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

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Abstract

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 backward linkages associated with high-tech production. The latter tends to attract production to the larger economy. We show that, for relatively weak R&D spillovers and intermediate trade costs, the smaller economy tends to specialize in R&D. For certain parameterizations, both concentration and dispersion of R&D activities are possible outcomes. Hosting an agglomeration of R&D activities does not necessarily lead to welfare gains.

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, 1991). 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. An implication of this assumption is that countries with a comparative advantage in knowledge creation would also have a comparative advantage in high-tech production.[1] Figure 1 shows a plot diagram of R&D expenditures in relation to GDP, and the share of high-tech goods in total exports relative to their world-market share of exports for a number of industrialized 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 with the highest ratio between R&D expenditures and GDP, does not belong to the countries with the highest share of high-tech goods in their exports. On the opposite side,

[1] Notable exceptions in this respect are papers analyzing vertically integrated multinational firms, meaning firms loctaing different stages of their production process in different countries. Helpman (1984) developed a model where firms operating under monopolistic competition could choose to locate their headquarters separately from their production plants. In a recent paper by Markusen (1997), the same possibility arises in a more general model where firms may be either vertically or horizontally integrated and where trade costs create advantages from locating production in the proximity to consumers.

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. Since a large part of total R&D is carried out by MNEs, an immediately obvious potential explanation for these two outliers is that they reflect the tendency of MNEs to concentrate their R&D activities in their home countries while producing R&D intensive goods elsewhere.[2] Traditionally, R&D activities seem to have been strongly concentrated in the parent firm, implying that R&D has primarily taken place in the home country. 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. More recently, R&D activities seem to have become more dispersed in the sense of a larger share taking place outside the firms's home countries.

The apparent geographical separation between R&D and production activities suggests that an appropriate analysis of the location choice of high-tech firms should allow for such a separation. In this paper, we develop a two-country model where firms may choose to locate their R&D activities and their production plants in separate countries. Furthermore, we allow for two different sources of agglomeration economies: knowledge spillovers associated with R&D activities and backward linkages associated with the production of final goods. The backward linkage arises from the combination of increasing returns to scale in production and transaction costs associated with cross-border trade. It makes it beneficial for firms to locate their production of final goods in the larger market.[3] This aspect of the model is similar to recent models within the so-called "new economic geography" (see

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

[3] The backward linkage is related to the increase in demand arising when a firm moves its production to a certain region, while the forward linkage is related to the decrease in wage costs when nominal wages fall to compensate for falling consumer prices due to reduced imports (Krugman, 1991, Fujita et al., 1999, Chapter 5).

Fujita, Krugman and Venables, 1999).

Our model thus involves two different mechanisms creating incentives for the concentration of activities. 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 the disadvantages of locating skill-intensive activities where skilled labor is relatively expensive.

In the paper, we focus on the location of high-tech production from a small-country perspective and assume 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 pure externalities generated by R&D activities and the strength of "pecuniary" externalities generated by linkages, thereby being able to address issues related to the ambition of many small, industrialized countries of attracting high-tech production. 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 discuss related literature on the location of high-tech industries. Section 3 presents and discusses the model, while section 4 analyzes the location choice by high-tech firms. Finally, section 5 concludes.

2 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).

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 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 were 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 the net exporter of headquarter services because skill-intensive headquarters activities tend to be located there.

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 headquarter 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 the large country when trade costs create benefits from producing in proximity to the consumer.

Neither of these papers allow for the possibility that skill-intensive 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).

In our model, we assume knowledge spillovers generated by R&D activities to be national in scope. If they were global in scope, there would be no advantages of having local R&D activities. In fact, if technological knowledge very easily diffuses 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.[4]

Our model adds knowledge spillovers associated with R&D activities to an analysis of the location choice of firms. The firms are potentially vertical MNEs in the sense that they may choose to geographically separate their R&D activities from their production of final goods. 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). This type of technological externality may interact with a home-market effect in a mutually reinforcing way. However, at the same time, if

[4] See also work by Keller (2002).

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.[5] It is the interaction between these forces that is the focus of the present analysis.

3 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 firm-specific knowledge (R), produced 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.

[5] 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.

3.1 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.[6] 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.

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

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

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.

3.2 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 subutility 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.[7]

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:

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

3.3 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

[7] 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).

g denotes national or multinational). Trade in X is assumed to involve an iceberg type of transaction 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:

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

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:

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

3.4 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 $j = H, F$, $k = H, F$, $j \neq k$

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

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

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

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

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

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

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

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

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

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

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.

4 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.[8]

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.

4.1 Stability of equilibria with only national firms

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.[9]

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

[9] Formally, if firms producing in H have incentives to locate R&D in F, the relative return to skilled labor in Home (w_{SH}/w_{SF}) must be greater than $\rho\varphi$, where $\varphi \equiv (1+\delta(n_H-1))\,/\,(1+\delta(n_F-1))$, $n_H = n_H^n + n_F^m$ and $n_F = n_F^n + n_H^m$. If firms producing in F have incentives to locate R&D in H, the relative return to skilled labor in Home must be smaller than φ/ρ. Since $1/\rho < \rho$, both conditions cannot hold simultaneously.

Suppose we start from a situation with only national firms. Assuming H to be a smaller economy than F (i.e., H has less endowments of S and L than F), conducting R&D in F will require smaller inputs of skilled workers because the technological externality is larger. This means that there may be incentives for firms producing in H to become multinationals by instead locating their R&D activities in F. However, in order for a situation with only national firms to be an equilibrium, there cannot be any such incentives. This means that the costs of producing one unit of R must be at least as high in F as in H, which requires that the following condition holds:

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

If the condition in (11) is satisfied, the reduction in production costs stemming from stronger spillovers and possibly a lower return to skilled labor in the large country is not sufficient to compensate for the additional costs arising from a geographical separation between R&D and production. There are three factors affecting whether (11) holds: the relative return to skilled labor in the two countries, the relative number of firms and the strength of R&D externalities as captured by δ. 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 higher the value of the left-hand side of the condition in (11) and the less likely it is to be satisfied. It is also clear that as long as $n_F^n > n_H^n$, a higher value of δ will increase the value of the left-hand side of (11).[10] It follows from this that whether firms producing in the small country have incentives to locate R&D in the large country depends on the difference in size between the countries, the strength of R&D externalities and the relative return to skilled labor. While differences in size and the strength of R&D externalities are given by parameters of the model, the relative return to skilled labor is endogenously determined and, in particular, affected by the level of trade costs.

