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Centralized R&D Subsidy Policy in an NEGG Model: A Welfare Analysis

Benjamin Montmartin*

1 Introduction

Since the Lisbon Agenda (2000), a growing number of European policies aim to support and strengthen the European dynamics of R&D and innovation. Although the objectives of this agenda have not been reached - 3% of the European Union GDP had to be devoted to R&D in 2010 (against only 1.9% of the GDP in 2008) - it appears that an increasing proportion of the EU budget is devoted to supporting R&D projects. The annual budget of the 7th Framework Program for Research and Development (2007-2013), was increased by more than 60% in comparison with the 6th. Another example which probably represents the most important change, concerns the European Regional Policy which was created to reduce regional disparities and support the development of lagging regions. Indeed, in previous programs, funds were mainly used to finance transport infrastructures in poorer regions while richer regions were not eligible for this program. The strategy for allocating funds of the Regional Policy has been profoundly changed for the current round (2007-2013) in order to meet the objectives of the Lisbon Agenda. For instance, whereas only 10.5 billion euros were used to finance innovation projects in the previous program, at least 183 billion euros will be devoted to this purpose within the actual one. Moreover, in this new program all European regions can obtain funds for innovative projects (even though most of the funds is still reserved for poor regions). In our point of view, this reflects a deep change in the European authorities’ vision of the best way to reach the objectives of a

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1 See Becker and Fuest (2010) for more details.
higher growth and a reduction of disparities between European regions, i.e., by helping all regions to develop through innovation in order to find their place in an economic system based upon knowledge.

Is this shift of European public policies in favor of R&D and innovation able to reach both objectives of higher growth and lower inequalities? and to remove distortions and increase national as well as global welfare?

Using a two-country NEGG (New Economic Geography and Growth) model with localized spillovers, we show that a centralized R&D subsidy policy can reach the objectives of both higher efficiency and lower inequalities. Indeed, by reducing the cost of R&D, the policy increases the investment in R&D and therefore the aggregate growth rate. We suppose that the policy is funded by a proportional tax on the profits of industrial firms so that the policy reduces the value of capital and therefore the capital revenue of consumers. As we suppose that country $a$ holds initially more capital than country $b$, it follows that the policy reduces the revenue inequality. The location framework of our model exhibits the famous Home Market Effect meaning that location of industrial firms depends on revenue inequality. As the policy reduces revenue inequality, industrial firms have less incentive to locate in the bigger market so that the spatial concentration of industrial sector in country $a$ decreases.

If the policy has the capacity to remove some distortions such as those due to the presence of knowledge spillovers in the innovation process, it does not achieve a first best. Moreover, we have to take into account the fact that the policy has also a cost. In order to determine the optimal level of public intervention, we conduct a welfare analysis using different criteria like Bentham or Rawls. Three main results emerge. Firstly, the policy can always improve global welfare. Secondly, the effect of the policy upon individual welfare and the level of the optimal policy depends fundamentally upon the intensity of international spillovers. The reason being that the pro-growth effect of the policy is an increasing function of the internationalization of knowledge externalities. As a consequence, the policy creates antagonistic effects on individual welfare when knowledge spillovers are localized. In that case, the welfare in the core country decreases with the policy’s magnitude whereas the welfare in the periphery country increases. The only case where the policy is a positive-sum game is when the intensity of international spillovers is high. Thirdly, our results show that trade integration significantly influences (and reduces) the (positive) effects of the policy when knowledge spillovers are strongly localized. The reason being that the pro-growth effect of the policy decreases with the level of trade integration. Therefore, the welfare analysis shows that the positive impact of the policy on efficiency and inequalities cannot be sufficient to justify its implementation.
The remainder of the paper is organized as follows: the next section introduces some results of the NEGG literature and highlights our contribution before presenting the general framework of our model in section 3. Section 4 presents our assumptions concerning the innovation process and defines the steady state of the economy. Section 5 analyzes the effects of the centralized R&D policy on endogenous variables and discusses its effects on distortions. Section 6 proposes a welfare analysis of the policy and section 7 concludes.

2 Related literature

Several elements of economic theory justify the implementation of a centralized policy supporting R&D. For instance, The Traditional Theory of Fiscal Federalism (Tiebout 1956, Musgrave 1959, Oates 1972) concludes that central authorities should be responsible for macroeconomic stabilization policies as well as for policies devoted to activities that exceed the bounds of lower level authorities’ interest because they generate important externalities. This result is quite apt where R&D activities are concerned. More generally, economic theory shows that coordinating R&D policies appears to be desirable from a welfare point of view (see Haaland and Kind 2006 and Chu 2009) because this allows some distortions to be internalized, especially those related to the presence of knowledge spillovers in R&D activities.

Other benefits of centralized R&D policies have also been highlighted by the NEGG literature. The advantage of this literature (Walz 1996, Martin and Ottaviano 1999, Baldwin et Forslid 2000a et 2000b) is that it proposes a synthesis of the new economic geography and the new growth theory. All contributions in this field of literature use a growth process à la Romer (1990) and Grossman and Helpman (1991). There exist however, some differences in the “location” framework used and we can break these contributions down into two categories. The first class of models includes cumulative causation mechanisms related to migration or vertical linkages whereas the second one with the Footloose Capital framework excludes such mechanisms. Consequently, the first class of agglomeration and growth models focused mainly upon the study of the stability of symmetric or Core-Periphery configurations in a context of economic integration. Some papers however, using a FC framework like those of Martin (1999), Riou (2003) or Baldwin et al. (2003), are more oriented towards studying the impacts of different public policies. Indeed, within such a framework, the location equilibrium is always stable and the issues of stability do not need to be addressed.
In his paper, Martin (1999) studies the effects of different public policies using the model of Martin and Ottaviano (1999) with localized spillovers. His results show that only a public support to R&D that decreases the cost of R&D or improves the productivity of such activities is able to meet objectives of both higher efficiency and lower inequalities; Other policies studied (direct transfer or investment in transport infrastructures) always lead to a tradeoff between growth and inequality. These results are extended by Riou (2003) showing that investment in telecommunication infrastructures which improve technology transfers between countries can also overtake this tradeoff. According to these results the increasing importance of R&D policies in the European budget and especially the shift of the new regional policy towards innovation appears to be heading in the right direction in order to reduce inequalities while strengthening economic growth.

Nevertheless, a direct application of the teachings gained from these contributions in terms of public policy could be misleading insofar as these papers only studied the effects of an exogenous decrease of R&D cost (on endogenous variables). They don’t model the financing and allocation of subsidies that would induce such a decline. In this paper, we introduce an endogenous R&D subsidy policy in a two-country NEGG model à la Martin and Ottaviano (1999) where the central government taxes the profit of industrial firms in order to subsidy R&D activities. This enables an improved understanding of the different effects of the policy and especially those related to the financing (which were absent in previous contributions).

The main contribution of this paper however, is to propose a welfare analysis of the endogenous centralized R&D policy. Indeed, by taking into account a budget constraint and the cost of the policy, it appears that even if the policy has positive effects on growth and inequalities it can have antagonistic effects on individual welfare when knowledge flows between countries are not high. Consequently, the optimal policy varies significantly according to the welfare criterion retained which can just as easily justify or reject the implementation of the centralized R&D policy. These results therefore suggest that the ease and the benefit of a centralized R&D policy crucially depends on the knowledge transfers between countries.

