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

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Abstract

We develop a two-country model where firms choose locations of R&D activities and production of R&D intensive goods. Plant-specific fixed costs and transaction costs associated with cross-border trade generate a home-market effect that tends to attract production of R&D intensive goods to the larger country. At the same time, knowledge spillovers associated with R&D activities create a tendency for R&D activities to concentrate in one region. We show that without knowledge spillovers R&D activities concentrate in the smaller country for a certain range of intermediate trade costs. However, in the presence of weak to intermediate level of spillovers R&D activities tend to concentrate in the larger country even in the presence of a strong home market effect in production of the technological goods. As externalities in R&D sector increase, an equilibrium where R&D concentrates in the small country irrespective of trade costs becomes possible.

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1 Introduction

The increased globalization of the economy has generated concerns about the location of industries, especially those in which 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 which are associated with positive externalities (e.g. Krugman, 1991). One sector where this may be a legitimate concern in particular, is the sector producing high-tech goods. This sector is characterized by the importance of R&D activities to generate new and more competitive goods. Moreover, the available empirical evidence suggests that R&D activities generate positive spillovers that are geographically limited in scope (see, e.g. Griliches, 1992 and Jaffe et al., 1993). This means that regions that tend attract R&D activities may gain in terms of welfare from the generated spillovers.

In most economic models, it is simply assumed that R&D is located where the rest of the firm's activities are located. In the past, the firms' R&D activities also seemed strongly concentrated to the firms' home countries and countries with a high share of R&D activities generally had a comparative advantage in the production of high-tech goods. However, there is empirical evidence suggesting that some of the most R&D intensive countries deviate from the general pattern of specialization by having a lower share of high-tech net exports than expected. One such country is Sweden, a small open economy that is a home country of several large multinationals with R&D-intensive production. Due to the high share of R&D activities located in Sweden one would expect that Sweden has a comparative advantage in the production of high-tech goods. However, the size of the high-tech sector is in fact relatively small.[1] A possible explanation for this is that while firms find it profitable to locate production of high-tech goods in large markets, they may choose to conducting R&D in Sweden where highly skilled labor is relatively abundant. Thus, it seems as if an approiate analysis of the location choice of high-tech firms should allow for a geographical separation of R&D activities from the actual production of goods.[2]

[1] Hansson and Lundberg (1995) find that Sweden and US deviate most from the average relationship among the OECD countries by using data for the 1987-90 period.

[2] Notable exceptions in this respect are papers analyzing vertically integrated multina-

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. In doing this, we allow for positive knowledge spillovers associated with R&D activities as well as externalities associated with the production of final goods. The externalities in the final goods market arise from the combination of increasing returns to scale in production and transaction costs associated with cross-border trade. In presence of these externalities firms tend to locate their production of final goods in the proximity of their largest market, the so called home market. This aspect of the model is similar to recent models within the so-called "new economic geography" (see Fujita, Krugman and Venables, 1999).

In our model, we assume that knowledge spillovers generated by R&D activities are national in scope. If they are international in scope, there are no potential welfare losses from a concentration of R&D activities abroad. If, for instance, technological knowledge diffuses very easily by reverse-engineering, it may be more 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 knowledge spillovers may be geographically limited in scope. Naturally, one explanation for the clustering of R&D activities in some industries might be that production activities are geographically concentrated (cf. Jaffe et al., 1993). However, Feldman and Audretsch (1996) find that even after controlling for the degree of geographical concentration of production, innovative activity tends to cluster more in industries where knowledge spillovers play a decisive role. We take this as evidence of the existence of geographically limited knowledge spillovers from R&D activities.

Our model thus involves two different types of externalities; both creating incentives for the concentration of activities in one location. However, at the same time we assume that both R&D activities and the production of high-tech goods require inputs of skilled labor and thereby compete for resources. The outcome in terms of the firms' location choices will then depend on the interplay between the advantages from concentrating activities in order to

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tional firms, meaning firms that locate different stages of the production process in different countries. Helpman (1984) developed a model where firms operating under monopolistic competion could choose to locate their headquarters separate 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 proximity to consumers.

benefit from externalities and the disadvantages of locating skill-intensive activities where skilled labor is relatively expensive.

In the paper, we analyze how the high-tech firms' location choices are affected by the strength of externalities generated by R&D activities and the level of trade costs. The latter will determine the strength of agglomeration economies created by a home market effect. We focus on the case where countries are dissimilar in size but similar in terms of relative factor endowments and examine under what conditions a small country is likely to end up with a concentration of R&D activities. The analysis is related to the one in Markusen (1997), where it is shown that a small country may end up headquartering vertically integrated multinationals with production in a larger country under certain conditions. A difference between the analysis in this paper and the analysis in Markusen (1997) is that here there are externalities associated with non-production activities, generating incentives for firms to locate those activities where most other firms have located them.

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

Krugman (1980) shows that the combination of increasing returns to scale and transaction costs associated with the cross-border trade may lead to a tendency for production to become concentrated in the largest market. Scale economies give incentive for the firm to concentrate production in one location. By locating production in the largest market it can obtain higher operating profits because trade costs will cut into profits made on exports. The analysis in Krugman (1980) establishes a home-market effect, meaning that countries with large home markets tend to become net exporters of goods produced with increasing returns to scale. 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 work related to the new economic geography models, 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 are determined by factor prices and the trade-off between the benefits from concentrating production in one location and the saving on trade costs from locating in proximity to the consumers. These models focus on MNEs that can be characterized as horizontal in the sense that they produce final goods in more than one country. However, MNEs may also become vertical in the sense that they carry out different stages of the production process in different countries. This case was analyzed within a framework of monopolistic competition, but without trade costs, in two papers by Helpman (1984, 1985). In Helpman's analysis, a skilled-labor abundant country may end up being net exporter of headquarter services because skill-intensive headquarters activities tend to be located there.