[10] We will assume that the parameter δ can take values between zero and one.

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:

$$S_H = n_H^n \left[\xi_H (1 + \alpha (\sigma - 1)) + \alpha \beta \sigma w_{SH}^{\alpha - 1} \right], \tag{12}$$

where $\xi_H \equiv (1 - \delta + \delta n_H^n)^{-1}$.[11]

This condition gives us the combinations of n_H^n and w_{SH} for which the demand for skilled labor equals the fixed supply. It is shown in Figure 2 as the upward sloping broken curve.[12]. The curve is upward sloping since a larger number of high-tech firms leads to a larger demand for skilled labor, implying an increased relative price of skilled labor being needed to restore equilibrium in the factor market. The level of δ affects the location of this curve so that a higher level of δ shifts the curve downwards (i.e. reduces the

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

[12] 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 $\sigma = 7.5$.

demand for skilled labor for a given number of firms).

{Figure 2: Goods and factor-market clearing 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 in Home gives us the following equilibrium condition:[13]

$$\frac{\sigma w_{SH}^{\alpha\sigma}\left[w_{SH}^{1-\alpha}\xi_H+\beta\right]}{\mu} = \frac{(w_{SH}S_H+L_H)}{\left[n_H^n w_{SH}^{\alpha(1-\sigma)}+n_F^n\left(w_{SF}^{\alpha}\tau\right)^{1-\sigma}\right]} + \frac{\tau^{1-\sigma}(w_{SF}S_F+L_F)}{\left[n_F^n w_{SF}^{\alpha(1-\sigma)}+n_H^n\left(w_{SH}^{\alpha}\tau\right)^{1-\sigma}\right]} \tag{13}$$

This condition gives us the combinations of n_H^n and w_{SH} for which supply equals demand in the market for high-tech goods for a given number of firms and return to skilled workers in Foreign. As is evident from (13), this condition is affected by 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 ($\tau = 2.0$).[14] 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.[15] This implies that for low and high

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

[14] The following values of the additional parameters have been used: $\delta = 0.05$, $\alpha = 0.5$, $\beta = 0.1$, $\mu = 0.7$, $\sigma = 7.5$, $\gamma = 1$, $S_H = 20$, $L_H = 20$, $S_F = 40$, $L_F = 40, n_F^n = 12.79$, and $w_{SF} = 0.65$. The values of n_F^n and w_{SF} have been chosen so as to be consistent with a free trade equilibrium.

[15] This is true at least when δ is sufficiently low and the given number of firms is close to the equilibrium value. For relatively high levels of δ, however, increases in τ lead to

levels of trade costs, the equilibrium price of skilled workers may be sufficiently high in Home as compared to Foreign for high-tech firms producing in Home to want to shift the location of their R&D activities to Foreign. For intermediate levels of trade costs, on the other hand, it is less likely that the firms will have incentives to shift the location of R&D, since the equilibrium price of skilled workers is lower. In Figure 2, the return to skilled labor in Foreign has been set to 0.65, which is the equilibrium value generated by the full model in free trade. This means that for the parameter values chosen, the return to skilled labor will actually be lower in Home than in Foreign for all three levels of trade costs. For high-tech firms considering moving their R&D activities to the larger country, there is thus a trade-off: the amount of skilled workers they must employ will be smaller but the wage they must pay will be higher. If the technological externality is relatively small so that the former effect is weak, it may even be the case that high-tech firms producing in Foreign have incentives to move their R&D labs to the smaller country in order to take advantage of the lower costs of hiring skilled workers. If this were the case, the small country would become specialized in conducting R&D while a substantial part of actual high-tech production would take place in the large country.

4.2 Numerical Simulations

The previous section showed that for given production costs and number of firms in Foreign, there may be incentives to locate R&D in Home. Whereas the analysis shows the possibility of an equlibrium where Home is specialized in R&D activities, it does not establish that such an equilibrium will occur when wages and number of firms in Foreign are allowed to be determined endogenously. In order to solve the full model, however, we have to rely on numerical simulations.[16] Different equilibria are characterized by the different types of firms that are active (national firms located in H and F will be denoted by n_H and n_F, respectively, whereas multinational firms

successive downward shifts of the goods market clearing curve.

[16] In the simulations discussed below we have used the follwing parameter values: $\mu = 0.9$, $\alpha = 0.5$, $\beta = 0.1, \gamma = 1$, $\sigma = 7.5$, $\rho = 1.1$, $S_H = 20$, $L_H = 20$, $S_F = 80$ and $L_F = 80$.

producing high-tech goods in H and F will be denoted by m_H, and m_F), by the pattern of specialization and the concentration of R&D activities in each of the two countries. We are mainly interested in the two parameters δ and τ, one capturing the strength of R&D externalities and the other the strength of the home-market effect (although not in a monotonic way). That is, we solve the model for different values of parameters δ and τ. With weak R&D externalities, there are weak incentives for firms to concentrate R&D activities in one of the countries. Close to free trade and autarky, the home-market effect is weak and therefore, there are only weak incentives for firms to concentrate their production activities in the large country. However, at the intermediate levels of trade costs, the home-market effect is relatively strong, which implies that firms have an incentive to locate the production of high-tech goods in the large country.