3 The framework

The general framework is based upon Martin and Ottaviano (1999). The economy is composed of two countries a and b, two factors of production (L and K), three private sectors (T, M and I) and one public sector. The labor endowment of each country is fixed and equal to L whereas the knowledge capital (K) is produced by the Innovative sector (I). Contrary to the knowledge capital which is supposed to be perfectly mobile, labor is geographically immobile but sectorially mobile.
I-sector is perfectly competitive and produces one unit of $K$ with $a_I$ units of $L$. I-Firms sell blueprints of variety to Manufacturing firms (M) with an infinitely lived patent which gives them a perpetual monopoly rent. M-firms face Dixit-Stiglitz monopolistic competition and increasing returns. Each differentiated variety is produced by a single M-firm using $\beta$ units of $L$ and one unit of $K$. The Traditional sector (T) is perfectly competitive and produces a homogeneous good using one unit of $L$. Trade in M-varieties is subject to Iceberg cost whereas trade is costless in the T-sector. Finally, in our model the public sector has a merely redistributive role, i.e., it applies a proportional tax on the monopoly rent of M-firms to subsidize R&D firms (the subsidy covers a part of the R&D cost. In this paper, we assume that the government does not geographically differentiate the tax rate or the level of subsidy such that $T = T_a = T_b$ and $S = S_a = S_b$, i.e., the tax rate on M-firms as well as the level of subsidy are the same in both countries\(^2\). In what follows, we assume that the T-sector is active in both countries at the equilibrium. Using the homogeneous good as numéraire, the wage rate and the price of this good are equal to one. We summarized the basic structure of the model in figure 1 below.

Figure 1. Basic structure of the model

\(^2\) We discuss this assumption in the conclusion.
3.1 Consumption and production

Let $N_w$ be the number of differentiated varieties available in the economy. Consumer preferences are given by a Cobb-Douglas utility function and an intertemporal CES function with unit elasticity of intertemporal substitution:

$$
\int_0^\infty \ln\left[D(t)^\alpha H(t)^{1-\alpha}\right] e^{-\rho t} dt
$$

where $H$ is the consumption of the homogeneous good, $\rho \in [0;1]$ is the time preference and $\alpha \in [0;1]$ represents the share of expenditure devoted to the consumption of differentiated goods. Demand for differentiated goods in country $a$ is represented by a CES function à la Dixit-Stiglitz (1977):

$$
D_a(t) = \left[\int_0^{N_a} D_a^c(t) \frac{e^s}{H_a} da + \int_0^{N_b} D_a^b(t) \frac{e^s}{H_a} da \right]^{\frac{\sigma}{\sigma - 1}}
$$

$N_a(N_b)$ denote the number of varieties produced in region $a$ ($b$) such that $N_a = N_{a-b}$ and $\sigma$ represents the elasticity of substitution between varieties as well as the price elasticity of demand for each variety. The expenditure of a representative consumer located in country $a$ is given by:

$$
E_a(t) = \left[\int_0^{N_a} D_a^c(t) P_a^c da + \int_0^{N_b} D_a^b(t) P_a^b da + P_a H_a \right]
$$

$D_a^c$ and $D_a^b$ are the demands for a variety produced in country $a$ and $b$ of a consumer located in $a$. $P_a^c$ and $P_a^b$ are prices of the $i$-th variety produced in $a$ and $b$. In what follows, we leave implicit the dependence of variables on time except for initial variables subscripted by 0.

Consumers solve their maximization problem in two separate steps. First, the consumer maximizes his utility (1) with respect to his budget constraint (3). For a representative consumer located in country $a$, we have:

$$
H_a = (1 - \alpha) E_a
$$

$$
D_a^c = \frac{\alpha E_a (P_a^c)^{-\sigma}}{\Delta} \quad D_a^b = \frac{\alpha E_a (P_a^b)^{-\sigma}}{\Delta}
$$

$$
\Delta = \int_0^{N_a} (P_a^c)^{1-\sigma} + \int_0^{N_b} (P_a^b)^{1-\sigma}
$$

Second, the representative consumer achieves an intertemporal trade off between consumption and saving. As in Grossman and Helpman (1991, chp.3), saving takes place in the form of a riskless asset that pays an interest rate $r$ or in the form of investment in shares of M-firms on a world stock market. Through this market, M-firms finance the unit of knowledge capital that they are required to produce. Therefore, individual income is composed of the wage rate equal to one and of the investment returns in

---

3 In this kind of model, firm shares are riskless assets because they will reflect the real value of firms. This is due to the fact that we remove the case of a speculative bubble.
M-firms. Knowledge capital $K_a(0)$ and $K_b(0)$ are assumed to be owned by consumers from the start with an inequality such that:

$$K_a(0) > K_b(0)$$  \hspace{1cm} (6)

This initial asymmetry will lead to an income and expenditure inequality between countries. The free capital mobility hypothesis ensures that the incentives to accumulate capital are the same in both countries. This implies that the share of knowledge capital owned by each country is stable over time and given by the initial distribution (6). In this second step, the consumer maximizes his utility (1) with respect to his intertemporal budget constraint which is given by:

$$\dot{z} = w + rz - E_a$$

where $z$ is the value of the asset stock of a representative consumer. Solving the Hamiltonian, we obtain the Euler equation for the evolution of expenditure:

$$\frac{E_a}{E_a} = r - \rho$$  \hspace{1cm} (7)

Note that as consumers’ preferences are the same in both countries, the growth rate of expenditure is also the same.

On the supply side, M-firms have the same technology and we assume that the tax rate is the same in both regions$^4$. Therefore, we can write the post-tax operating profit of an M-firm located in country $a$ as:

$$\Pi_a = [(P^a_o D^a_o + P^a_e D^a_e) - \beta(D^a_o + \tau D^a_e)](1 - T)$$  \hspace{1cm} (8)

As trade in M-varieties is subject to Iceberg cost, $r > 1$ units must be shipped to sell one unit abroad which explains why M-firms have to produce $\tau D^a_e$ to meet foreign demand. Maximization of profit implies that M-firms mark up price over marginal cost by a factor of $\frac{\beta}{\sigma - 1}$. Using a corresponding expression of (8) for country $b$, the optimal pricing policy of M-firms is given by:

$$P^a_o = P^b_o = \frac{\beta \sigma}{\sigma - 1} \quad P^a_e = P^b_e = \frac{\tau \beta \sigma}{\sigma - 1}$$  \hspace{1cm} (9)

As firms’ and consumers’ behavior are the same in both regions, we can rewrite the operating profit of a firm located in region $a,b$ as:

$$\Pi_{a,b} = \frac{\beta x_{a,b}}{\sigma - 1}(1 - T)$$  \hspace{1cm} (10)

where $x_{a,b}$ represents the total production of a firm located in country $a,b$.

$^4$ Note that in our model a proportional tax on the operating profit of M-firms is equivalent to a tax on GDP to within one constant. This hypothesis reflects the fact that most of the EU budget comes from a uniform tax applied to the GDP of each member.
3.2 Location equilibrium of the industrial sector

In a first step, we introduce optimal prices (9) in demand functions (5) to obtain optimal demands of a consumer located in region $a$:

$$D_a^e = \frac{\sigma - 1}{\beta \sigma} \frac{\alpha E_a}{N_a + \phi N_b} \quad D_a^b = \frac{\sigma - 1}{\beta \sigma} \frac{\alpha E_a e^{-\rho}}{N_a + \phi N_b}$$

(11)

where $\phi = \tau^{-\sigma}$ represents the level of trade integration.