Markusen (1997) presents a model which incorporates horizontal as well as vertical MNEs. As in the analysis by Helpman (1984), vertical MNEs arise when there are advantages to fragment 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 on trade costs. This is important since the advantages of locating production in a small country because production costs are lower there may be weakened if large trade costs create disadvantages from exporting to the large country.

Neither of these papers allow for the possibility that the skill-intensive headquarters activities generate externalities. In the presence of such externalities, e.g., knowledge spillovers from the knowledge capital generated by the R&D activities of one firm, the location of the headquarters become important. Such spillovers may arise because firms learn from each other, for example through cooperation, by reverse-engineering each others' products or as a consequence of turnover of highly specialized labor. Several studies have found evidence of such spatially limited knowledge spillovers (e.g. Jaffe, 1989, Acs et al., 1992, 1994, Feldman, 1994, and Audretsch and Feldman, 1996).

Our model adds knowledge spillovers associated with R&D activities to an analysis of the location choice of firms that are potentially vertical MNEs in the sense that they can choose to separate geographically their R&D activities from the 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, our analysis is related to the literature on technology sourcing and so-called "centres of excellence". It has been argued that multinational firms locate R&D in "centres of excellence" in order to source technology available there (Kogut and Chang, 1991, Neven and Siotis, 1996). This type of technological externalities may interact with market externalities 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 prices of these resources so much that the other type of activity will be located elsewhere.[3]

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, which is produced with constant returns to scale in a perfectly competitive sector and a high-tech good, X, which is 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 such that one unit of L produces one unit of Y. Production of X requires inputs of firm-specific knowledge (R), which is produced by R&D labs that potentially can be located in a different country from 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 à la Helpman (1984).

The R&D labs produce an input which is transferrable across national border 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 incentive to internalize R&D

[3] 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.

within the firm. However, at the same time we assume that the firms are unable to completely internalize the benefits from their R&D. We assume that the firm-specific knowledge produced by individual firms spills over to all firms conducting R&D in the same country. More specifically, we assume that the cost of inventing additional varieties in terms of skilled labor inputs decrease with the amount of R&D conducted in the country. The production function of a representative R&D lab is specified as follows:

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

where the sum $\overline{R}_j$ is aggregate R&D conducted in country j. The parameter $\rho^g \geq 1$ denotes a cost for geographically separating the production of R and X.[4] 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 nature of R&D spillovers, we have simply chosen to model them as being constant.

A cost-minimizing firm chooses S_{Ri}, given the level of $\overline{R}$, 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 their location decision. In order for a firm to enter the market with a new variety, it has to generate one unit of R. This implies the following demand for skilled labor stemming from a R&D lab located in country j:

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

[4] Transferring R from one country to another within a multinational enterprise involves an "iceberg" type of cost which implies that $\rho \geq 1$ units must be shipped from the R&D lab located in one country in order to use one unit of R in the production plant located in the other country.

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). Therefore, a firm that decides to conduct its R&D in a 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) in order to produce their final products. There are fixed costs in production, creating incentive for concentrating final production to one country. More specifically, we assume the following production function of a representative high-tech firm:

$$f\left(S_{Xij}, L_{Xij} \mid R_i = 1\right) = S_{Xij}^{\alpha} L_{Xij}^{1-\alpha} - \beta \tag{3}$$

where $\alpha \in [0, 1]$ and β represents the fixed cost of production.

3.1 Consumer behavior

In modelling consumer preferences we follow the approach in Dixit and Stiglitz (1977) and assume a representative consumer with love of variety. We assume the following utility function:

$$U = \left(C_X\right)^{\mu}\left(C_Y\right)^{1-\mu}, \; C_X = \left(\int_{i=0}^{n^w} c_i^{1-\frac{1}{\sigma}} di\right)^{\sigma/(\sigma-1)} \tag{4}$$

where C_X is a subutility function defined over a continuum of varieties of high-tech goods; c_i denotes the consumption of each available variety and $n^w$is the total number of varieties produced.

Given the preferences specified in (4), a representative consumer's utility maximization problem is a two-stage budgeting procedure. In the first stage the consumer divides her income between the differentiated high-tech goods and the homogeneous good. The second stage implies choosing consumption of each variety of X so as to minimize the cost of attaining the composite C_X. Solving this problem gives us the compensated demand function for the ith variety of the high-tech good:

$$c_i = \frac{p_i^{-\sigma}}{\left[\int_{j=0}^{n^w} p_j^{1-\sigma} dj\right]^{\frac{\sigma}{\sigma-1}}} C_X \tag{5}$$

Finally, we can derive an expression for the minimum expenditure of attaining the composite C_X by integrating over all i :

$$\int_{i=0}^{n^w} p_i c_i di = \left(\int_{i=0}^{n^w} p_j^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}} C_X \tag{6}$$

We follow the practice of regarding the expression in front of C_X as the price index of manufactured goods and denote this with P.Using this to solve the first stage of the consumer's utility maximization problem, we get the following demand functions for Y and X for given total expenditures E:

$$C_Y = \frac{(1-\mu)\,E}{p_Y} \tag{7}$$

$$c_i = \frac{p_i^{-\sigma} \mu E}{P^{1-\sigma}} \tag{8}$$

3.2 Profit Maximization of Firms

In the first stage of decision-making a firm decides whether to locate production and R&D in the same or different countries. In the second stage, the firm chooses output of X (the required quantity of R is given). With symmetric firms, the price index from equation (6) reduces to:

$$P_j = \left[\sum_j n_j^g (p_j \tau)^{1-\sigma} \right]^{1/(1-\sigma)}, \; j = H, F \qquad g = n, m \tag{9}$$

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 cost denoted with $\tau \geq 1$.

