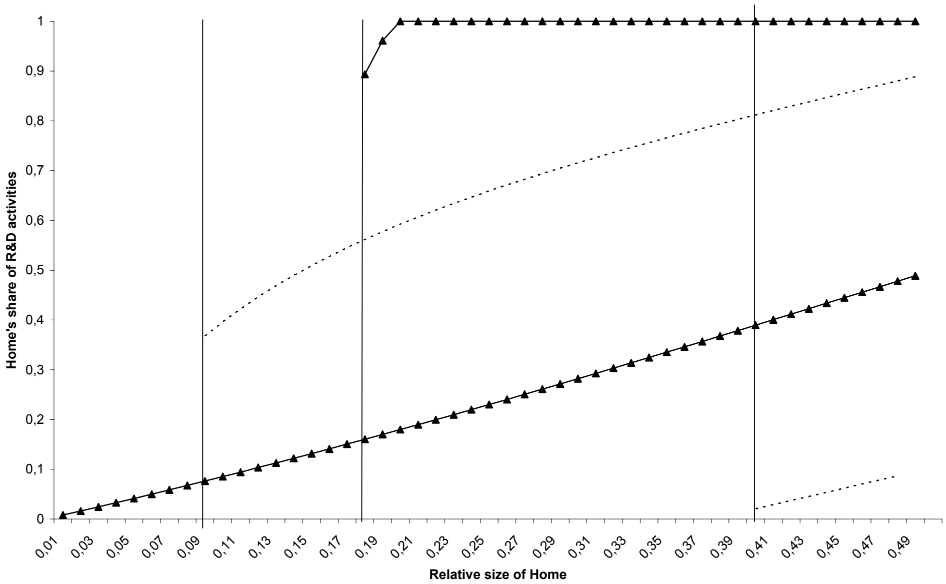

Figure 12: Relative country size and equilibria with moderate externalities.

A Appendix

Derivation of equilibrium condition (14)

Assume that both countries produce Y so that $w_{Lj} = w_{Lk} = 1$ and only national firms are operating. For country j, supply equals demand for skilled labor when:

$$S_j = n_j^n \left[\left(1 - \delta + \delta n_j^n\right)^{-1} + \alpha \left(w_{Sj}\right)^{\alpha-1} \left(\gamma \left(X_{jj} + \tau X_{jk}\right) + \beta\right) \right]. \tag{19}$$

The equilibrium price of a differentiated good is given by the first-order condition for profit maximization, which for a good produced in j can be written as:

$$p_j = \frac{\sigma \gamma w_{Sj}^{\alpha}}{\sigma - 1}. \tag{20}$$

Subtracting marginal costs for both sides gives us:

$$p_j - \gamma w_{Sj}^{\alpha} = \frac{\gamma w_{Sj}^{\alpha}}{\sigma - 1}. \tag{21}$$

Using this in the expression for total profits of a national firm yields:

$$\Pi_j^n = \frac{\gamma w_{Sj}^{\alpha} \left(X_{jj} + \tau X_{jk}\right)}{\sigma - 1} - w_{Sj} \left(1 - \delta + \delta n_j^n\right)^{-1} - \beta w_{Sj}^{\alpha}. \tag{22}$$

Setting profits to zero yields:

$$\frac{\gamma w_{Sj}^{\alpha} \left(X_{jj} + \tau X_{jk}\right)}{\sigma - 1} = w_{Sj} \left(1 - \delta + \delta n_j^n\right)^{-1} + \beta w_{Sj}^{\alpha}. \tag{23}$$

Solving for $X_{jj} + \tau X_{jk}$ gives us:

$$X_{jj} + \tau X_{jk} = \frac{\sigma - 1}{\gamma} \left[w_{Sj}^{1-\alpha} \left(1 - \delta + \delta n_j^n\right)^{-1} + \beta \right]. \tag{24}$$

Substituting $X_{jj} + \tau X_{jk}$ in (19) for the right-hand side of (24) and simplifying gives us:

$$S_j = n_j^n \left[\left(1 - \delta + \delta n_j^n\right)^{-1} \left(1 + \alpha \left(\sigma - 1\right)\right) + \alpha \beta \sigma w_{Sj}^{\alpha-1} \right], \tag{25}$$

which corresponds to expression (14).