4.2.1 Location of Production and R&D

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), namely that countries of different size have identical relative factor endowments and trade costs are moderately high. 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 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). As was clear from Figure 2, this implies that the price of skilled labor tends to increase, creating a factor market reason for high-tech firms to locate R&D activities in the small country (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.[17]

{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 regions beyond this threshold 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.[18]

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

[17] With the size differences chosen in Figure 2, 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.

[18] 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.

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

In order to analyze how R&D externalities and agglomeration economies created by a home-market effect interact in determining the location structure, we look at cases where we either keep the degree of R&D externalities fixed, varying the level of trade costs, or *vice versa*. First, we choose a relative country size that does not prevent a concentration of R&D activities in the smaller country due to a resource restriction. Figure 6 shows a case where we keep R&D externalities at a constant level; a relatively low one in this particular case ($\delta = 0.01$). The R&D externalities create incentives for firms to locate their R&D activities in the same country at the same time as they have an incentive to locate production in the large country for intermediate levels of trade costs. As seen in Figure 6, at relatively low levels of trade costs, we get an agglomeration of R&D in either the large or the small country. In addition, there is an unstable equilibrium, marked by a dashed line, where R&D activities are spread between the countries. For a range of intermediate trade costs where the home-market effect is particularly strong, a concentration of R&D activities in the large country is not possible, however. In this case, both agglomeration of R&D in the small country and dispersion of R&D are stable equilibria. For relatively high trade costs, both countries will be engaged in producing high-tech products since high-tech firms are mainly producing for their domestic market. In this situation, both high-tech production and R&D are spread and there is no agglomeration of either high-tech activity.

{Figure 6: Case with moderate R&D externalities}

In Figures 7 and 8, we have assumed stronger R&D externalities ($\delta = 0.2$). As is clear from these figures, agglomeration of R&D is the outcome for all levels of τ. Once more, we cannot determine whether R&D becomes concentrated in the large or the small country, and there is an unstable equilibrium where R&D activities are spread between the countries. Irrespective of whether R&D concentrates in H or F, however, there is a tendency for F to specialize in high-tech production for intermediate levels of τ because of the home-market effect (see Figure 8).

{Figure 7: Home's share of R&D for relatively strong R&D externalities}

{Figure 8: Home's share of high-tech production for relatively strong R&D externalities}

Figure 9 shows Home's share of R&D activities in the case where we keep trade costs fixed at a level where the home-market effect is especially strong and let the parameter δ vary. From Figure 3, we know that we should find an equilibrium where the small country specializes in R&D activities and the large country in high-tech production for low levels of δ. This is also what we find in Figure 9. For high levels of δ, we find an agglomeration of R&D activities in either country and an unstable equilibrium with R&D activities spread out, just as would be expected from Figure 7. Within a certain range of δ, however, we now have a case of multiple equilibria in the sense of both concentration and dispersion of R&D being possible. R&D may be concentrated in the small country or may become spread out to both countries. However, it cannot become concentrated in the large country because the home-market effect creates a tendency for high-tech production to be located in the large country, which puts upward pressure on the return to skilled labor there. Only if R&D spillovers are sufficiently strong, the advantages of locating R&D in proximity to other R&D labs in the large country outweigh the disadvantage of incurring higher costs for inputs of skilled labor.

{Figure 9: Home's share of R&D for strong home-market effect}

{Figure 10: Home's share of high-tech production for strong home-market effect}

From Figure 10, which shows Home's share of high-tech production, we see that for a sufficiently high level of δ, the small country may produce high-tech goods even when R&D activities are completely concentrated there. The reason is that high levels of δ are associated with relatively low demand for skilled labor from the R&D sector. This means that the return to skilled labor in the smaller country becomes sufficiently low for some firms to find it profitable to produce high-tech goods in the smaller market.

4.2.2 Product Variation and 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 in 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:

$$u_j = \frac{\mu^{\mu}(1-\mu)^{(1-\mu)}(w_{Sj} + w_{Lj})}{P_j^{\mu}}. \tag{14}$$

In order to assess the welfare implications, we first analyze the degree of product variation associated with different equilibria. When there are no R&D externalities at all, the number of produced varieties only varies marginally with changes in trade costs. The degree of product variation is highest in free trade and autarky and lowest for intermediate levels of trade costs where the resources spent on shipping the high-tech good reduce the resources available for developing varieties. However, 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 and it is larger when it is agglomerated in the large country than when it is agglomerated in the small economy. However, as shown in Figure 11, it is possible that the degree of product variation is higher when R&D agglomerates in the smaller country. This occurs when R&D externalities are relatively strong ($\delta = 0.2$) and trade costs are such that the home-market effect is strong. In this case, there are especially strong incentives for firms to locate their production of high-tech goods in the large country, leading resources to be freed up in the small country to conduct more R&D. More R&D leads to more varieties, and therefore the degree of product variation is the highest in such a situation.

{Figure 11: The degree of product variation for relatively strong R&D spillovers}

Now, we use equation (14) to analyze the level of per-capita utility in both countries in the different equilibria. Figure 12 shows the case where there are relatively strong spillovers ($\delta = 0.2$). Naturally, welfare is at a generally higher level as compared to the case without spillovers. Furthermore, irrespective of where R&D ends up being concentrated, Foreign's welfare is higher than Home's for all levels of τ but the free trade level. However, whether the welfare of a particular country is higher in one type of equilibrium as compared to another depends crucially on the level of trade costs. As shown by the location of the curves in Figure 12, for relatively low levels of τ, welfare is the lowest in Home and the highest in Foreign when R&D activities are concentrated in Home. For relatively high levels of τ, on the other hand, it is the other way around, welfare is the highest in Home and the lowest in Foreign when R&D activities are concentrated in Home.