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

$$p_j \left(1 - \frac{1}{\sigma} \right) = w_{Sj}^{\alpha} w_{Lj}^{1-\alpha} \tag{10}$$

where σ is the perceived 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:

$$\Pi_j^g \leq 0 \qquad n_j^g \geq 0 \qquad \text{and} \qquad \Pi_j^g n_j^g = 0 \tag{11}$$

Given the pricing condition (10), the profits of a national enterprise in country j are:

$$\Pi_j^n = (p_j - w_{Sj}^{\alpha} w_{Lj}^{1-\alpha}) (X_{jj} + \tau X_{jk}) - w_{Sj}^{\alpha} w_{Lj}^{1-\alpha} \beta - w_{Sj} \left(1 - \delta + \delta(n_j^n + n_k^m)\right)^{-1} \tag{12}$$

where the first subscript of X_{jj} denotes the location of the production plant and the second subscript the market where the final good is sold. The second term in (12) represents the fixed costs in production and the third term the costs of producing one unit of R. Profits of a multinational enterprise locating production in country j but R&D in country k is given by:

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

3.3 Equilibrium

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

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

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

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

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

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

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

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

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

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

$$w_{Lj}\geq p_y \qquad (Y_j)$$

$$(E_H+E_F)(1-\mu)=(Y_H+Y_F)p_y \qquad (p_y)$$

The associated variables are given in parenthesis after each equilibrium condition. In total this is a system of 21 equations solving for the 21 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, Y_F, and p_y.

4 Analysis

In this model, the combination of increasing returns to scale and trade costs create a home market effect leading to a tendency for the larger country to attract final production of the differentiated good. Final goods production in the X-sector is similar to the one in Krugman (1980), where a relatively large country is shown to become net exporter of differentiated products that are traded at a cost. As in several so-called new economic geography models, the advantages of locating increasing returns to scale production in the larger market are the strongest for intermediate levels of trade costs.

Because of the tendency for final goods production of X to become concentrated in the large country, the small country will have advantages 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 agglomerated in the large country. This will arise when technological externalities for R&D activities are relatively large while the return to skilled labor is not substantially lower in the small country (e.g. because market externalities are relatively weak).

Whether firms producing in the small country have incentive to locate R&D in the large country depends on the difference in size between the countries, the strength of R&D externalities and on the relative return to skilled labor. This can be shown as follows: Suppose we start from a situation where there are only national firms. For this to be an equilibrium, there cannot be any incentive for a firm producing in the small country to locate its R&D activities in the larger economy instead. Assuming that H is the smaller economy, this requires that the following condition holds:

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

If the condition in (13) is satisfied, the reduction in production costs stemming from stronger spillovers and possibly lower return to skilled labor in the large country is not enough to compensate for the additional costs arising from a geographical separation between R&D and production. There are three factors affecting whether (13) holds or not: the relative return to skilled labor in the two countries, the relative number of firms in the two countries and the strength of R&D externalities as captured by δ. If follows directly from (13) 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 (13) and the less likely it is that it will be satisfied. It is also clear that as long as $n_F^n > n_H^n$, a higher value of δ will reduce the value of the left hand side of (13)[5]

4.1 Numerical Simulations

Given the dimensionality of the model we rely to a large extent on numeral simulations in order to solve the model.[6] Different equilibria are characterized by the different types of firms that are active (national firms located

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

[6] In all simulations $\mu = 0.5$, $\alpha = 0.5, \beta = 0.1, \delta = 4.0, \rho = 1.1, S_H = 10,$

in H and F will be denoted n_H and n_F, respectively, whereas multinational firms producing high-tech goods in H and F will be denoted m_H, and m_F, respectively), by the pattern of specialization and concentration of R&D activities in each of the two countries. We are mainly interested in the two parameters, one capturing the strength of R&D externalities and the other the strength the home market effect. That is, we solve the model for different values of the 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 production activities in the large country. However, at intermediate levels of trade costs, the home market effect is relatively strong, which implies that firms have incentive to locate the production of high-tech goods in the large country (country F).

We first analyze a benchmark case in which there are no externalities in the R&D sector, that is $\delta = 0$. This case corresponds to one of the cases analyzed by Markusen (1997), namely the case where countries of different size have identical relative factor endowments and trade costs are positive but moderately high. Figure 1 shows Home's share of the total number of R&D labs and its share of total high-tech production. At free trade and at high levels of trade costs 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 the firms to locate high-tech production in the large country (country F). As this happens, the price of skilled labor will tend to increase, creating a factor market reason for high-tech firms to locate R&D activities in the small country (country H). Hence, for intermediate levels of trade costs, there exists multinational firms which produce high-tech goods in the large country while carrying out R&D in the small country in equilibrium. In this range of trade costs, the large country becomes specialized in the production of high-tech goods, while the small country becomes specialized in R&D. Whereas R&D is undertaken in both countries for all levels of trade costs, the production of high-tech goods becomes completely concentrated in the large country for a certain range of trade costs.