We now have to define the condition which ensures equilibrium on the differentiated goods market. Using expressions (11) and corresponding expressions for region $b$, we obtain the level of production in each country:

$$x_a = \frac{\alpha L (\sigma - 1)}{\beta \sigma N_w} \left( \frac{E_a}{s_n + \phi (1 - s_n)} + \frac{\phi E_b}{\phi s_n + (1 - s_n)} \right)$$

(12)

$$x_b = \frac{\alpha L (\sigma - 1)}{\beta \sigma N_w} \left( \frac{\phi E_a}{s_n + \phi (1 - s_n)} + \frac{E_i}{\phi s_n + (1 - s_n)} \right)$$

(13)

where $s_n = N_a / N_w$ is the share of M-firms located in country $a$. With perfect capital mobility, location equilibrium must satisfy the condition of equality of post tax operating profit. Indeed, for a constant share of manufacturing firms ($s_p$) exists, M-firms must have no incentives to relocate their production, i.e, $\Pi_p(1 - T) = \Pi_b(1 - T)$. Using equations (12) and (13), we get:

$$s_n = \frac{s_a - \phi (1 - s_n)}{1 - \phi}$$

(14)

where $s_n = E_a / E_w$ is the share of expenditure and income held by consumers located in country $a$. This last expression highlights the famous Home Market Effect that reflects the fact that due to the presence of increasing returns and trade cost, the country that has the highest market size (or the highest level of spending) will attract a more than proportional share of firms ($s_n > s_p$). Note that the higher the trade integration, the higher the concentration of M-firms in the core country. Finally, we can establish the equilibrium production of M-firms for a given level of expenditure by introducing (14) in (12):

$$x = \frac{\alpha L \sigma - 1}{\beta \sigma N_w}$$

(15)

Expression (15) corresponds to the optimal production of all M-firms (regardless of their location).
4 Innovation production function, location of R&D and the steady state

4.1 Innovation process and knowledge externalities

In this model, the innovation sector works as in Grossman and Helpman (1991, chap.3). Innovation corresponds to the increase in the number of available M-varieties and is a constant returns to scale activity for individual firms. It produces however, increasing external returns to scale. In order to produce one unit of knowledge capital, researchers must use \( a_I \) units of labor. Following Romer (1990), we assume that \( a_I \) follows a learning curve, i.e., the marginal cost of one unit of knowledge capital decreases gradually as the number of M-firms increases (R&D productivity increases with the number of M-firms). Therefore, knowledge spillovers are transmitted from production to design. Moreover, we make the assumption as Baldwin et al. (2001) do that these knowledge externalities are partially localized. This implies that a country’s production cost for knowledge capital depends negatively on the number of national M-firms and to a lesser extent on the number of M-firms located in the other country. It refers to the idea that intranational spillovers or Marshall-Arrow-Romer externalities (Glaeser and al., 1992) are stronger than international spillovers that are transmitted by trade for instance (Feldman, 2000). This assumption is directly related to the stylized fact that knowledge spillovers are geographically bounded and decrease as geographical distance increases. We can summarize these assumptions by the following innovation production function:

\[
K = \frac{L_I}{a_I} = \frac{L_I^a}{a_I^a} + \frac{L_I^b}{a_I^b}
\]

\[
a_I^a = \frac{1}{K^a A^a} \quad a_I^b = \frac{1}{K^b A^b}
\]

\[
A_a = s_a + \lambda (1 - s_a) \quad A_b = \lambda s_a + 1 - s_a
\]

where \( a_I^a \) and \( a_I^b \) represent the productivity of R&D in countries a and b, \( K^a A^a \) and \( K^b A^b \) represent knowledge externalities for I-firms located in country a and b, \( L_I^a \) and \( L_I^b \) are the quantity of labor employed in R&D in country a and b and \( \lambda \in [0,1] \) is the intensity of international knowledge spillovers, i.e., the geographical scope of knowledge spillovers. Note that when spillovers are (partially) localized \((0 < \lambda < 1)\), it is less costly to conduct R&D in the country with the highest number of M-firms. As \( K^a(0) > K^b(0) \), the income of consumers in country a is higher than in country b for all \( t \) because initial endowments represent pure rents. Therefore, more M-firms locate in country a, see (14), thereby rendering R&D productivity higher in this country.
Consequently, the whole I-sector will locate in the richer country to benefit from higher knowledge spillovers.

Central government uses the tax revenue to subsidize I-firms. More specifically, we assume that it gives a subsidy covering a percentage of the R&D cost. In this paper, we only consider the case where the government does not differentiate the level of subsidies according to the country \((S_a = S_b = S)\) so that all R&D activities are located in country \(a\). Thus, we can rewrite the innovation production function (16) as:

\[
K_w = L_t K_w A
\]

and using the fact that the wage rate is equal to one, we can write the cost of producing one unit of knowledge capital as:

\[
F_I = \frac{1 - S}{K_w A}
\]

where \(S\) represents the level of the subsidy, i.e., the percentage of R&D cost covered by the subsidy. In order to express the level of the subsidy, we have to find the world labor demand for R&D activities using expressions (16):

\[
L_I = \frac{g}{A}
\]

(17)

where \(L_I\) is the world quantity of labor employed in R&D activities, \(g\) is the aggregate growth rate and \(A = A_a\) as all R&D activities are located in country \(a\).

In this model, we assume that the government has a balanced budget constraint. The rule of a balanced budget for the government is satisfied when the tax income is equal to expenditure. The government tax revenue is the sum of taxes collected from the \(N_w\) M-firms which corresponds to \(T\) times the tax base. Inserting (15) in (10), we obtain:

\[
\text{Tax Revenue} = T \frac{\alpha L E_w}{\sigma}
\]

Total government expenditure is simply equal to the quantity of labor employed in R&D multiplied by the percentage of R&D cost covered by the subsidy:

\[
\text{Total Expenditure} = L_t S
\]

---

5 Note that subsidizing production will have exactly the same effect.

6 This assumption is made for two main technical reasons. Firstly, the fact that the government proposes the same level of subsidy implies that the policy does not change the geography of R&D activities, i.e., all R&D firms are located in the large country and all subsidies go towards this country. This simplifies the analysis considerably. Secondly, if we differentiate the level of subsidy, then due to the assumption on the R&D sector, we cannot calculate the point where location of R&D is entirely in the periphery country. Indeed, the assumption of perfect competition makes the location equilibrium of R&D discontinuous so that there is an autodetermination problem. Nevertheless, we discuss the implications of a differentiated R&D subsidy policy in the conclusion.
Using these expressions and (17), we can define the level of subsidy satisfying the balanced budget constraint as:

$$S = T \frac{\alpha L A E_w}{\sigma g}$$

(18)

4.2 Labor market equilibrium and the growth rate

4.2.1 Labor market

As the labor is sectorially mobile, it will be used in all three private sectors of the economy. The world labor supply is fixed and equal to $2L$. Labor demand in the T-sector is obtained from (4). The quantity of labor used in the M-sector corresponds to the product of the individual production of firms (15), the number of M-firms ($N_w$) and the marginal need for labor ($\beta$). The demand of labor in the I-sector is simply given by (17). Therefore, the equilibrium condition for the labor market is:

$$2L = \frac{g}{A} + LE_w \left( \frac{\sigma - \alpha}{\sigma} \right)$$

(19)

As the labor supply is a constant, an equilibrium exists if and only if the demand for labor is also constant. Note that in (19), all terms are constant excepting $E_w$. Thus, $E_w$ has to be constant over time to have an equilibrium. This condition implies that:

$$r = \rho$$

(20)

Expression (20) means that the interest rate of riskless assets is constant and equal to the rate of time preference.