Implicit differentiation yields:

$$\frac{dw_{Sj}}{dn_j^n} = \frac{w_{Sj}}{n_j^n(1-\alpha)} \frac{\left[(1+\alpha(\sigma-1))(1-\delta) + \left(1-\delta+\delta n_j^n\right)^2 \alpha\beta\sigma w_{Sj}^{\alpha-1}\right]}{\left(1-\delta+\delta n_j^n\right)^2 (1-\alpha)\alpha\beta\sigma w_{Sj}^{\alpha-1}} \tag{26}$$

Substituting $\left[S_j\left(1-\delta+\delta n_j^n\right) - n_j^n(1+\alpha(\sigma-1))\right]/n_j^n$ for $\alpha\beta\sigma w_{Sj}^{\alpha-1}\left(1-\delta+\delta n_j^n\right)$ in the numerator and denominator yields:

$$\frac{dw_{Sj}}{dn_j^n} = \frac{w_{Sj}}{n_j^n(1-\alpha)} \frac{\left[S_j\left(1-\delta+\delta n_j^n\right)^2 - \delta(n_j^n)^2(1+\alpha(\sigma-1))\right]}{\left(1-\delta+\delta n_j^n\right)\left[S_j\left(1-\delta+\delta n_j^n\right) - n_j^n(1+\alpha(\sigma-1))\right]} \tag{27}$$

A sufficient condition for this expression to be positive is $S_j\left(1-\delta+\delta n_j^n\right) \geq n_j^n(1+\alpha(\sigma-1))$, which holds according to (14).

Derivation of equilibrium condition (15)

Assume once more that both countries produce Y so that $w_{Lj} = w_{Lk} = 1$ and that only national firms are operating. The condition that supply equals demand for a differentiated good produced in country j is given by:

$$X_{jj} + \tau X_{jk} = \mu p_j^{-\sigma}\left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma}E_k}{P_k^{1-\sigma}}\right]. \tag{28}$$

Substituting p_j in (28) for the equilibrium price in (20) gives us:

$$X_{jj} + \tau X_{jk} = \mu\left(\frac{\sigma\gamma w_{Sj}^{\alpha}}{\sigma-1}\right)^{-\sigma}\left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma}E_k}{P_k^{1-\sigma}}\right], \tag{29}$$

which can be rewritten as:

$$X_{jj} + \tau X_{jk} = \frac{\mu}{w_{Sj}^{\alpha\sigma}}\left(\frac{\sigma-1}{\sigma\gamma}\right)^{\sigma}\left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma}E_k}{P_k^{1-\sigma}}\right] \tag{30}$$

Substituting the left-hand side of (30) for $X_{jj} + \tau X_{jk}$ given by the zero profit condition in (24), gives us:

$$\frac{\sigma-1}{\gamma}\left[w_{Sj}^{1-\alpha}\xi_j + \beta\right] = \frac{\mu}{w_{Sj}^{\alpha\sigma}}\left(\frac{\sigma-1}{\sigma\gamma}\right)^{\sigma}\left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma}E_k}{P_k^{1-\sigma}}\right], \tag{31}$$

where $\xi_j = \left(1-\delta+\delta n_j^n\right)^{-1}$. This expression can be rewritten as:

$$\frac{(\sigma-1)^{1-\sigma}\sigma^{\sigma}\gamma^{\sigma-1}}{\mu} w_{Sj}^{\alpha\sigma}\left[w_{Sj}^{1-\alpha}\xi_j+\beta\right]=\left[\frac{E_j}{P_j^{1-\sigma}}+\frac{\tau^{1-\sigma}E_k}{P_k^{1-\sigma}}\right]. \tag{32}$$

Using the expression for the equilibrium price in (20), we get the following expression for the CES price index in country j:

$$P_j^{1-\sigma}=\left(\frac{\sigma\gamma}{\sigma-1}\right)^{1-\sigma}\left[n_j^n\left(w_{Sj}^{\alpha}\right)^{1-\sigma}+n_k^n\left(w_{Sk}^{\alpha}\tau\right)^{1-\sigma}\right]. \tag{33}$$

Noting that E_j is given by $w_{Sj}S_j+L_j$ and using the expression for the CES price index above, gives us the following equilibrium condition for country j:

$$\frac{\sigma w_{Sj}^{\alpha\sigma}}{\mu}\left[w_{Sj}^{1-\alpha}\xi_j+\beta\right] = \frac{(w_{Sj}S_j+L_j)}{\left[n_j^n\left(w_{Sj}^{\alpha}\right)^{1-\sigma}+n_k^n\left(w_{Sk}^{\alpha}\tau\right)^{1-\sigma}\right]} \tag{34}$$

$$+\frac{\tau^{1-\sigma}(w_{Sk}S_k+L_k)}{\left[n_k^n\left(w_{Sk}^{\alpha}\right)^{1-\sigma}+n_j^n\left(w_{Sj}^{\alpha}\tau\right)^{1-\sigma}\right]}, \tag{35}$$

corresponding to condition (15) in the text.