Another potential benchmark case is one where there are R&D externalities but no trade costs. In this case, the R&D externalities create incentive

$L_H = 10$, $S_F = 90$ and $L_F = 90$.

for firms to locate their R&D activities in the same country. Figure 2a and 2b 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, all R&D activities become concentrated in the large country. This is a unique equilibrium for a certain range of δ, but as we increase δ eventually we get two additonal equilibria. one in which there is concentration of R&D in the large country and another in which R&D activities are conducted in both countries. The latter equilibrium is not stable in the sense that a small perturbation of the equilibrium creates 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.[7] There are thus only two stable equilibria above for high levels of δ: complete concentration of R&D in the small or in the large country.

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. Figure 3a shows a case where we keep R&D externalities at a constant level; in this particular case at a relatively low level ($\delta = 0.05$). 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 incentive to locate production in the large country for intermediate levels of trade costs. When R&D externalities are relatively weak, R&D will be be concentrated in the large country despite the home market effect. The greater size of country F is in this case the decisive factor attracting R&D to F. The home market effect however manifests itself in Home's share of high-tech production for different levels of trade costs. Home's share of high-tech production is especially small for intermediate levels of τ where the home market effect is strong.

In Figures 3b and 3c, we have assumed somewhat stronger R&D externalities ($\delta = 0.15$). As is clear from these figures, we now get multiple equilibria. The equilibrium where all R&D is concentrated in the large country is one possible equilibrium. However, R&D spillovers are now sufficiently strong for an outcome where the entire R&D sector locates in the small country to be an equilibrium. Again, we also have an unstable equilibrium where R&D

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

activities are spread between the countries. Irrespective of the type of equilibrium, there is a tendency for the large country to specialize in high-tech production for intermediate levels of τ because of the home market effect (see Figure 3c).

Figure 4a shows 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. We know from Figure 1 that we should find an equilibrium where the small country specializes in R&D activities and high-tech production is completely concentrated in the large country for low levels of δ. This is also what we find. Also for higher levels of δ, the small country may specialize in R&D activities. Again, however, we have multiple equilibria. There are two stable equilibria with complete concentration of R&D activities in one of the economies and one unstable equilibrium where R&D is spread out between the countries. For lower levels of δ, we do not find any equilibria where R&D activities become completely concentrated in the small country. They may either be concentrated in the large country or spread out in both countries (in which case the small country is still specialized in R&D activities).

As shown in Figure 4b, for a sufficiently high level of δ, the small country may produce high-tech goods even when R&D activities are completely concentrated in the small country. The reason for this is that high levels of δ are associated with a 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.

In order to assess how the location of R&D and high-tech production affects the economy, we examine the corresponding effects on the degree of product variation and welfare. When there are no R&D externalities at all, the produced number of varieties of the high-tech good remains independent of the level of trade costs. However, in the presence of externalities the number of varieties varies with trade costs and with the different equilibria. Figure 5 shows the case with moderate externalities ($\delta = 0.05$) when there is a unique equilibrium in which all R&D activities concentrate in the larger country. The number of produced varieties is highest with free trade and then decreases as trade costs are increased up to a certain point. Thereafter, the degree of product variation increases again. The degree of product variation is thus the lowest at intermediate levels of trade costs. The reason for this is that trading high-tech goods requires inputs of resources that otherwise would be spent on producing additional variants.

Figure 6 shows the case where R&D externalities are relatively strong ($\delta = 0.15$). Now we have two stable equilibria; one with concentration of R&D activities in the small country and one with concentration of R&D activities in the small country. In both equilibria a larger number of varieties is produced at low levels of trade costs than in the case with moderate externalities. However, the number of varieties is much more sensitive to the level of trade costs in the equilibrium where R&D actitivities are concentrated in the smaller economy. The largest number of varieties is produced when the home market effect is the strongest, and the countries specialize completely in one of the two skill-intensive activities. However, as the level of trade costs is increased, more skilled labor is used in the high-tech sector of the small country and less varieties can be generated by the R&D sector.

Figure 7-9 show how welfare changes with trade costs for different levels of δ. Welfare is measured as the utility of a representative consumer and it is normalized so that the representative consumer of both countries is endowed with the same amount of $L$and S. Figure 7 shows the case where there are no R&D externalities at all. We see that the normalized utility is lower in the small country for all levels of τ except at the point where there is free trade. The reason for this is that because Home has a larger share of imported high-tech products, consumer prices are higher and thus real income lower. Figure 8 shows the case where R&D externalities are relatively small ($\delta = 0.05$). The pattern of welfare looks very similar to the case where there are no R&D externalities. A difference, however, is that the level of welfare is higher in both countries. Furthmore, the difference in welfare is larger. The concentration of R&D activities in the large country means that there is an additional reason for why welfare is higher in F than in H.

Figure 9 shows the case where there are relatively strong spillovers ($\delta = 0.15$) and we have multiple equilibria. The equilibrium where R&D activities are concentrated in the large country generate welfare relatively similar to the case with moderate R&D spillovers. The level is somewhat higher than in the case with moderate spillovers, but we find again that Foreign's welfare is substantially higher than Home's for all levels of τ but the free trade level. However, in the equilibrium where all R&D activities concentrate in the small country, the pattern is altogether different. Welfare is higher than in the other type of equilibrium for Home at all levels of τ. However, as is evident from figure 9, whereas welfare in Home first decreases and then increases as trade costs increase, the opposite holds true for the large country. In fact, welfare is the highest for Foreign at intermediate trade costs when R&D is concentrated in the small country. The concentration of R&D activities in Home frees up resources that are used in high-tech production in Foreign. Foreign gain from this through the effect on consumer prices. In Home, there is a negative effect on welfare as trade costs increase through the effect on consumer prices through imports of high-tech products imported from the large country. At the same time, the concentration of R&D activities in H puts upward pressure on the return to skilled labor and therefore tends to increase income. This effect is particularly strong when the home market effect is weak, since there is then a higher demand for skilled labor originating from the production sector. Because of this, Home's welfare exhibits a u-shaped relationship with trade costs.