4.2.2 The equilibrium growth rate

The equilibrium growth rate is derived from the incentives to innovate. This requires the traditional condition of no opportunity for arbitrage between investing in R&D and borrowing at the safe rate $r$. Let’s call $v(t)$ the stock market value of an M-firm. This value corresponds to the present discounted value of its post tax operating profit. That is,

$$v(t) = \int_0^t e^{-[R(s) - R(t)]} \frac{\beta e(s)}{\sigma - 1} (1 - T) ds$$

(21)

where $R(t) = \int_0^t r(u) du$ is the cumulative discount factor applicable to profits earned from the period 0 to $t$. Differentiating (21) with respect to time gives us the no arbitrage condition which has to hold at every moment in time in order to ensure stock market equilibrium:

$$\dot{v} + \frac{\beta e}{\sigma - 1} (1 - T) = rv$$

(22)
With conditions of free entry and zero profits in the I-sector, the value of a firm is equal to the price of one unit of knowledge capital, i.e., the marginal cost of producing one unit of capital $F_I$. With a wage rate equal to one, we have the following equality at the equilibrium:

$$F_I = v = \frac{(1 - S)}{K_vA} \quad (23)$$

At the steady state, $A$ and $(1 - S)$ are constants. We can therefore easily calculate the growth rate of a firm’s value:

$$\frac{F_I}{v} = \frac{\dot{v}}{v} = -g \quad (24)$$

The firm’s value declines at a rate equal to the growth rate. The reason being that an increase of the growth rate means that more firms enter the market. This increases the competition in the M-sector thereby reducing individual profit. The value of a firm being the present discounted value of its profit, it follows that the value of a firm decreases when growth is positive. Substituting (15), (20), (23), (24) in (22), we can express the no arbitrage condition as:

$$\frac{\alpha LE}{\sigma (1 - S)} = \rho + g \quad (25)$$

To obtain the equilibrium growth rate, we have to substitute the expressions (18) and (19) in (25). We have to find the solution of a second degree polynomial function in $g$. There are two solutions but we focus on the case where the growth rate is positive, that is:

$$g = \frac{\Lambda + \sqrt{\Lambda^2 + 8\alpha \rho ALT}}{2\sigma} \quad (26)$$

$$\Lambda = \alpha [2AL - \rho T] - \rho (\sigma - \alpha)$$

Expression (26) indicates that a higher spatial concentration of M-firms in country $a$ will lead to a higher aggregate growth rate. The reason for this is that the spatial concentration of the industrial sector in the richer country increases R&D productivity which in turn increases the incentives to innovate and hence the growth rate. It should also be noted that parameters $\Lambda, \alpha$ and $L$ have a positive effect on growth whereas parameters $\sigma$ and $\rho$ have the opposite effect.

### 4.3 Income inequality and the steady state equilibrium

#### 4.3.1 Income inequality and growth

To obtain the steady state of the model, we have to define a last equilibrium relation. We have already defined how the equilibrium location of M-firms ($s_a$) is determined by expenditure inequality (14) and how the
equilibrium growth rate $g$ depends on $s_n$ (26). The last relation defines the income and expenditure inequality as a function of $g$. We know that in both regions nominal expenditure and consumers’ income are stable at the steady state. The consumer’s income is the sum of his labor income plus his capital income. Concerning labor income, each worker perceives a wage equal to one at each period. Concerning capital income, it should be noted that in both regions, the consumers’ capital stock grows at rate $g$ and the value of one unit of capital decreases at rate $g$. Thus, the value of capital income is stable over time. The consumer will then consume his labor income and $\rho$ times the value of the initial per-capita stock of assets as only the profits of this initial stock are pure rents. The income and expenditure of a representative consumer are therefore given by:

\[
E_a = 1 + \frac{\rho K_s(0)e(0)}{L} \quad \text{and} \quad E_b = 1 + \frac{\rho K_s(0)e}{L}
\]

Inserting (23), we can rewrite these expressions as

\[
E_a = 1 + \frac{\rho s_k(1 - S)}{LA} \quad \text{and} \quad E_b = 1 + \frac{\rho (1 - s_k)(1 - S)}{LA} \quad (27)
\]

Using expressions (19) and (26) and inserting them into expressions (27), we can express the equilibrium relation between the income inequality ($s_e$) and the growth rate ($g$):

\[
s_e = 1 + \frac{\alpha \rho (2s_k - 1)(1 - T)}{2 \sigma (g + \rho)}
\]

where $s_k = K_s / K_w$ represents the share of world capital stock owned by consumers located in country $a$. Note that, as long as $s_k > 1/2$ and $T < 1$, the nominal income is higher in country $a$ than in country $b$. Moreover, it should be noted that the income and expenditure gap decreases in $g$; the reason being that a higher growth rate implies higher competition in the M-sector and therefore a reduction of individual profit. It should be remembered that the value of a firm is the present discounted value of its profits. As income from capital is a more important part of total income in country $a$ than in country $b$, the fall in the firm’s value will have a higher impact on consumers in country $a$. For this reason, the income inequality between countries decreases with the growth rate.

4.3.2 The steady state

To close the model, we have to define the location equilibrium of M-firms and the growth rate at the steady state. Inserting expressions (26) and (28) in (14), we obtain:

\[
s_n = \frac{1}{2} + \frac{\alpha \rho (1 - T)(2s_n - 1)}{\rho (\alpha + \sigma) + \sqrt{\Lambda^2 + 8ALT \alpha \sigma \rho + \alpha (2AL - \rho T)} \left(1 + \frac{\phi}{1 - \phi}\right)}
\]

with $A = s_n + \lambda(1 - s_n)$.
We can rewrite (29) as $f(s_n) = a s_n^3 + b s_n^2 + c s_n + d = 0$. This implies that $s_n$ is the solution of a third degree polynomial function. The solution of this polynomial function is given in appendix A. To obtain the equilibrium growth rate, we have to replace the solution of (29) in expression (26).

5 Distortions and effects of the R&D subsidy policy

5.1 Distortions in the model

Three main distortions are present in the model of Martin and Ottaviano (1999) with localized spillovers. Two of these are classical distortions of endogenous growth models, namely, the presence of knowledge spillovers in the innovation process and the market power of manufacturing firms. Both lead agents to under-invest in R&D. The last distortion is more specific to new economic geography models and related to the location’s choice of M-firms which generates different externalities that consumers do not internalize. More precisely, the location choice implies three types of externalities. In what follows, we describe the incidence of these externalities by analyzing how the location choice influences the real revenue of consumers.

Firstly, agents do not internalize that the spatial concentration has a negative effect upon the world price index in each region (because differentiated goods are traded with cost). It can be easily shown that the sum of price indexes is minimized when industrial firms are perfectly dispersed between countries. From the point of view of this externality, optimal location is $s_n = 1/2$ whereas free market location is higher. The spatial concentration being positively related to the level of investment in R&D this externality leads agents to over-invest in R&D.

Secondly, agents do not internalize that the spatial concentration has a pro-growth effect. Consequently, from the point of view of this externality, optimal location is a total concentration of industry in the core country. When free market equilibrium is different from $s_n = 1$ then this

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7 The world price index is equal to the sum of national price indexes. The price index in country $i$ is given by $P_i = N_i^{1/2} [s_n P_i^{1-\sigma} + (1 - s_n) P_i^{2-\sigma}]^{1/2}$ and the price index in country $j$ is given by $P_j = N_j^{1/2} [1 - s_j] P_j^{1-\sigma} + s_j P_j^{2-\sigma}]^{1/2}$.

8 Indeed, in the model of Martin and Ottaviano (1999), the level of investment in R&D is measured by the quantity of labor employed in the R&D sector (as labor is the only input of R&D). This level of investment in R&D is given by $L_g = g A$ where $g$ and $A$ increases with the spatial concentration of manufacturing firms $s_n$. It can be easily shown that $dL / ds_n > 0$ so that in the model an increase of spatial concentration leads to an increase of R&D investment.
externality leads agents to under-invest in R&D (the reason again being that in the model, investment in R&D is positively correlated with spatial concentration).

Finally, agents do not internalize that spatial concentration has a negative effect upon the nominal income (see (27)). Consequently, from the point of view of this externality, optimal location is a dispersed equilibrium so that free market location is suboptimal. It follows that this externality leads agents to over-invest in R&D at the market equilibrium.

To summarize, the location decision of M-firms generates three types of externalities which agents do not internalize. Two of these lead agents to over-invest in R&D whereas the other leads them to under-invest. Consequently, the net effect of the location choice depends on the relative strength of these externalities. Martin and Ottaviano (1999) point out however, that it is impossible to analytically determine the optimal location and hence we cannot conclude on the net effect of the distortion introduced by the location choice.