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. Thus, in this setting, becoming specialized in R&D activities is not necessarily associated with welfare gains. As shown in Figure 12, a country suffers a welfare loss from being specialized in R&D activities for low and intermediate levels of trade costs.[19]

At the same time, the concentration of R&D activities in one country puts upward pressure on the return to skilled labor in that country. Apart from having a positive effect on income, this also makes it more costly to separate R&D activities from production, since these costs are incurred in terms of skilled labor. When the home-market effect is relatively strong, this effect is outweighed by the strong incentives for producing high-tech goods in the larger Foreign for firms with R&D activities in Home. However, when the home-market effect is relatively weak, as it is for high trade costs, the higher costs associated with the multinational strategy changes the composition of high-tech production so that relatively more production takes place in Home and relatively less in Foreign. The consequence of this is lower consumer prices in Home and higher in Foreign, which is why, for higher levels of τ, Home's welfare tends to be higher and Foreign's lower when R&D is concentrated in Home.[20]

[19] The exception to this is at the free trade level, where the country hosting an agglomeration of R&D will have a higher return to skilled labor. In this case, there will co-existence of national firms and multinational firms with R&D activities in one country. 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), the costs associated with plant production must be lower for the multinationals in order for the zero profit conditions for both types of firms to be satisfied. This implies that the return to skilled labor in the country where the multinational firms carry out their plant production has to be lower than in the country where they carry out their R&D. As is evident from Figure 12, however, the difference in per-capita utility is very small.

[20] We have also analyzed the welfare implications of different equilibria at moderate R&D externalities ($\delta = 0.01$). Product variation is then smaller when R&D concentrates in Home (as it only does for low/intermediate trade costs). However, Home's per-capita utility is the highest in the equilibrium in which R&D is concentrated in Home for relatively low trade costs. In this equilibrium, there is only one type of firm: multinational firms producing in Foreign and conducting R&D in Home. The positive effect of an upward pressure on wages for skilled labor in Home from the concentration of R&D activities

{Figure 12: Welfare for relatively strong R&D spillovers}

The result that specialization in R&D may be associated with a welfare loss is worth emphasizing. This welfare loss occurs 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 pecuniary externality stemming from backward linkages 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 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. Depending on the strength of R&D spillovers and the level of trade costs, Home may either lose or gain from becoming specialized in R&D activities.

4.2.3 Relative Size

The relative size of countries may affect the results obtained above. In particular, an important issue is how the strength of the home-market effect is affected as countries become more symmetric in size. Above, we showed that for moderate R&D externalities and the level of trade costs creating a strong home-market effect, R&D activities can only be concentrated in the small country. When R&D externalities are stronger or trade costs are lower, however, a concentration of R&D activities in the large country becomes possible. This suggests that externalities in the R&D sector can partly offset the home-market effect.

outweigh the negative effect on the price index from having to import all varieties. At higher trade costs, however, the latter effect dominate and Home's welfare is higher when R&D activities are dispersed.

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 13 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.[21] Thus, in order for such an equilibrium to be possible, Home cannot be too small in relation to the rest of the world.

{Figure 13: Relative country size and equilibria with moderate externalities}

[21] In the case with strong externalities ($\delta = 0.2$), a concentration of R&D activities can occur in Home at a relative country size equal to around 0.1. For a higher share, the equilibria are the same as in Figure 7.

5 Conclusions

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 backward linkages between firms. These two sources generate agglomeration economies affecting the choice of locating R&D differently from the choice of locating high-tech production. The pecuniary externality in the form of linkages 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 at the same time, there may be advantages associated with locating R&D in the small economy. When trade costs are such that the pecuniary externality 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 strong R&D spillovers, R&D becomes concentrated in either country.

We also compare different outcomes with respect to the degree of product variation and welfare. The most beneficial case for the large country from a welfare point of view may be when R&D is concentrated in the small country. In this case, resources are freed up for the production of high-tech goods in the large country. Because the consumer price index increases with the share of imported products, this means that real income tends to be higher than when these resources are spent conducting R&D. For the small country, it may for similar reasons be beneficial to have R&D activities concentrated in the large country. Being specialized in R&D activities tends to draw resources from the production of high-tech products and with a larger import share, consumer prices tend to be higher. The opposing effect is an upward pressure on wages of skilled labor, which leads to higher incomes and to the multinational strategy to become more costly, thereby inducing more domestic production. However, when R&D externalities are relatively strong, this effect is only sufficiently strong to outweigh the negative effect on consumer prices for relatively high trade costs. In this analysis, it is thus not necessarily welfare improving for a country to specialize in R&D activities, even though these activities are associated with externalities that are national rather than global in scope.

The possibility of having R&D concentrated in a small country fits in well with the observation that small, skill-labor abundant countries such as Sweden and Finland are among those with the highest R&D expenditures as a share of their GDP, but not necessarily among those most specialized in high-tech production. In particular in the case of Sweden, it seems clear that the focus on R&D activities is related to Sweden being the home country of many MNEs operating in the high-tech sector and conducting R&D at home, but carrying out a substantial part of their actual production in the large OECD economies.

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Appendix

Derivation of equilibrium condition (12)

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:

$$S_j = n_j^n \left[\left(1 - \delta + \delta n_j^n\right)^{-1} + \alpha \left(w_{Sj}\right)^{\alpha - 1} \left(\gamma \left(X_{jj} + \tau X_{jk}\right) + \beta\right) \right]. \qquad (15)$$

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:

$$p_j = \frac{\sigma \gamma w_{Sj}^{\alpha}}{\sigma - 1}. \qquad (16)$$

Subtracting marginal costs for both sides gives us:

$$p_j - \gamma w_{Sj}^{\alpha} = \frac{\gamma w_{Sj}^{\alpha}}{\sigma - 1}. \qquad (17)$$

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

$$\Pi_j^n = \frac{\gamma w_{Sj}^{\alpha} \left(X_{jj} + \tau X_{jk}\right)}{\sigma - 1} - w_{Sj} \left(1 - \delta + \delta n_j^n\right)^{-1} - \beta w_{Sj}^{\alpha}. \qquad (18)$$