5 Conclusions

This paper has analyzed location choices by firms operating in a high-tech sector on the assumption that there are forces generating agglomeration tendencies within this sector: knowledge spillovers from R&D activities and home market effects arising from the combination of increasing returns to scale and trade costs. Both types of forces create incentives for high-tech firms to concentrate their activities in the larger economy. However, because skilled labor is assumed to be used in both production and R&D, the tendency for activities to concentrate in the large country, thereby putting upward pressure on the return to skilled labor, implies that at the same time there are disincentives for high-tech firms to locate both R&D and production in the larger economy. When trade costs are such that the home market effect is especially strong and externalities in the R&D are sufficently large, the disincentive effect dominates and R&D activities become completely concentrated either in the smaller or in the larger economy. For R&D activities to become concentrated in the smaller economy, higher level of externalities is required than in the outcome where R&D activities are concentrated in the larger economy. Thus, for moderate externalities and at all trade costs, there is only one possible outcome: R&D activities are concentrated in the larger economy. On the other hand, when the home market effect is weak at low trade costs vis-a-vis R&D externalities, we find that several types of equilibria are possible; complete concentration of R&D activities in the small country, complete concentration of R&D activities in the large country or a division of R&D activities between the two countries.

The possibility of having R&D concentrated in a small country fits in well with the observation that small skill abundant countries such as Sweden and Finland tend to be home countries of MNEs operating in the high-tech sector, conducting R&D at home, but carrying out a substantial part of actual production in the large OECD economies.

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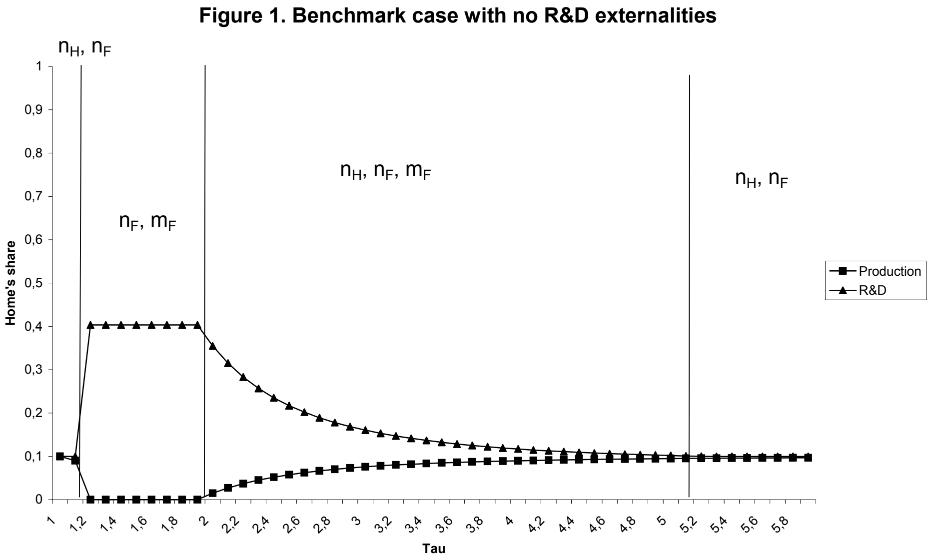

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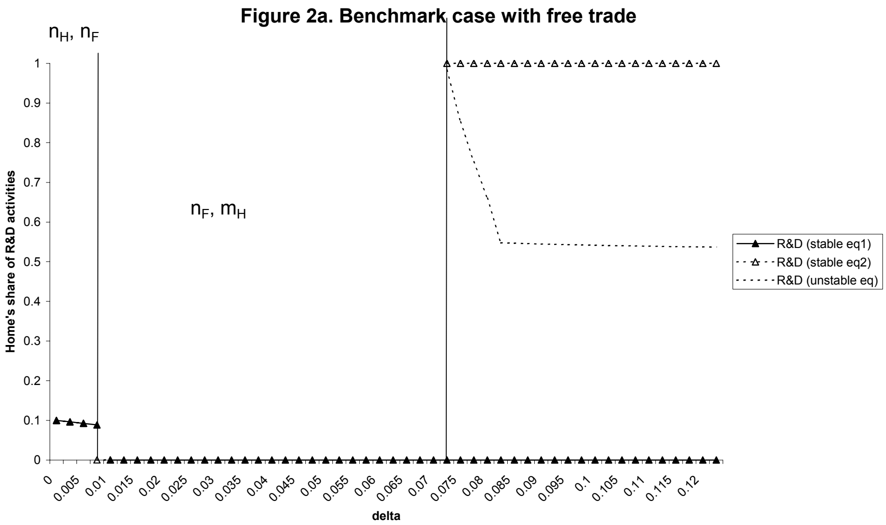