We will now analyze the effects of the centralized R&D subsidy policy on the endogenous variables of the model \((s_n, g, s_e)\) which will allow us to understand its effects upon distortions.

### 5.2 Effects of the R&D subsidy policy

#### 5.2.1 Impact upon the location of manufacturing firms

Here, we seek to understand the impact of a variation of the subsidy upon the location of M-firms. As the level of subsidy is directly (and positively) related to the tax rate due to the budget constraint, it is easier to directly analyze the impacts of a variation of the tax rate. Using expressions (14), (26) and (28), the first derivative of \(s_n\) with respect to \(T\) can be expressed as:

\[
\frac{ds_n}{dT} = \left( \frac{\partial s_n}{\partial s} \frac{\partial s}{\partial T} + \frac{\partial s_n}{\partial g} \frac{\partial g}{\partial T} \right) \left( 1 - \frac{\partial s_n}{\partial s} \frac{\partial s}{\partial g} \frac{\partial g}{\partial s_n} \right)^{-1} < 0
\]

(30)

The proof of this result is given in appendix B. This expression shows us that the higher the tax rate (the level of subsidy) the lower the spatial concentration in the core country. This result is related to three different effects.

The inequality effect represents the influence of the policy on the location of M-firms via its direct effect upon income inequality. To illustrate this first effect, we suppose that the government raises its tax rate. In this case, the level of subsidy increases which allows a decrease in the cost of producing one unit of capital. The value of capital being equal to its marginal cost of production, it follows that a higher tax rate leads to a lower value of...
capital. Consumers of country $a$ having a higher part of wealth related to capital revenue, it follows that income inequality and the spatial concentration of M-firms in the core country decreases. Therefore, the inequality effect refers to the direct impact of the policy’s financing upon the value of capital which is absent from Martin’s (1999) analysis.

The growth effect represents the influence of the policy upon the location of M-firms via its effect upon the growth rate. As before, to illustrate this effect, we suppose that the government raises its tax rate. In this case, ceteris paribus, public funds and the level of subsidy increase and contribute to the decrease of the cost of R&D. It follows that investment in R&D and growth increase. A higher growth rate means a higher decrease of the value of the capital. Consumers of country $a$ having a higher part of wealth related to capital revenue, it follows that income inequality decreases. Agglomeration of industrial activities being directly (and positively) correlated with income inequality (see (29)), the “growth effect” leads to a delocation of a part of M-firms towards the periphery country. This effect is different from the previous one because it refers to the impact of a higher growth on the income inequality, i.e., it is a consequence of inequality effect. Nevertheless, these two effects can be viewed as centrifugal forces.

The R&D productivity effect is the consequence of the two first. It represents the influence of the policy upon the location of M-firms via its indirect effect on R&D productivity. We have seen that the “growth and inequality” effects will lead to a reduction of the spatial concentration of M-firms. But as we can see in (26), a decrease in the concentration of M-firms influences the growth rate because it reduces the R&D productivity (spillovers effect). Thus, the move of M-firms towards the poorer region has in itself an influence upon the growth rate and income inequality. This “productivity effect” will limit the decrease in the spatial concentration of M-firms and forms a centripetal force.

If the net effect of the policy upon the location of M-firms is the same as highlighted by Martin (1999) when studying an exogenous policy, this analysis improves our knowledge about how the mechanisms come into play. Indeed, if Martin (1999) highlights “the growth effect” and its impact upon “the productivity effect”, he omits the “inequality effect” and its impact upon the “productivity effect”.

### 5.2.2 Impact upon the growth rate

Using expressions (26), the first derivative of $g$ with respect to $T$ can be expressed as:

$$\frac{dg}{dT} = \frac{\partial g}{\partial T} + \frac{\partial g}{\partial s} \frac{ds}{dT} > 0$$

(31)
The proof of this result is given in appendix C. This expression shows us that the higher the tax rate (the level of subsidy), the higher the growth rate. This result is related to two different effects.

The first, namely the “cost effect”, represents the influence of the policy upon growth via its direct effect on the reduction of the R&D cost. A higher level of subsidy will lower the R&D cost and increase the incentives of agents to engage in these activities. It follows from the innovation production function that an increase of investment in R&D increases the growth rate.

The second, namely the “location effect”, represents the influence of the policy upon growth via its direct effect on the location of M-firms. As we have seen before, a higher tax rate will decrease spatial concentration in the core country thereby lowering the R&D productivity (via a reduction of knowledge spillovers). Ceteris paribus, this effect reduces the incentives to engage in R&D and the positive effect of the policy upon the growth rate.

5.2.3 Impact upon income inequality

The last endogenous variable of the model is the income inequality between countries. Using (29), we can express the derivative of $s_e$ with respect to $T$ as:

$$\frac{ds_e}{dT} = \frac{\partial s_e}{\partial T} + \frac{\partial s_e}{\partial g} \frac{dg}{dT} < 0$$

This result becomes obvious when the previous two are verified. This expression demonstrates that the higher the tax rate (the level of subsidy), the lower income inequality is. This result is related to two different effects.

The first, namely the “wealth effect”, represents the influence of the policy upon the income inequality via its direct effect on nominal income. If the government raises the tax rate then the subsidy increases and the value of capital decreases. As consumers in country $a$ own more capital it follows that the income inequality decreases.

The second, namely the “competition effect”, represents the influence of the policy upon the income inequality via its direct effect on the competition in the M-sector. As we have seen before, a higher tax rate increases growth and competition in the M-sector. Individual profit of M-firms decreases thereby lowering the value of capital. Consequently, the “competition effect” decreases the income inequality.

These two effects reinforce each other. If the net effect of the policy upon the income inequality is the same that highlighted by Martin (1999), our analysis improves our knowledge concerning the mechanisms which
come into play. Indeed, if Martin highlights the “competition effect”, his analysis does not take into account the “wealth effect” which is the most significant and directly related to the financing of the policy.

The analysis of the effects of the R&D subsidy policy on the endogenous variables of the model leads us to write the following proposition:

**Proposition:** The implementation of a centralized R&D subsidy policy can reach the objectives of both higher efficiency and lower inequalities in the sense that it allows the growth rate to increase (i), a decrease in income inequality (ii) and a decrease in the concentration of industrial activities in the core country (iii).

### 5.2.4 Impact upon distortions

As we only consider an R&D policy, it is not possible to correct the distortion related to the market power of M-firms. Consequently, this kind of policy can only reach a second best. Concerning the distortion related to the presence of knowledge spillovers, it is clear that the policy increases the level of investment in R&D and is able to correct this distortion. Indeed, the level of investment given by expression (17) has $g$ as numerator and $A$ as denominator. As an increase of $T$ increases $g$ and lowers $A$, it follows that the policy has a strong impact upon R&D investment. By contrast, as we cannot determine the optimal location, we are unable to reach a conclusion concerning the distortion related to the location choice of manufacturing activities. Consequently, the impact of the policy upon the distortion related to the location choice could be either positive or negative depending on the sign of the gap between free market equilibrium location and optimal location. It therefore appears necessary to carry out a welfare analysis.