Implicit differentiation yields:

$$\frac{dw_{Sj}}{dn_j^n}=\frac{\left[\mu w_{Sj}^{\alpha(1-\sigma)}\Psi_j-\sigma\delta w_{Sj}^{1+\alpha(\sigma-1)}\xi_j^2\right]}{\Lambda}, \tag{36}$$

where

$$\Lambda=\left[\mu S_j\Phi_j^{-1}+\alpha\mu(\sigma-1)n_j^n w_{Sj}^{\alpha(1-\sigma)-1}\Psi_j-\sigma w_{Sj}^{\alpha(\sigma-1)}\left(\alpha\sigma\beta w_{Sj}^{\alpha}+(1+\alpha(\sigma-1))\,\xi_j\right)\right], \tag{37}$$

$\Phi_j=\left[n_j^n\left(w_{Sj}^{\alpha}\right)^{1-\sigma}+n_k^n\left(w_{Sk}^{\alpha}\tau\right)^{1-\sigma}\right]$, and $\Psi_j=\frac{E_j}{\Phi_j^2}+\frac{\tau^{2(1-\sigma)}E_k}{\Phi_k^2}$. This expression is not very informative about the nature of the relationship between w_{Sj} and n_j^n as goods market clearing prevail. However, it shows that for low δ (implying a positive value of the numerator), we would expect a positive relationship for high n_j^n, whereas the relationship might be negative for low values of n_j^n. This potential non-monotonicity indicates the possibility of multiple equilibria.

Deriving condition for restricting the level of δ

Aggregate demand for skilled labor in R&D activities in country j can be expressed as:

$$\overline{S}_{Rj} = \left(n_j^n + \rho^m n_k^m\right)\left(1 - \delta + \delta(n_j^n + n_k^m)\right)^{-1} \tag{38}$$

In order for aggregate demand to increase with the number of R&D labs, the effect of a marginal increase in the number of firms carrying out R&D activities in country j has to be positive:

$$\frac{\partial \overline{S}_{Rj}}{\partial n_j^n} = \frac{1}{\left(1 - \delta + \delta(n_j^n + n_k^m)\right)}\left(1 - \delta \overline{S}_{Rj}\right) > 0, \tag{39}$$

and

$$\frac{\partial \overline{S}_{Rj}}{\partial n_k^m} = \frac{1}{\left(1 - \delta + \delta(n_j^n + n_k^m)\right)}\left(\rho^m - \delta \overline{S}_{Rj}\right) > 0. \tag{40}$$

The first of these conditions is the most restrictive. It implies the following condition:

$$\delta < \frac{1}{\overline{S}_{Rj}}. \tag{41}$$

which, by substituting $\overline{S}_{Rj}$ for the right hand side of expression (38), can be rewritten as:

$$\delta < \frac{1}{\left(1 + n_k^m \left(\rho^m - 1\right)\right)} \leq 1. \tag{42}$$

In the absence of any multinational firms ($n_k^m = 0$), a sufficient condition for aggregate demand to increase with R&D is $\delta < 1$. However, in the presence of multinational firms, the condition becomes more restrictive.

B Appendix

Table 2: Summary Statistics

	Obs	Mean	Std. Dev.	Min	Max
MP	66	1.25×10^7	4260797	6006190	2.20×10^7
$Skill$	66	11.667	4.390	4.000	25.000
$R\&D$	66	22.642	12.972	1.625	63.703
$HTexp$	66	17.312	10.876	3.800	46.900
RHE	57	0.840	0.317	0.379	2.013
$GDPcap$	66	19891.36	3430.59	12307.47	26607.16
$HERD$	66	0.386	0.130	0.170	0.810
$Trade$	66	70.698	32.547	36.034	163.568

Note: Data for $Skill$ in 1990 is from 1989. RHE is the number of full-time equivalent researchers in higher education per 1000 population, $GDPcap$ GDP per capita, $HERD$ R&D expenditures in higher eduction as a share of GDP and $Trade$ foreign trade as a share of GDP.

Table 3: Correlation Table

	MP	$Skill$	$R\&D$	$HTexp$	RHE	$GDPcap$	$HERD$	$Trade$
MP	1.000							
$Skill$	0.384	1.000						
$R\&D$	0.430	0.267	1.000					
$HTexp$	0.240	0.212	0.240	1.000				
RHE	0.665	0.370	0.665	0.018	1.000			
$GDPcap$	0.739	0.465	0.739	0.184	0.482	1.000		
$HERD$	0.798	0.468	0.798	0.077	0.639	0.639	1.000	
$Trade$	0.225	0.234	0.080	0.630	0.073	0.191	0.187	1.000

Note: The sample consist of 57 observations. RHE is the number of full-time equivalent researchers in higher education per 1000 population, $GDPcap$ GDP per capita, $HERD$ R&D expenditure in higher eduction as a share of GDP and $Trade$ foreign trade as a share of GDP.