Setting profits to zero yields:

$$\frac{\gamma w_{Sj}^{\alpha} \left(X_{jj} + \tau X_{jk}\right)}{\sigma - 1} = w_{Sj} \left(1 - \delta + \delta n_j^n\right)^{-1} + \beta w_{Sj}^{\alpha}. \qquad (19)$$

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

$$X_{jj} + \tau X_{jk} = \frac{\sigma - 1}{\gamma} \left[w_{Sj}^{1-\alpha} \left(1 - \delta + \delta n_j^n\right)^{-1} + \beta \right]. \qquad (20)$$

Substituting $X_{jj} + \tau X_{jk}$ in (15) for the right-hand side of (20) gives us:

$$S_j = n_j^n \left[\left(1-\delta+\delta n_j^n\right)^{-1} + \alpha \left(w_{Sj}\right)^{\alpha-1} \left[(\sigma-1) \left[w_{Sj}^{1-\alpha} \left(1-\delta+\delta n_j^n\right)^{-1} + \beta \right] + \beta \right] \right]. \tag{21}$$

Simplifying this expression yields:

$$S_j = n_j^n \left[\left(1-\delta+\delta n_j^n\right)^{-1} \left(1+\alpha(\sigma-1)\right) + \alpha\beta\sigma \left(w_{Sj}\right)^{\alpha-1} \right], \tag{22}$$

which corresponds to expression (12).

Derivation of equilibrium condition (13)

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:

$$X_{jj} + \tau X_{jk} = \mu p_j^{-\sigma} \left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma} E_k}{P_k^{1-\sigma}} \right]. \tag{23}$$

Substituting p_j in (23) for the equilibrium price in (16) gives us:

$$X_{jj} + \tau X_{jk} = \mu \left(\frac{\sigma\gamma w_{Sj}^{\alpha}}{\sigma-1} \right)^{-\sigma} \left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma} E_k}{P_k^{1-\sigma}} \right], \tag{24}$$

which can be rewritten as:

$$X_{jj} + \tau X_{jk} = \frac{\mu}{w_{Sj}^{\alpha\sigma}} \left(\frac{\sigma-1}{\sigma\gamma} \right)^{\sigma} \left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma} E_k}{P_k^{1-\sigma}} \right] \tag{25}$$

Substituting the left-hand side of (25) for $X_{jj} + \tau X_{jk}$ given by the zero profit condition in (20), gives us:

$$\frac{\sigma-1}{\gamma} \left[w_{Sj}^{1-\alpha} \left(1-\delta+\delta n_j^n\right)^{-1} + \beta \right] = \frac{\mu}{w_{Sj}^{\alpha\sigma}} \left(\frac{\sigma-1}{\sigma\gamma} \right)^{\sigma} \left[\frac{E_j}{P_j^{1-\sigma}} + \frac{\tau^{1-\sigma} E_k}{P_k^{1-\sigma}} \right], \tag{26}$$

which can be rewritten as:

$$\frac{(\sigma-1)^{1-\sigma}\sigma^{\sigma}\gamma^{\sigma-1}}{\mu}w_{Sj}^{\alpha\sigma}\left[w_{Sj}^{1-\alpha}\left(1-\delta+\delta n_j^n\right)^{-1}+\beta\right]=\left[\frac{E_j}{P_j^{1-\sigma}}+\frac{\tau^{1-\sigma}E_k}{P_k^{1-\sigma}}\right]. \tag{27}$$

Using the expression for the equilibrium price in (16), we get the following expression for the CES price index in country j:

$$P_j^{1-\sigma}=\left(\frac{\sigma\gamma}{\sigma-1}\right)^{1-\sigma}\left[n_j^n\left(w_{Sj}^{\alpha}\right)^{1-\sigma}+n_k^n\left(w_{Sk}^{\alpha}\tau\right)^{1-\sigma}\right]. \tag{28}$$

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:

$$\frac{\sigma w_{Sj}^{\alpha\sigma}}{\mu}\left[w_{Sj}^{1-\alpha}\left(1-\delta+\delta n_j^n\right)^{-1}+\beta\right]=$$
$$\frac{(w_{Sj}S_j+L_j)}{\left[n_j^n\left(w_{Sj}^{\alpha}\right)^{1-\sigma}+n_k^n\left(w_{Sk}^{\alpha}\tau\right)^{1-\sigma}\right]}+\frac{\tau^{1-\sigma}(w_{Sk}S_k+L_k)}{\left[n_k^n\left(w_{Sk}^{\alpha}\right)^{1-\sigma}+n_j^n\left(w_{Sj}^{\alpha}\tau\right)^{1-\sigma}\right]}, \tag{29}$$

corresponding to condition (13) in the text.

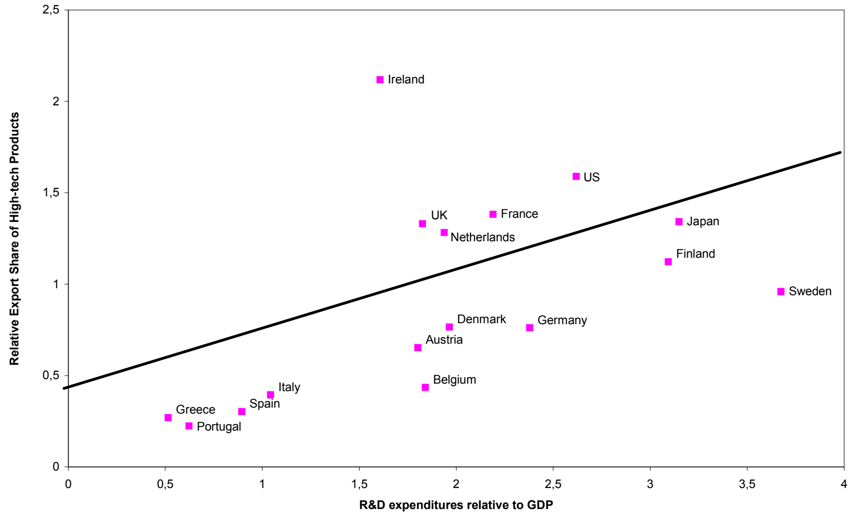

Figure 1: R&D expenditures and exports of high-tech products in 2000. (Sources: IFS (world market shares of exports), EU (export shares of high-tech goods) and IMD (R&D)).