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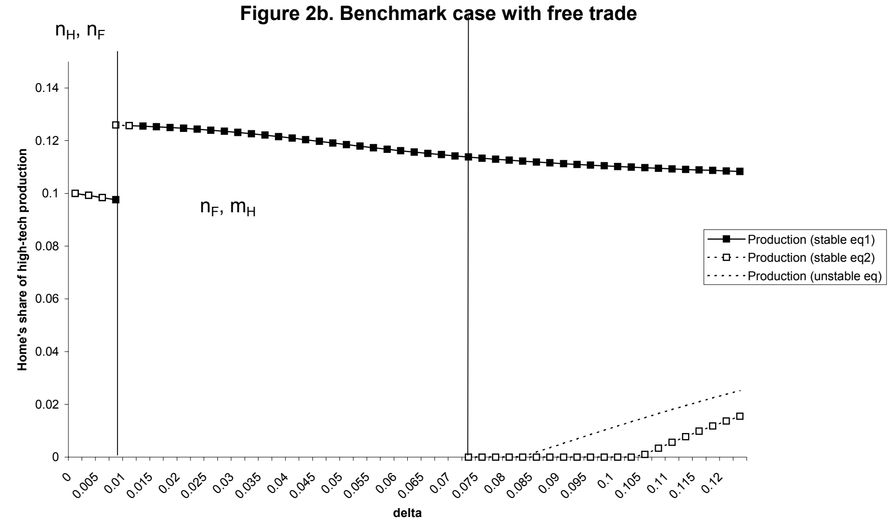

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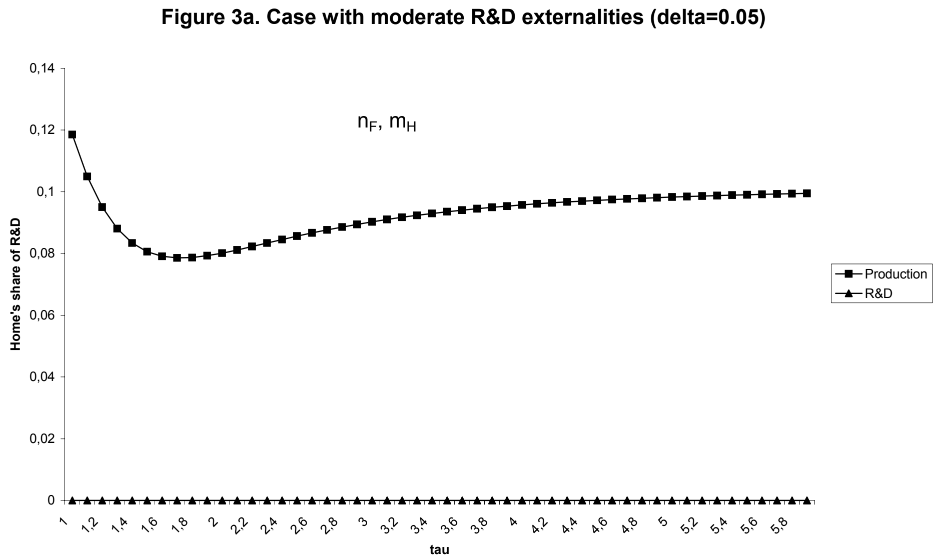

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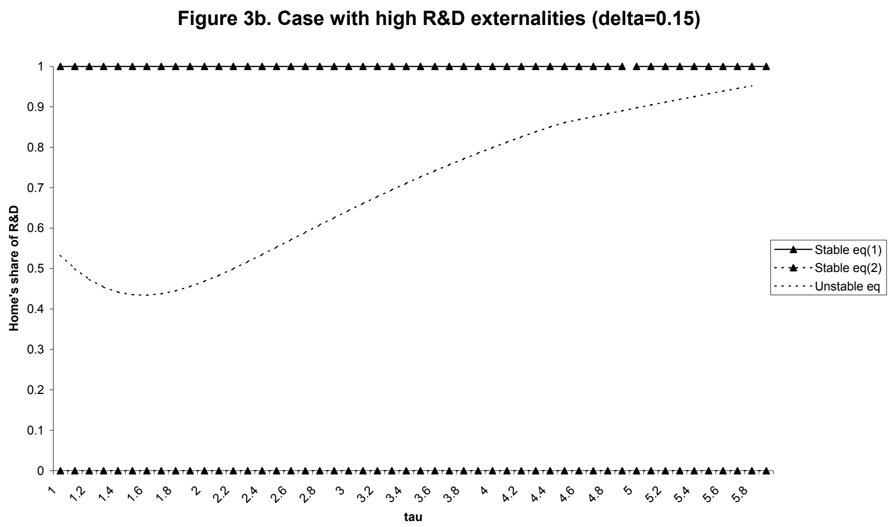

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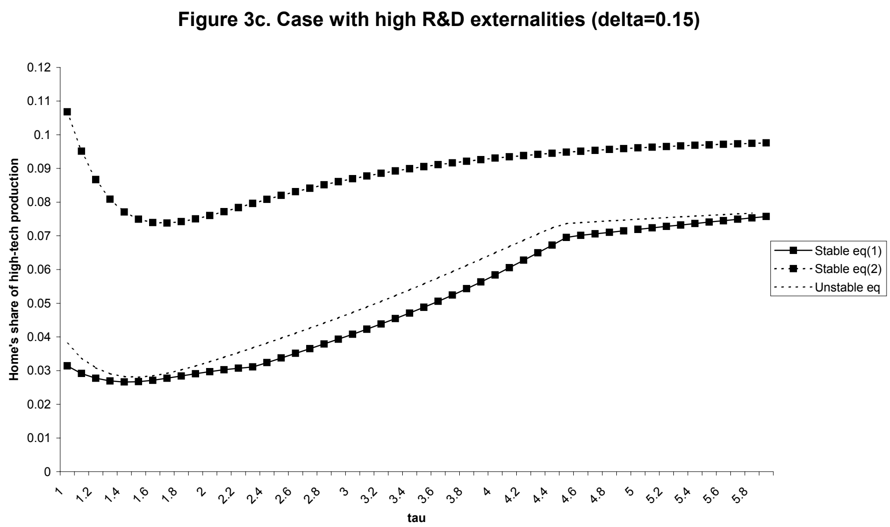