### 6 Welfare analysis

#### 6.1 Policy’s impact on welfare and welfare criteria

We measure individual welfare using the indirect utility of consumers. Let us call $V_a$ and $V_b$ the indirect utility of a representative consumer in countries $a$ and $b$. Using equations (1), (4), (5) and (27), we obtain the following expressions:

\[
V_a = \frac{1}{\rho} \log \left[ C \left( 1 + \frac{\lambda_s (1 - S)}{LA} \right) s_n (1 - \phi) e^{\frac{\sigma}{\rho}} \right] \tag{33}
\]

\[
V_b = \frac{1}{\rho} \log \left[ C \left( 1 + \frac{\lambda_k (1 - S)}{LA} \right) (1 - s_n (1 - \phi)) e^{\frac{\sigma}{\rho}} \right] \tag{34}
\]
with

\[ C = \alpha^c (1 - \alpha)^{1-\alpha} N_v(0)^{\frac{\alpha}{\sigma(1-\sigma)}} \]

In order to highlight the different impacts of the innovation subsidy policy upon the consumer’s welfare, we will analyze the first derivative of expressions (33) and (34) with respect to \( T \):

\[
\frac{dV_a}{dT} = \frac{\alpha}{\rho(\sigma-1)(1-s_a(1-\phi) + \phi) dT} \frac{1}{\rho} \frac{d\log E_a}{dT} + \frac{\alpha}{\rho^2(\sigma-1)} \frac{dg}{dT} \quad (35)
\]

\[
\frac{dV_b}{dT} = -\frac{\alpha}{\rho(\sigma-1)(1-s_b(1-\phi) dT} + \frac{1}{\rho} \frac{d\log E_b}{dT} + \frac{\alpha}{\rho^2(\sigma-1)} \frac{dg}{dT} \quad (36)
\]

The first term of expressions (35) and (36) or the transport cost effect refers to the impact of the policy upon the consumer’s welfare via its effect upon the location of manufacturing firms. Indeed, it should be recalled that an increase of the tax rate reduces income inequality and leads to a relocation of some M-firms from country \( a \) to country \( b \). Therefore, consumers from country \( b \) will save the transport cost on the goods produced by M-firms that move whereas the opposite occurs in country \( a \). This explains why the transport cost effect is negative for country \( a \) and positive for country \( b \). It should also be noted that in absolute value, the impact of the transport cost effect is lower for country \( a \) than for country \( b \). In other words, the transport cost effect is positive at the global level. The reason being the transport cost effect is lower in country \( a \) than in country \( b \) in absolute value, i.e, the increase of the price index in region \( a \) is lower than the decrease of the price index in region \( b \).

The second term of expressions (35) and (36) or the wealth effect refers to the impact of the policy upon the consumer’s welfare via its effect on nominal income. It should be remembered that the value of knowledge capital decreases with the level of subsidy, see (23). An increase in the tax rate will therefore reduce the nominal income in both countries but the effect will be stronger in the core country \( (a) \) as a more important part of the total income is related to capital income. To summarize, the wealth effect is negative because it reduces the nominal income in both countries but the effect is greater in the richer country.

The third term of expressions (35) and (36) or the growth effect refers to the impact of the tax rate upon the consumer’s welfare via its effect on the growth rate. A higher growth rate corresponds to a stronger creation dynamic of industrial activities so that at each period the number
of M-firms increases. This greater dynamic will lead to a decrease of the price index in both countries and hence to an increase of real incomes. This explains why the growth effect is positive for both countries.

To summarize, the R&D subsidy policy affects the consumer’s welfare through three vectors. The wealth effect decreases welfare in both countries because it reduces nominal income. In contrast, the growth effect increases welfare in both countries because it raises the real income. Finally, the transport cost effect is positive for consumers located in country $b$ as opposed to those located in country $a$ as the R&D policy leads to a delocation of industrial activities from country $a$ to country $b$.

Our welfare analysis is strongly influenced by Charlot et al.’s (2006) method which applies different welfare approaches to Krugman’s (1991) Core-periphery model to compare agglomeration and dispersion outcomes. In our case, we propose to discuss and compare outcome optimality according to three different welfare criteria. Unfortunately, and contrary to Charlot et al. (2006), given the complexity of the model, we will be obliged to use simulations. Indeed, given this complexity, we cannot determine analytically the optimal policy.

Among the three criteria, two are classical welfare criteria (Bentham and Rawls) which define the notion of optimality in very different ways. Indeed, the Bentham criterion only takes global welfare into account whereas the Rawls criterion only takes the situation of the poorest country into account. Nevertheless, we think that it is useful to use a more complex criterion which takes global welfare into account but also individual considerations. This criterion that we will call Participation criterion defines the optimum as the level of tax rate which maximizes global welfare and ensures, for the two countries, at least, the same level of welfare as that obtained without the policy.

### 6.2 Optimal policy

In this sub-section, we will analyze the optimal level of the policy according to the various welfare criteria previously defined. The values of the parameters used for the simulations presented below are based upon those of Martin and Ottaviano (1996).9

#### 6.2.1 An economy with a low intensity of international knowledge spillovers

Here, we will investigate the optimality of the R&D subsidy policy when knowledge spillovers are strongly localized, i.e., the flow of knowledge spillovers between countries is very low (we suppose that $\lambda = 0.1$). The figures...

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9 More precisely the values of the parameters used are: $\sigma = 0.5$, $\sigma = 3$, $\rho = 0.1$, $L = 0.4$, and $x_k = 0.7$
below represent the evolution of the welfare in each country and in the whole economy for different levels of trade integration. We will then denote the optimal tax rate as $T_x^*$ where $x$ is the abbreviation of the welfare criterion retained ($R$ for Rawls, $B$ for Bentham and $P$ for participation criterion).

Figure 2a. Evolution of welfare in country a

Figure 2b. Evolution of welfare in country b

Figure 2c. Evolution of global welfare

We can see in figures 2a and 2b that an increase in the tax rate (whatever the level of trade integration) has a conflicting effect upon consumer welfare. Indeed, whereas the consumer’s welfare in country $b$ increases with the tax rate, the consumer’s welfare in country $a$ decreases. According to the Rawls criterion, the government should implement the largest possible R&D subsidy policy ($T_R^* = 1$) whereas according to the Participation criterion, the government should not implement the policy ($T_P^* = 0$). Two reasons explain the conflicting effect of the policy. Firstly, the transport cost effect is positive for region $b$ whereas it is negative for region $a$. Secondly, the growth effect of the policy which is positive for both regions decreases with $\lambda$, i.e., the intensity of international knowledge spillovers. It should be remembered that the policy leads to a more dispersed geography of industrial activities which reduces R&D productivity.
and limits the positive effect of this policy upon growth. And the lower the intensity of international knowledge spillovers, the higher the cost (in terms of growth reduction) of the delocation of industrial activities towards the periphery country\textsuperscript{10}.

At the global level, we can see on figure 2c that the Bentham-optimal tax rate does not correspond to an extreme value of tax rate as it does for the other criteria. This figure highlights a very interesting result. Indeed, the Bentham-optimal tax rate decreases with the level of trade integration. This means that the positive effects of the policy decrease in a context of increasing trade integration when knowledge flows between countries are very limited. The reason for this result is that the higher the level of trade integration, the higher the impact of the policy upon the delocation of industrial activities (see proof in appendix D). Combining this with the fact that the delocation cost (in terms of growth reduction) of industrial firms is higher for a low value of international knowledge spillovers, it follows that the level of the Bentham-optimal tax rate decreases with the level of trade integration.

6.2.2 An economy with a higher intensity of international knowledge spillovers

Here, we will investigate the optimality of the R&D subsidy policy in an economy where the knowledge flows between countries are stronger than in the previous case. As we said before, the negative impact of the policy upon R&D productivity decreases with the intensity of knowledge spillovers, so that the positive impact of the policy on growth (and by extension on welfare) should be stronger. This is exactly what happens. Indeed, by carrying out simulations for $\lambda = 0.5$ et $\lambda = 0.9$, it clearly appears that optimal policies (according to the different criteria) converge to the same value as the intensity of international knowledge spillovers increases. For convenience, we do not represent figures corresponding to this case but compile a table summarizing the optimal policies according to the intensity of international spillovers and the welfare criterion retained.

Table 1 shows that although the policy always has a conflicting effect upon consumer welfare whatever the level of trade integration when $\lambda = 0.5$, at the global level, welfare always increases. Consequently if the optimal policy according to the Participation criterion is still defined by $T_P^* = 0$, the optimal policy according to the Bentham and Rawls criteria becomes the same and defined by $T^* = 1$. And when international knowledge spillovers are intense ($\lambda = 0.9$), then the conflicting effect of the policy on national

\textsuperscript{10} The first derivative of the intensity of international knowledge spillovers ($\lambda$) with respect to the location equilibrium ($s_i$) is given by $1 - \lambda$. Consequently, the lower $\lambda$ the higher the negative impact of a decrease of $s_i$ on $\lambda$ (and by extension on R&D productivity).
welfare disappears so that the optimal policy according to all welfare criteria is the same and defined by $T^* = 1$. Note that the cases where optimal policy is defined by $T^* = 1$ do not correspond to an optimum in the mathematical sense but to a corner solution. That means that, in these cases, welfare is an increasing function of $T$ on the interval $[0,1]$ and we suppose that the government cannot taxe profit at a higher rate than 100%.

Table 1. Optimal policies according to the intensity of international knowledge spillovers

<table>
<thead>
<tr>
<th>Criteria</th>
<th>$\lambda = 0.1$</th>
<th>$\lambda = 0.5$</th>
<th>$\lambda = 0.9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bentham</td>
<td>$T^* = f(\phi) \in [0,1]$</td>
<td>$T^* = 1$</td>
<td>$T^* = 1$</td>
</tr>
<tr>
<td>Rawls</td>
<td>$T^* = 1$</td>
<td>$T^* = 1$</td>
<td>$T^* = 1$</td>
</tr>
<tr>
<td>Participation</td>
<td>$T^* = 0$</td>
<td>$T^* = 0$</td>
<td>$T^* = 1$</td>
</tr>
</tbody>
</table>

This result is due to the fact that the higher the intensity of international knowledge spillovers the lower the impact of geography on growth and welfare. So, the negative impact of the policy on R&D productivity decreases and the positive effects of the policy on welfare increases. Consequently, the welfare analysis shows that it is necessary for knowledge flows between countries to be well-transmitted in order for the policy to be a positive sum-game.

In the European case, where policy decisions are more likely to be taken on a Participation criterion than on a Bentham or Rawls criterion, this result leads us to propose two main remarks. Firstly, it seems that between European countries knowledge externalities are more likely to be localized rather than global due to the importance of existing transfer barriers so that a centralized subsidy policy would be a zero-sum game where the core country loses welfare. This result may be one of the elements explaining the persistent weakness of the EU budget (around 1% of European Union GDP). Secondly, to make the implementation of a centralized R&D subsidy policy a positive sum-game, it appears important to develop the flows of knowledge between countries. Policies developing telecommunication infrastructures and human capital as vectors of knowledge flows could be used to serve this purpose.

7 Concluding Remarks

Given the increasing importance of R&D policies implemented at the European level, the main objective of this paper was to improve the theoretical understanding of the effects of a centralized R&D subsidy policy in
an economy composed of asymmetric countries with free capital mobility and localized knowledge spillovers.

Previous works by Martin (1999) and Baldwin et al. (2003) have shown that an exogenous decrease of R&D cost was able to simultaneously reach both objectives of higher efficiency and lower inequalities. If the endogenization of a (undifferentiated) centralized R&D subsidy policy does not change the net effects of the policy, it improves the understanding of such a policy in many ways. Firstly, the endogenization allows us to highlight new effects of the policy. Secondly, it allows us to analyze the effects of the policy on distortions and show that if this policy can reach (in the best case) a second best, it may also potentially lead to a deadweight loss. Thirdly, by realizing a welfare analysis, we show that such a policy has antagonistic effects on national welfare when knowledge flows between countries are limited (the core country loses in terms of welfare). Consequently, the implementation of a centralized R&D subsidy policy is a positive sum-game only if knowledge flows between countries are strong. This contrasts quite sharply with the positive impact of the policy on efficiency and inequalities.

In this paper, we have only studied an undifferentiated policy, i.e., we have supposed that the tax rate and the level of subsidies are the same in both countries. As the whole R&D sector is localized in the core country, this implies that all subsidies go towards the core country and are used to decrease the cost of R&D. What would happen if the central government chose to differentiate the level of subsidies to the benefit of the periphery country or chose a repartition of funds between countries? The answer is quite intuitive. If the differential level of the subsidy is high enough to compensate the R&D productivity gap between countries, then at least a part of R&D activities will be undertaken in the periphery country. That means that a part of the funds will be used in order to compensate a gap in productivity instead of decreasing the cost of R&D. It follows that the policy will have a lower positive impact on growth and by extension its capacity to remove distortions as well as to increase welfare will decrease.

In conclusion, it seems that the positive effects of a centralized subsidy policy in an economy composed of asymmetric countries strongly depends on its design and on the characteristics of the economy (in particular the level of knowledge flows between countries).

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8 Appendices

Appendix A

The equilibrium location of manufacturing firms has to satisfy the condition given by (29). We can rewrite (29) as a third degree polynomial function of \( s_n \):

\[
 f(s_n) = a s_n^3 + b s_n^2 + c s_n + d = 0
\]

with

\[
 a = -8L \alpha \varphi (1 - \lambda)(1 - T)
\]

\[
 b = -4L \alpha \varphi (1 - T) \frac{L \alpha (1 + \phi)(1 - \lambda)(1 - 2s_n) + \sigma (1 - \phi)[\rho + 2L(2\lambda - 1)]}{(1 - \phi)}
\]

\[
 c = \frac{2 \alpha \varphi (1 - T)[(1 - 2s_n)(1 + \phi)(L \alpha (1 - 3\lambda) - \rho \alpha (1 - T))]}{1 - \phi}
\]

\[
 + \frac{2 \alpha \varphi (1 - T)[\rho \sigma (1 - 3\phi + 2s_n(1 + \phi) - L \sigma (1 - \phi)(1 - 5\lambda)]}{1 - \phi}
\]

\[
 d = \frac{2 \alpha \varphi (1 - T)}{(1 - \phi)^2} L \lambda(1 - \phi)[\alpha (1 + \phi)(1 - 2s_n) - \sigma (1 - \phi)]
\]

\[
 + \frac{2 \alpha \varphi (1 - T)}{(1 - \phi)^2} \rho (s_n - \phi (1 - s_n))[(1 + \phi)(1 - 2s_n)(1 - T) - \sigma (1 - \phi)]
\]

There are three real solutions to such an equation but by using expression (29) and simulations, we can easily see that only one is admissible. This solution is given by:

\[
 s_n = \sqrt[3]{-\frac{p}{3}} \cos \left( \frac{\arccos \left( \frac{3q}{2p} \sqrt{-\frac{27}{p}} + 4\pi \right)}{3} - \frac{b}{3a} \right)
\]

with

\[
 p = \frac{c}{a} - \frac{b^2}{3a^2}
\]

\[
 q = \frac{d}{a} + \frac{b}{27a} \left( \frac{2b^3}{a^3} - \frac{9c}{a} \right)
\]

It should be noted that when \( T = 0 \), the concentration of the industrial sector in the richer country is complete \((s_n = 1)\) when the degree of trade integration exceeds the threshold level:

\[
 \phi^* = \frac{L + \rho(1 - k)}{L + \rho k}
\]

(37)
Appendix B

In this appendix, we demonstrate that an increase of the tax rate decreases the concentration of manufacturing firms in the core country.