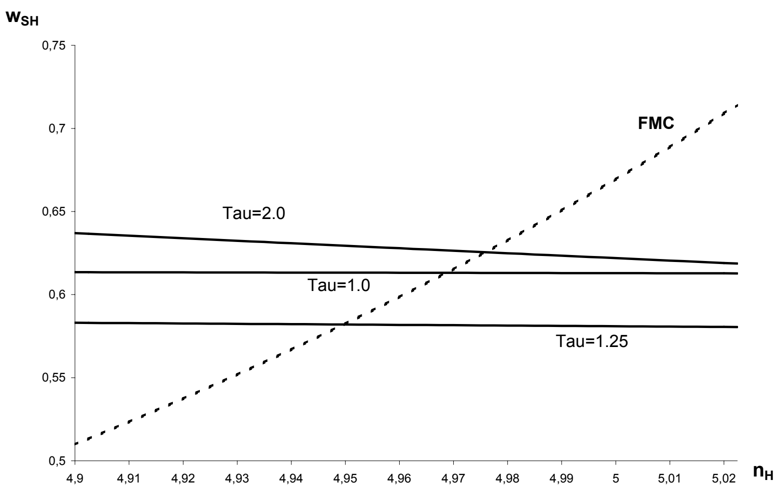

Figure 2: Goods and factor market clearing with national firms only.

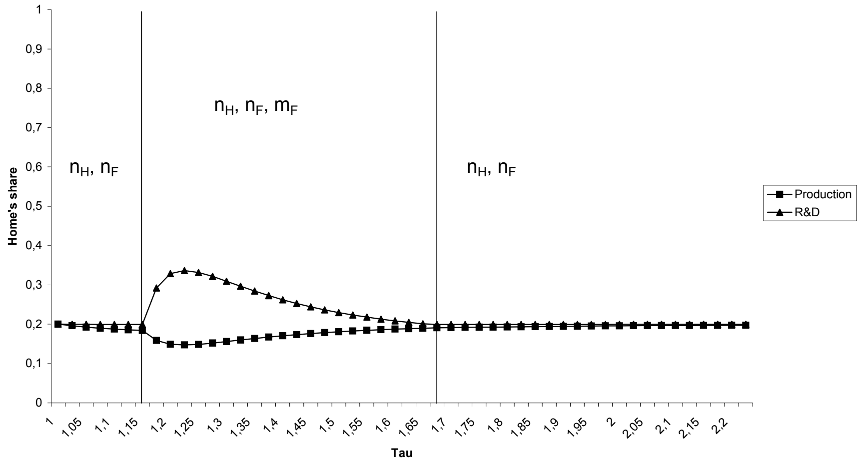

Figure 3: Benchmark case with no R&D externalities.

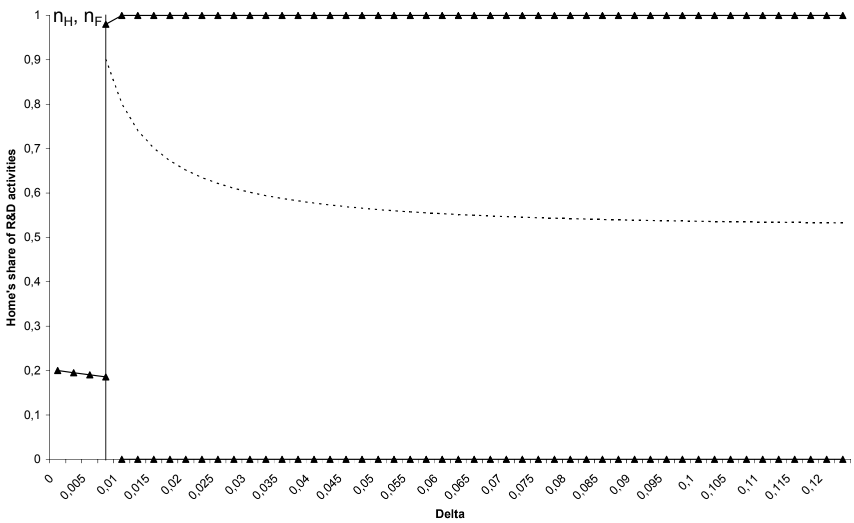

Figure 4: Home's share of R&D activities in a benchmark case with free trade.

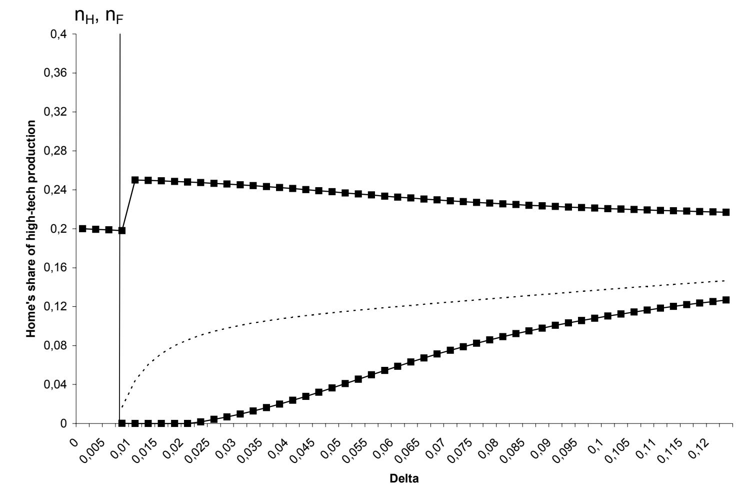

Figure 5: Home's share of high-tech production in a benchmark case with free trade.

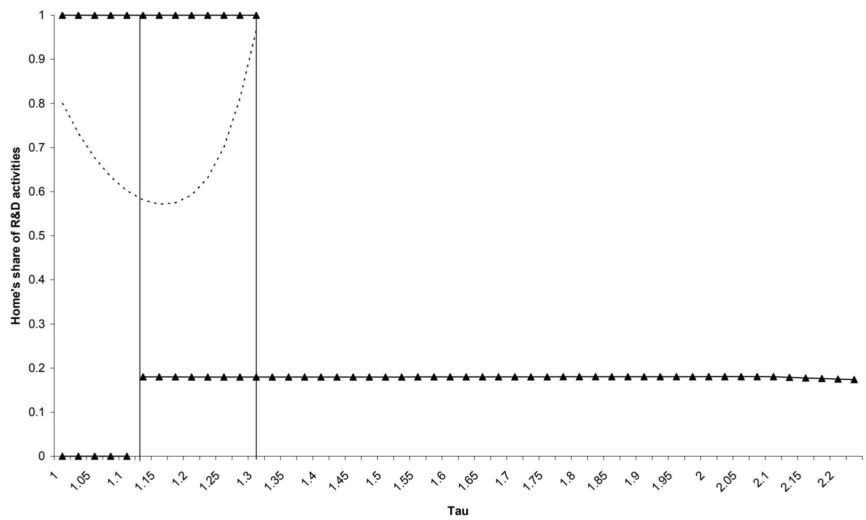

Figure 6: Home's share of R&D activities for moderate R&D externalities ($\delta = 0.01$).

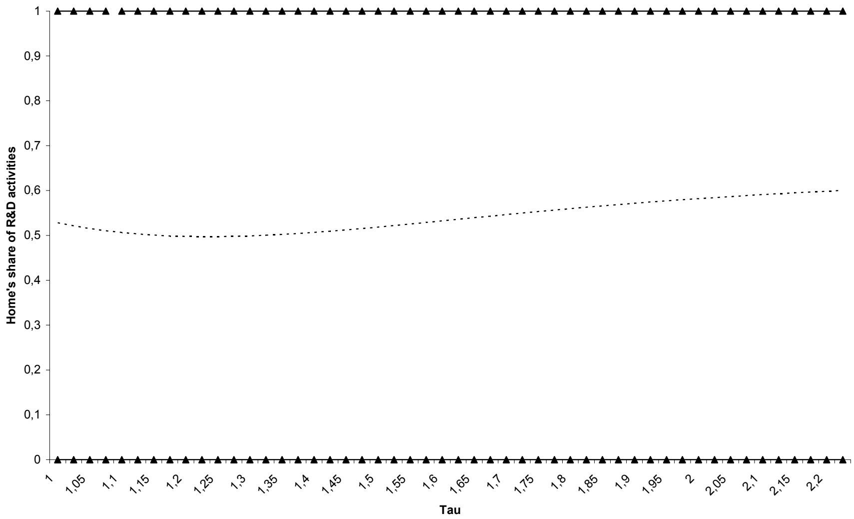

Figure 7: Home's share of R&D for relatively strong R&D externalities ($\delta = 0.2$).

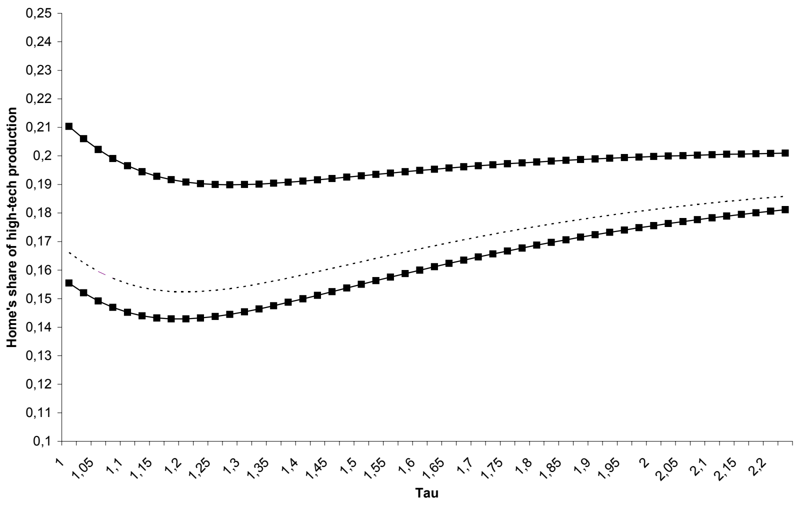

Figure 8: Home's share of high-tech production for relatively strong R&D externalities ($\delta = 0.2$).

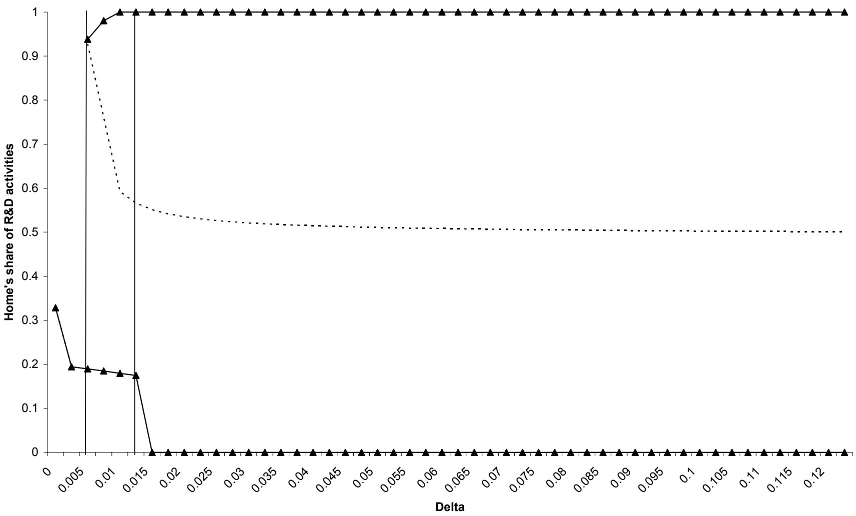

Figure 9: Home's share of R&D for a strong home-market effect ($\tau = 1.2$).

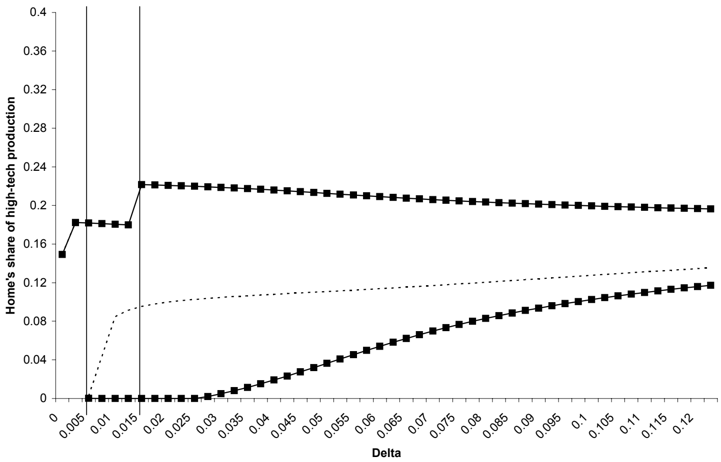

Figure 10: Home's share of high-tech production for a strong home-market effect ($\tau = 1.2$).

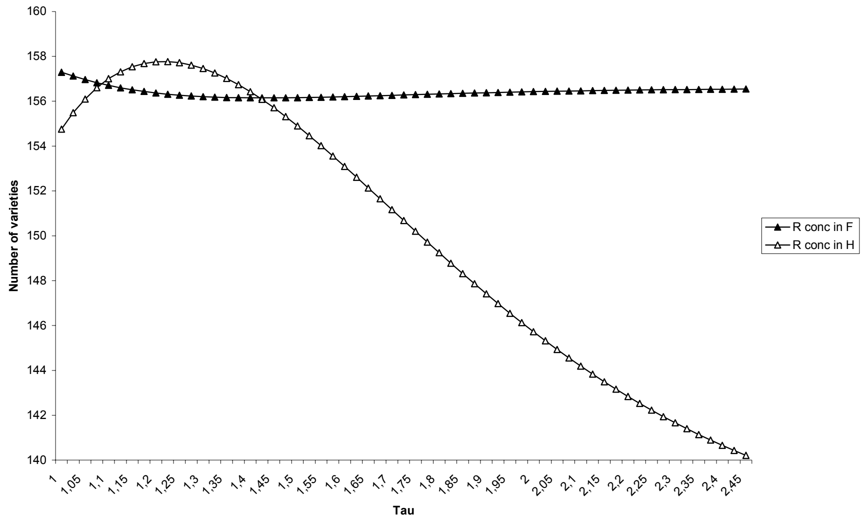

Figure 11: The degree of product variation for relatively strong R&D externalities ($\delta = 0.2$).

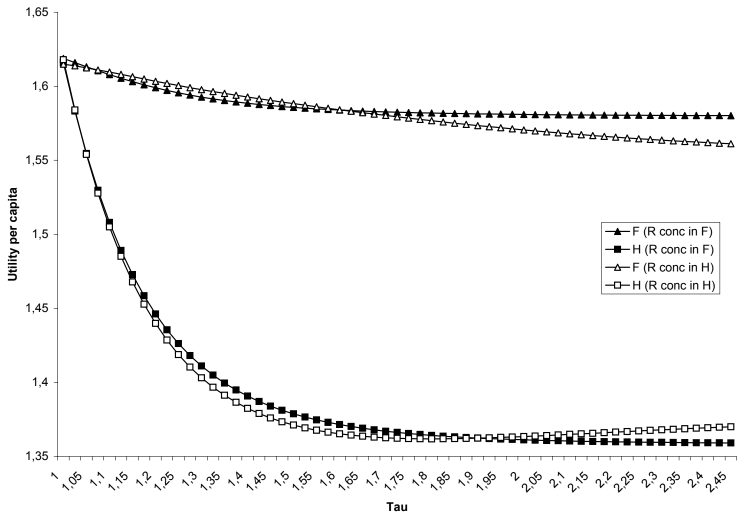

Figure 12: Welfare in the case with strong R&D externalities ($\delta = 0.2$).

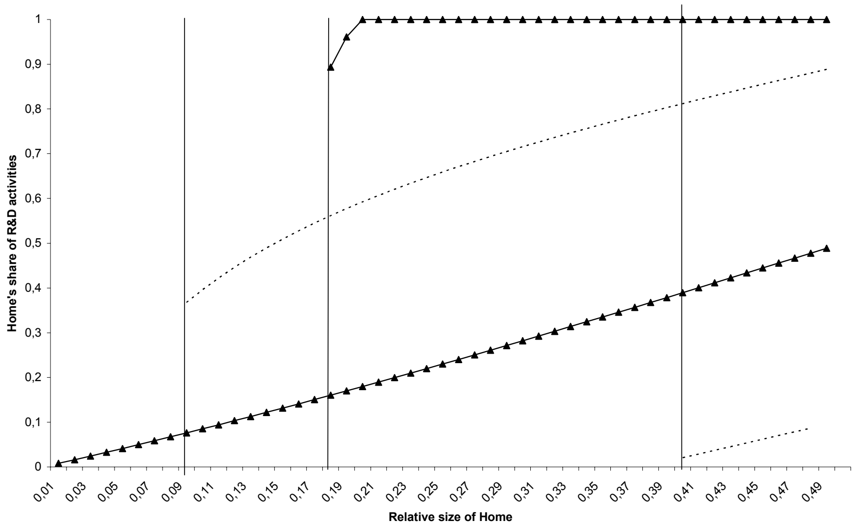

Figure 13: Relative country size and equilibria with moderate externalities.