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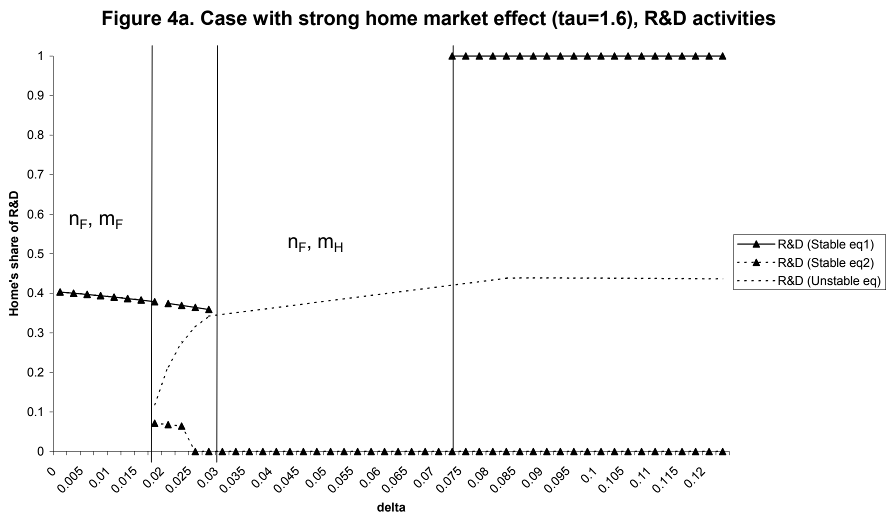

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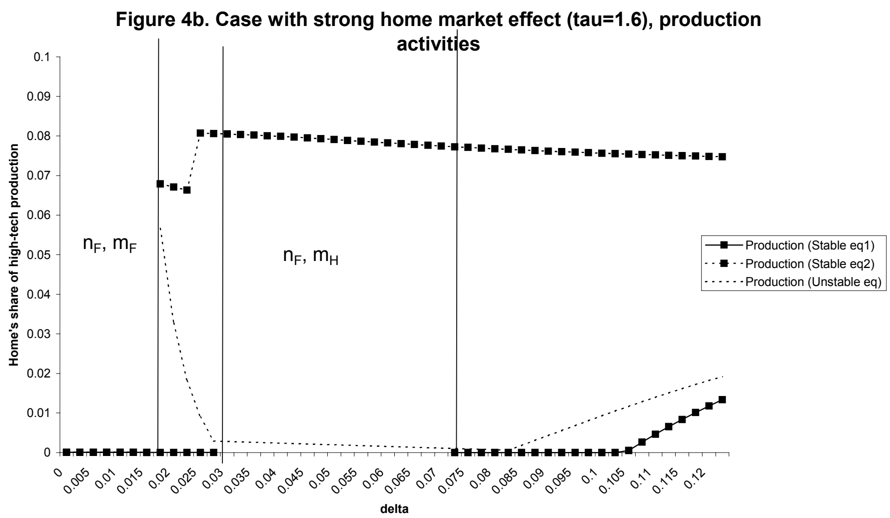

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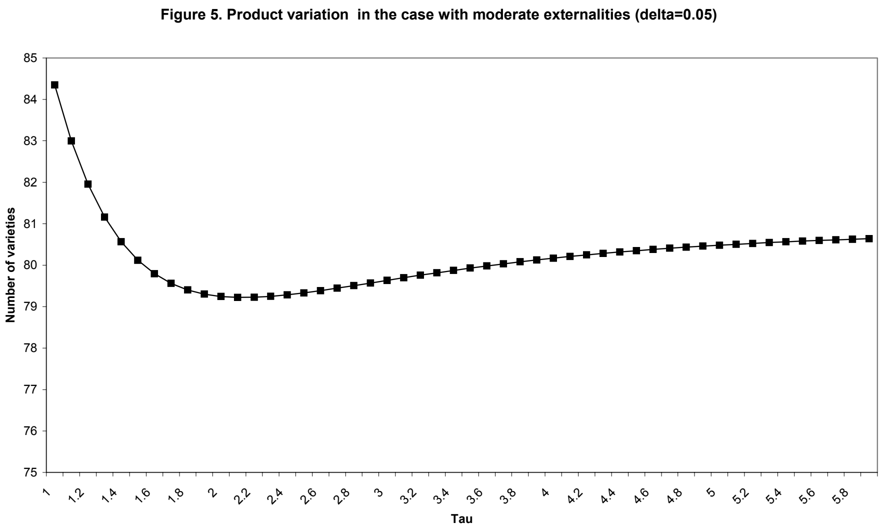