Using (14), (26) and (28), the derivative of $s_n$ with respect to $T$ is given by:

$$\frac{ds_n}{dT} = \left( \frac{\partial s_n}{\partial s_n} \frac{\partial s}{\partial T} + \frac{\partial s_n}{\partial s_g} \frac{\partial g}{\partial T} \right) \left( 1 - \frac{\partial s_n}{\partial s_n} \frac{\partial s}{\partial g} \frac{\partial g}{\partial s_n} \right)^{-1}
$$

With the same expressions as are used above, we can calculate the following partial derivatives:

$$\frac{\partial s_n}{\partial s_c} = \frac{1 + \phi}{1 - \phi} > 0 \quad \frac{\partial s_n}{\partial g} = -\frac{\alpha \rho (2s_n - 1)(1 - T)}{2\sigma (g + \rho)^2} < 0$$

$$\frac{\partial g}{\partial T} = \frac{\alpha \rho}{2\sigma} \left( \frac{4AL\sigma - g}{\sqrt{\Lambda^2 + 8ALT\alpha \rho}} \right) > 0 \quad \frac{\partial s_n}{\partial T} = -\frac{\alpha \rho (2s_n - 1)}{2\sigma (g + \rho)} < 0$$

$$\frac{\partial g}{\partial s_n} = \frac{L\alpha (1 - \lambda)}{\sigma} \left( \frac{g + 2T\sigma \rho}{\sqrt{\Lambda^2 + 8ALT\alpha \rho}} \right) > 0$$

with

$$\Lambda = \alpha [2AL - \rho T] - \rho (\sigma - \alpha)$$

Using signs of these partial derivatives, we see immediately that an increase of the tax rate will reduce the spatial concentration of manufacturing firms in the core country, i.e, $ds_n/dT < 0$.

Appendix C

In this appendix, we demonstrate that an increase of the tax rate increases the aggregate growth rate.

We know that the first derivative of $g$ with respect to $T$ is expressed by (31). Using (30), we can write:

$$\frac{dg}{dT} \left( 1 - \frac{\partial s_n}{\partial s_n} \frac{\partial s}{\partial g} \frac{\partial g}{\partial s_n} \right) = \frac{dg}{dT} + \frac{dg}{dT} \frac{\partial s_n}{\partial s_n} \frac{\partial s}{\partial \delta_s} \frac{\partial \delta_s}{\partial T}
$$

As the second term on the left side of the expression is positive, we know that:

$$\text{sign} \left( \frac{dg}{dT} \right) = \text{sign} \left( \frac{dg}{dT} + \frac{dg}{dT} \frac{\partial s_n}{\partial s_n} \frac{\partial s}{\partial \delta_s} \frac{\partial \delta_s}{\partial T} \right)$$
Consequently, \( dg / dT > 0 \) is positive if and only if:

\[
\frac{\partial g}{\partial T} > 1 \iff \frac{\sigma(1-\phi)(g+\rho)(4AL\sigma-g)}{\alpha L(1-\gamma)(1+\phi)(2s_k-1)(g+2T\alpha\rho)} > 1
\]

which is equivalent to:

\[
-\sigma(1-\phi)g^2 + [L\alpha(1-\lambda)(1+\phi)(2s_k-1) + \sigma(1-\phi)(4AL\sigma-\rho)]g
+4AL\rho(1-\phi)\sigma^2 + 2LT\alpha\rho(1-\lambda)(1+\phi)(2s_k-1)\sigma > 0
\]

This second degree polynomial function in \( g \) has two real roots given by:

\[
g_1 = \frac{Y - \sqrt{Y^2 + 8L\sigma^2(1-\phi)[2A\sigma(1-\phi) + (1+\phi)(1-\lambda)T\alpha(2s_k-1)]}}{2\sigma(1-\phi)} < 0
\]

\[
g_2 = \frac{Y + \sqrt{Y^2 + 8L\sigma^2(1-\phi)[2A\sigma(1-\phi) + (1+\phi)(1-\lambda)T\alpha(2s_k-1)]}}{2\sigma(1-\phi)} > 0
\]

with

\[
Y = L\alpha(1+\phi)(1-\lambda)(2s_k-1) + \sigma(1-\phi)(4AL\sigma-\rho)
\]

Thus, the polynomial function is positive if and only if \( g \) given by (26) ranges between \( g_1 \) and \( g_2 \). We know by definition that \( g > 0 > g_1 \). We have to compare \( g \) with \( g_2 \) to conclude. To simplify the proof, we first compare the first element of \( g_2 \) with the first element of \( g \), i.e., we calculate the difference between \( Y / 2\sigma(1-\phi) \) and \( \Lambda / 2\sigma \). This difference is given by:

\[
\frac{L\alpha(1+\phi)(1-\lambda)(2s_k-1) + \sigma(1-\phi)(4AL\sigma-\rho)}{2\sigma(1-\phi)} - \frac{2AL - \rho(\sigma - \alpha)}{2\sigma} \]

The numerator of this expression is equal to:

\[
L\alpha(1+\phi)(1-\lambda)(2s_k-1) + 2AL(1-\phi)(2\sigma - \alpha) - \alpha\rho(1-\phi)(1-T) > 0
\]

This numerator is positive as long as we suppose \( g \) to be positive. This means that the first element of \( g_2 \) is higher than the second element of \( g \). Now, we have to compare the second element of \( g_2 \) with the second element of \( g \). This difference is equal to:

\[
\frac{\sqrt{Y^2 + 8L\sigma^2(1-\phi)[2A\sigma(1-\phi) + (1+\phi)(1-\lambda)T\alpha(2s_k-1)]}}{2\sigma(1-\phi)} - \frac{\sqrt{\Lambda^2 + 8\alpha\rho ALT}}{2\sigma}
\]
We have shown that \( \frac{\gamma}{2\sigma(1-\phi)} > \frac{\Lambda}{2\sigma} \) so that the second element of \( g_2 \) is always higher than the second element of \( g \) if:

\[
8L\sigma^2(1-\phi)[2A\sigma(1-\phi) + (1 + \phi)(1 - \lambda) T \alpha(2s_k - 1)] > (1 - \phi)^2 8 \alpha \sigma \alpha \rho \Lambda T
\]

which corresponds to:

\[
A(1 - \phi)^2(2\sigma^2 - T \alpha) + \sigma(1 - \phi^2)(1 - \lambda) T \alpha(2s_k - 1) > 0
\]

This inequality is always verified whatever the value of the parameters. Consequently, we know that the second element of \( g_2 \) is higher than the second element of \( g \). It follows that if the two elements of \( g_2 \) are higher than those for \( g \) then \( g_2 > g \). Consequently, we have \( g_2 > g > g_1 \), i.e., the growth rate is in the range where \( \frac{dg}{dT} > 0 \). We can conclude that the first derivative of \( g \) with respect to \( T \) is positive.

Appendix D

In this appendix, we demonstrate that the higher the level of trade integration, the higher the impact of the tax rate upon the delocation of industrial activities.

To do this, we have to calculate the partial derivative of \( \frac{ds_n}{dT} \) with respect to \( \phi \). Using expression (30) and the expressions of partial derivatives given in Appendix B, we can rewrite:

\[
\frac{ds_n}{dT} = \frac{-ap(2s_k - 1)}{\sigma(1 + \rho)(1 + \phi)} \left( \frac{ap(1 + T)}{\sigma(1 + \rho)} + \frac{2aL - g}{\sqrt{N + 8ALT \alpha \phi}} + 1 \right)
\]

This expression has the form:

\[
\frac{ds_n}{dT} = \frac{X}{(1 + \phi)} + Y
\]

where \( X < 0 \) and \( Y > 0 \). The partial derivative of \( \frac{ds_n}{dT} \) with respect to \( \phi \) has the form:

\[
\frac{\partial}{\partial \phi} \left( \frac{ds_n}{dT} \right) = \frac{4X}{Y(1 + \phi) + 2(1 - \phi)^2} < 0
\]

This result means that the higher the level of trade integration, the higher the impact of the tax rate upon the delocation of industrial activities.
References