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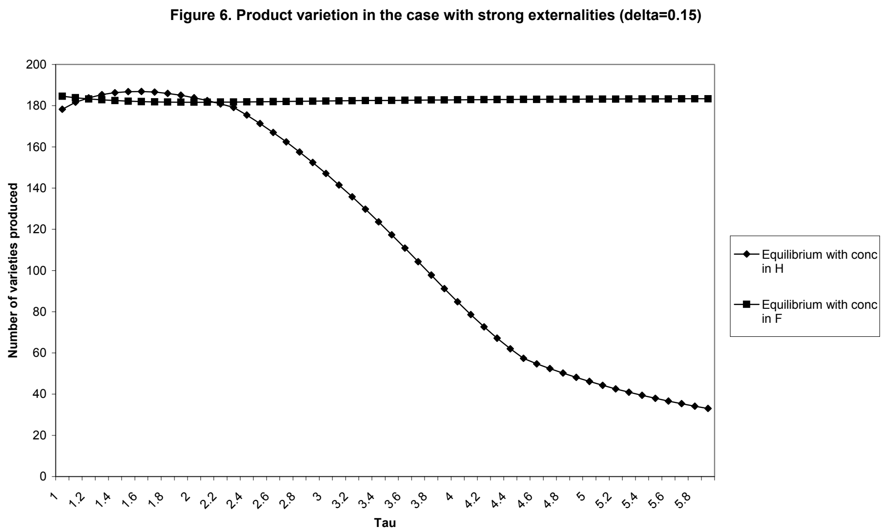

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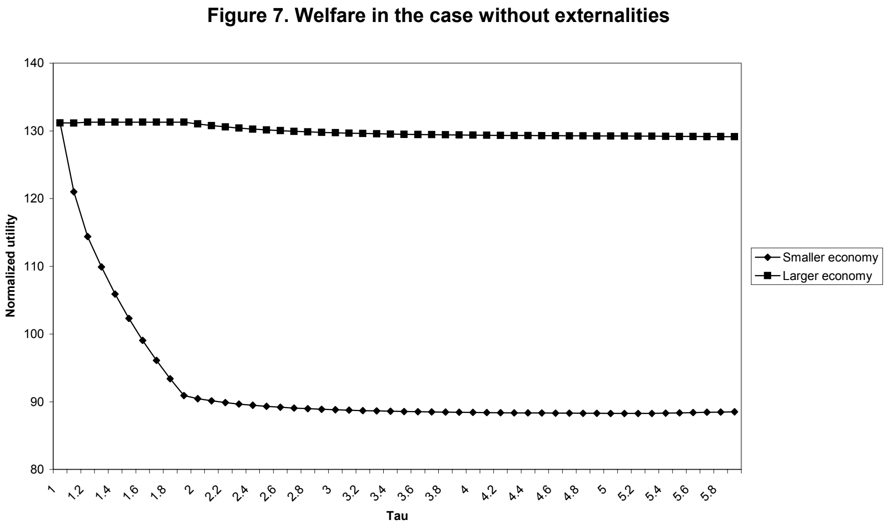

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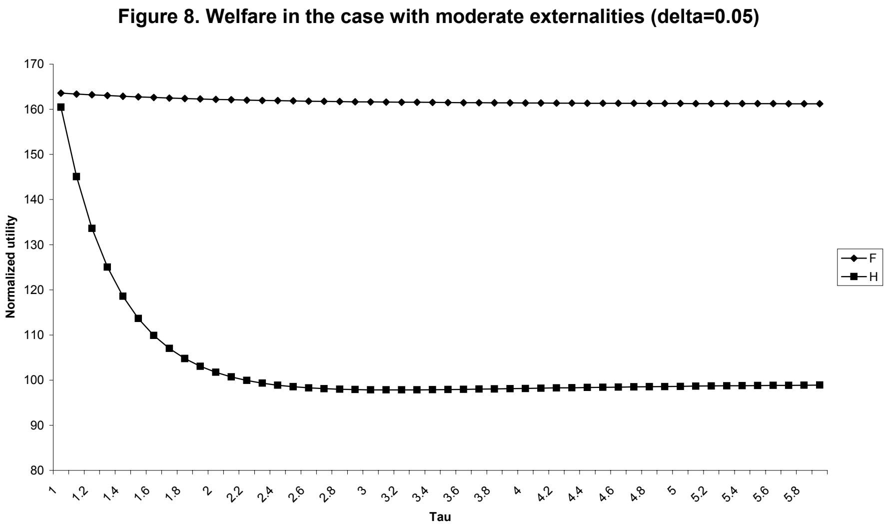

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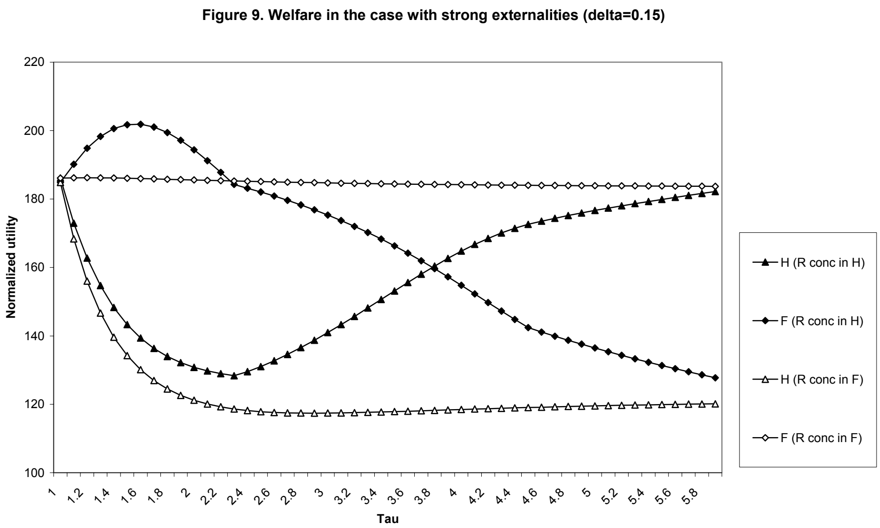

Figure 9. Welfare in the case with strong externalities (delta=0.15)
Normalized utility
Tau
H (R conc in H)
F (R conc in H)
H (R conc in F)
F (R conc in F)

Figure 13: