Should Basic Research be Concentrated?*†

Olivier Schneller

CER-ETH
Center of Economic Research
at ETH Zurich
ZUE D10
8092 Zurich, Switzerland
oschneller@ethz.ch

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Abstract

We use a Schumpeterian growth model with a public basic-research sector to explore the socially desirable concentration level of basic-research resources on specific sectors. We find that basic research should be aimed at technologically leading sectors to protect the rents of those sectors in the world market. Targetting basic research on a fraction of high-technology sectors is optimal when the degree of openness towards world markets diverges across sectors. Basic research should then be concentrated on high-technological sectors with a high (low) degree of openness, if the size of innovation steps is small (large).

Keywords: Basic Research, Sectoral Concentration, Openness, Distance to Frontier, Economic Growth.

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1 Introduction

Considerations on how to allocate governmental basic-research[1] budgets across sectors has gained importance on the political agenda of recent years. On the one hand, R&D policy in general has obtained increasing attention in line with Europe's Lisbon strategy that aims at spending three percent of GDP in R&D. On the other hand, globalization has given rise to new challenges with respect to the allocation of basic research. The increasing degree of international competition and the rapidly changing research frontier requires adjusted basic-research strategies, whereas its efficiency depends in large part on the positioning within the global technological environment. Thus, a central task of a country's basic-research policy is to determine to what degree basic-research resources should be concentrated on a few core fields in order to benefit from competitive advantages in the respective areas.

Countries adopt different strategies with respect to targeting basic research. A prominent classification concept is to distinguish between mission-oriented and diffusion-oriented strategies (Ergas 1987). According to Ergas' work, "the dominant feature of mission-oriented R&D is concentration". The mission-oriented strategy aims at the attainment of clearly defined national goals resulting in an allocation of public basic research that is heavily biased towards a few fields. By contrast, the diffusion-oriented strategy consists of disseminating the R&D resources throughout the economy in order "to provide a broadly based capacity for adjusting to technological change". The mission-oriented strategy is used most prominently in the US. In 2006, 52% of the government's R&D budget was directed to the health sector and 18% to space programmes (OECD 2007). In most European countries, the R&D budget is allocated more equally.

In this paper we analyze the issue of concentrating basic research within a theoretical framework. We build on Gersbach et al. (2008) where a Schumpeterian growth model introduced in Aghion et al. (2006) is expanded by a publicly financed basic-research sector. Gersbach et al. explore the question of how much a country should invest in public basic research dependent on its degree of openness and its distance from the world's technological frontier. We choose a different direction by focusing on the optimal sectoral concentration of basic research, also depending on openness and on the technological level.

[1]A standard definition of basic research is given by the OECD: "Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view" (OECD, 2002, p. 30).

We consider an economy featuring a final good sector, intermediate goods sectors, a private R&D sector and a public basic-research sector. Intermediate firms have the possibility to conduct private R&D in order to realize an innovation with positive probability. A successfull innovation increases the firm's technological level. It is assumed that basic research increases the innovation probability of intermediate firms within a country.[2] We allow for intermediate sectors to differ in their technological level, which is measured by the distance from the world's technological frontier. The country's degree of openness is reflected by the probability of market entry by a foreign intermediate firm. The country is exposed to the technological frontier, i.e. foreign firms always enter at the world's most advanced technological level, and consequently drive domestic firms that do not operate at the technological frontier out of the market.

The government runs the basic-research sector by allocating a share of labor to basic research and by financing it with an income tax. Furthermore, the government can exclude some sectors from the basic-research programme, respectively it can concentrate basic research on specific sectors. The government's decision on sectoral basic-research concentration is mainly characterized by the following trade-off: Concentration decreases the amount of firms that benefit from basic research, but it increases the effectivity of basic research for the benefiting firms.

Our results are derived by numerical simulations. For large sets of parameter values, we find that optimal basic-research concentration consists of spreading basic research across all high-technological sectors. Technologically backward sectors should be excluded. Basic-research concentration within the high-technological sectors is welfare reducing mainly due to the different sectoral scope of the two trade-off effects. On the one hand, concentration decreases only the amount of the important high-technological firms, that benefit from basic research. On the other hand, concentration increases the basic-research effectivity of both, the high-technological firms as well as the less important backward firms. Thus, the negative effect dominates. The exclusion of the backward sectors from basic-research support improves a country's competitiveness as it increases the effectivity of basic research for the high-technological competitive sectors.

When broadening the sector diversification by allowing for different openness across sectors we still obtain the optimality condition to forgo basic research in the backward

[2]Several empirical studies (e.g. Acs et al. 1992, Katz 1994, Narin et al. 1997, Zellner 2003; see Salter and Martin (2001) for a detailed review of this literature.) support our assumption by indicating that basic research has a strong tendency to produce local effects. They suggest, for instance, that basic research increases the innovation chances of domestic firms by the education of problem-solvers and local informal face-to-face interactions.

sectors. However, basic-research concentration within the high-technological sectors now depends on the innovation size. If it is low, it is optimal to target basic research on the more open high-technological sectors. A low innovation size implies that technological progress achieved by research is low. Thus, a basic-research policy that aims at protecting the domestic market from foreign entry by supporting the most threatend sectors is optimal. If it is high, basic-research should be concentrated on the more closed high-technological sectors. Under this condition technological progress is important, and thus, basic-research policy should focus on maximizing technological growth. As in the more open sectors high technology can be imported from foreign firms, basic research should be performed in the more closed sectors, where technological progress has to be secured by domestic innovation activities.

Our paper is organized as follows: In the next section we review the related literature. The model is introduced in section 3. Section 4 contains the discussion of the effects of basic-research concentration, followed by a comparative-statics analysis in section 5. In section 6 the results are discussed including a slight extension of the basic model. Finally, we conclude our work in section 7.

2 Relation to Literature

This paper is related to two strands of literature. First, there is the theoretical growth literature that comprises basic research. It mostly focuses on optimal basic-research investment, and has been pioneered by Shell (1967). More recent contributions are Pelloni (1997), Park (1998), Morales (2004) and Gersbach et al. (2008). The latest is closest to our work, and has already been introduced in the previous section. None of the work in this strand of literature has dealt with the basic-research concentration issue yet.

Second, the literature that analyzes the relationship between technological specialization and economic growth is related to our paper. Among this strand, a series of theoretical contributions (e.g. Verspagen 1993, Giovanni Dosi and Meacci 1994, Lorentz 2006 and Los and Verspagen 2006) highlight the emergence of specialisation patterns, and emphasize that sectoral specialisation can explain growth rate differences among economies. In these papers multi-sector multi-country growth models, that include evolutionary features and draw on the technology-gap theory, are developed. A country competes with other countries in a number of sectors. If competitiveness of a country in a sector is higher than average, the country will export the respective good, and thus, expand its market share in that sector. As the models imply that different sectors grow at different rates, a country's specialization affects growth.

The approach of these papers differs considerably from ours. They consider specialization respectively concentration in a positive way by explaining how specialization can occur in an open economy framework with trade. We take a normative approach. In our paper the question of the optimal degree of concentration is raised. Furthermore, we consider the issue to allocate ressources optimally in the public research sector. The papers mentioned above focus on the technological specialization in the private sector.

There are also some empirical studies that focus on the relationship between technological specialization and economic growth. E.g. Jungmittag (2004), Laursen (2000) and Meliciani (2001) quantify technological specialization with patent data to show that it significantly matters for growth. This lends support to our model's implication that R&D concentration affects the economy's performance.

3 The Model

We build on a Schumpeterian growth model proposed by Aghion et al. (2006), and in line with Gersbach et al. (2008) we introduce a public basic-research sector operated by the government. We assume that there is a continuum of identical households that live for one period, enjoy strictly increasing utility in consumption, inelastically supply one unit of labor, and receive an equal share of the firms' profits. We consider a government maximizing domestic consumption over a single period[3] by providing the optimal amount of basic research for an exogenously given sectoral concentration of basic research. The public expenses are financed by a linear income tax.[4] Accordingly, we first describe the production side of the economy, and derive the equilibrium for a given level of basic research. We then proceed to solve the government's optimization problem. The optimal basic-research concentration is derived in a later stage on the basis of a comparative-statics analysis. We observe how the maximized consumption level is affected by varying the basic-research concentration parameters.

[3] As we are only considering a single period, we can omit the time index t.

[4] The model can be seen as a non-overlapping generations model in which each generation elects a government to provide public goods (here basic research) in order to maximize its well-being. The latter is equivalent to maximizing the consumption of the current generation. This, however, does not square with a social planner aiming at maximizing the utility of all generations.

3.1 Final Good Sector

In the final good sector, the homogeneous consumption good y is produced under perfect competition according to the technology:

$$y = \int_0^1 A(i)^{1-\alpha} x(i)^\alpha \, di. \tag{1}$$

$x(i)$ stands for the amount of the intermediate input of variety i and $A(i)$ is this variety's productivity factor. The parameter α determines the output elasticity of the intermediate goods with respect to the technological level. The price of the final consumption good is normalized to one. Maximization of the final good firm's profits π^y gives the inverse demand functions for intermediate goods $x(i)$:

$$\max_{x(i)} \pi^y = y - \int_0^1 p(i)x(i)\, di \quad \Longrightarrow \quad p(i) = \alpha \left(\frac{A(i)}{x(i)} \right)^{1-\alpha}, \tag{2}$$

where $p(i)$ is the price of good $x(i)$.

3.2 Intermediate Goods Sectors

The intermediate goods $x(i)$ are produced only by labor $L^x(i)$ with a linear technology:

$$x(i) = L^x(i). \tag{3}$$

Intermediate goods firms act competitively in the labor market. Furthermore, the intermediate sectors either feature a monopolistic leader or are fully competitive. These cases are labelled by c and m, respectively. A competitive intermediate firm sets prices equal to the marginal costs, $p^c(i) = w$, and profits vanish. Using (2), the labor demand of a competitive intermediate firm can be written as

$$L^{xc}(i) = \left(\frac{\alpha}{w} \right)^{\frac{1}{1-\alpha}} A(i), \tag{4}$$

where w denotes the wage level.

The monopolistic intermediate firm demands a price $p^m(i) = \frac{w}{\alpha}$ for its goods, leading to a labor demand of

$$L^{xm}(i) = \left(\frac{\alpha^2}{w} \right)^{\frac{1}{1-\alpha}} A(i), \tag{5}$$

and profits

$$\pi^{xm}(i) = \frac{\kappa A(i)}{w^{\frac{\alpha}{1-\alpha}}} \quad \left(\kappa := (1-\alpha)\alpha^{\frac{1+\alpha}{1-\alpha}}\right). \tag{6}$$

3.3 Technological State, Innovation and Foreign Entry

We assume that there is a world's technological frontier $\bar{A}$, which grows exogenously over time according to

$$\bar{A} = \gamma \bar{A}_{-1},$$

where $\bar{A}_{-1}$ denotes the technological frontier of the preceding period.[5] γ determines the speed of growth, and it is assumed to fulfill $1 < \gamma \leq 2$.

In the intermediate sectors, we assume a competitive fringe two steps behind the technological frontier. Accordingly, at the end of the preceding period, each intermediate sector can be in one of the three states:

State 1 A monopolistic leader produces at the current technological frontier, $A_{-1}(i) = \bar{A}_{-1}$.

State 2 A monopolistic leader produces with a technology that is one step behind the technological frontier, $A_{-1}(i) = \bar{A}_{-2}$.

State 3 A competitive fringe, of two or more firms, produces with a technology that is two steps behind the technological frontier, $A_{-1}(i) = \bar{A}_{-3}$.

We denote the fractions of the states by s_1 (state 1), s_2 (state 2) and s_3 (state 3), where $s_1, s_2, s_3 \geq 0$ and $s_1 + s_2 + s_3 = 1$. Additionally, the fractions of intermediate sectors in which basic research is invested are designated by s_j^{BR} ($j = 1, 2, 3$), whereas $s_j^{BR} \in [0, s_j]$. Furthermore, s_j^N stands for the intermediate sectors that do not benefit from basic research, so that $s_j^{BR} + s_j^N = s_j$.

By investing in research and development, an intermediate firm can enhance its probability of a successful innovation. A successful innovation increases the firm's technology level by factor γ. Hence, it allows to keep its relative position to the technological frontier. We specify the innovation probability as

$$\rho(i) = \begin{cases} \min\left\{2\theta\sqrt{L^I(i) L^B \phi}, 1\right\} & \text{if } i \in s_j^{BR} \\ 0 & \text{if } i \in s_j^N, \end{cases} \tag{7}$$

[5] In general, the index $-t\,(t \in \mathbb{N})$ indicates of how many periods back the indexed term is.

where $\theta > 0$ is a parameter that captures the effectivity of research. $L^I(i)$ denotes the intermediate firm's labor employed for R&D, and L^B the amount of labor in the basic-research sector financed by the government. ϕ is the measure of the sectoral concentration of basic research, which is defined as $\phi = \frac{1}{s_1^{BR}+s_2^{BR}+s_3^{BR}}$. We recognize, that the higher the concentration of basic research is, the larger its effect on innovation probability is. Moreover, we note that basic research is a necessary input for innovation activities with respect to two dimensions. First, if the government forgoes basic research, none of the intermediate firms is able to innovate. Second, only in sectors in which the government invests basic research, innovation activities are possible.

As Aghion et al. (2006) we neglect adoption costs of mature technologies, i.e. technologies two steps behind the world's frontier, and assume that the technology of the competitive fringe is upgraded automatically. Hence, the competitive intermediate firms as well as the government have no incentives to invest in research in the state 3 sectors. On that account, $s_3^{BR} = 0$ is assumed from here on, and ϕ reduces to $\frac{1}{s_1^{BR}+s_2^{BR}}$.

We model the country's degree of openness by the probability of market entry by a foreign intermediate firm. We assume that the foreign firm enters with frontier technology $\bar{A}$, produces locally and takes over the whole market.[6] In each sector i not producing at the world's technological frontier, the probability of a foreign competitor entering the domestic market is determined by σ. In sectors where the domestic intermediate firm produces at the highest possible level, foreign competitors will stay outside.[7] Hence, this can only be the case in sectors where a state 1 monopolist innovates successfully.

In a later stage of our work, we will broaden our sector diversification by differentiating between two openness factors, σ^o and σ^c, whereas $\sigma^o > \sigma^c$. This implies that the labeling of the sectors has to be augmented according to s_j^{ok} and s_j^{ck} ($j = 1, 2, 3$; $k = BR, N$). The model's tractability is not influenced by the amount of openness factors. Hence, for simplicity and illustrative reasons we neglect the openness diversification for now.

[6]This implies that there is a fourth state for the intermediate sectors, i.e. with a foreign type 1 leader holding a monopoly. For simplicity, we assume that at the beginning of the period considered no intermediate sector is in this state. Allowing for foreign firms from the outset would only lead to a downscaling of the effects and thus does not alter the results substantially.

[7]This statement can be justified by small entry costs preventing the foreign firm from entering the market under perfect competition (see Aghion et al. 2006).

3.4 R&D Decisions of Intermediate Firms

Given the technological state of the sector, the entry threat of foreign firms and the level of basic research, the domestic intermediate firms maximize their expected profits with respect to the amount of labor employed in private R&D:

- State 1 monopolist, whose sector benefits from basic research

$$\max_{L^I(i)} \left\{ \left(\rho(i) \frac{\kappa}{w^{\frac{\alpha}{1-\alpha}}} \bar{A} + \big(1 - \rho(i)\big)(1-\sigma) \frac{\kappa}{w^{\frac{\alpha}{1-\alpha}}} \bar{A}_{-1} \right) - wL^I(i) \right\}. \tag{8}$$

The state 1 leader retains the market and makes profits, if it innovates successfully or if it does not innovate and there is no entry. The maximization problem leads to the following labor demand

$$L_1^I = \frac{L^B \phi}{w^{\frac{2}{1-\alpha}}} (\bar{A}_{-1})^2 \kappa^2 \theta^2 \big(\gamma - (1-\sigma)\big)^2, \tag{9}$$

and consequently, implies an innovation probability and expected profits of the state 1 monopolist according to:

$$\rho_1^{BR} = 2\frac{L^B \phi}{w^{\frac{1}{1-\alpha}}} \bar{A}_{-1} \kappa \theta^2 \big(\gamma - (1-\sigma)\big) \tag{10}$$

$$\pi_1^{BR} = \frac{L^B \phi}{w^{\frac{1+\alpha}{1-\alpha}}} \kappa^2 \theta^2 \big(\gamma - (1-\sigma)\big)^2 (\bar{A}_{-1})^2 + (1-\sigma) \frac{\kappa}{w^{\frac{\alpha}{1-\alpha}}} \bar{A}_{-1}. \tag{11}$$

- State 2 monopolist, whose sector benefits from basic research

$$\max_{L^I(i)} \left\{ \rho(i)(1-\sigma) \frac{\kappa}{w^{\frac{\alpha}{1-\alpha}}} \bar{A}_{-1} - wL^I(i) \right\}. \tag{12}$$

The state 2 leader only makes profits if it innovates successfully, and there is no foreign entry. If it does not innovate, the competitive fringe automatically catches up. The sector is then subject to perfect competition, and profits are zero. The solution to the problem yields:

$$L_2^I = \frac{L^B \phi}{w^{\frac{2}{1-\alpha}}} (\bar{A}_{-1})^2 \kappa^2 \theta^2 (1-\sigma)^2 \tag{13}$$

$$\rho_2^{BR} = 2\frac{L^B \phi}{w^{\frac{1}{1-\alpha}}} \bar{A}_{-1} \kappa \theta^2 (1-\sigma) \tag{14}$$

$$\pi_2^{BR} = \frac{L^B \phi}{w^{\frac{1+\alpha}{1-\alpha}}} \kappa^2 \theta^2 (1-\sigma)^2 (\bar{A}_{-1})^2. \tag{15}$$

- All the remaining domestic intermediate firms will not invest in R&D for different reasons. Either they belong to the competitive fringe, and thus, they have no prospects to make profits. Or their sector gets no basic-research support, which is necessary for innovation activities.

3.5 Equilibrium

The economy comprises the market for the final consumption good with price unity, the labor market with the wage rate w and a continuum of intermediate good markets with prices $\{p(i)\}_{i=0}^{1}$. It follows from section 3.2 that the market clearing conditions in the intermediate good markets yield prices $p^m(i) = \frac{w}{\alpha}$ in the monopolistic sectors and $p^c(i) = w$ in the competitive ones. From (3), (4) and (5) we obtain the equilibrium values of intermediate goods supply of

$$x^c(i) = \left(\frac{\alpha}{w}\right)^{\frac{1}{1-\alpha}} A(i) \tag{16}$$

$$x^m(i) = \left(\frac{\alpha^2}{w}\right)^{\frac{1}{1-\alpha}} A(i) \tag{17}$$

in the monopolistic intermediate sectors and the competitive intermediate sectors, respectively.

In the labor market, labor $\bar{L}$ is inelastically supplied. Labor demand consists of the government's demand for basic researchers, of the intermediate firm's demand for private R&D-personnel and of the demand for workers for the production of the intermediate goods. Hence, the labor market clears when

$$\bar{L} = L^B + \int_0^1 L^I(i)\,di + \int_0^1 L^x(i)\,di. \tag{18}$$

As we know from section 3.3, the demand for R&D-personnel depends on the intermediate firms' sector state. Consequently, the first integral in equation (18) is given by

$$\int_0^1 L^I(i)\,di = s_1^{BR} L_1^I + s_2^{BR} L_2^I. \tag{19}$$

Note that the total demand for private researchers is determined by the number of sectors that are characterized by domestic monopolies and are supported by basic research. In contrast, the demand for workers in intermediate goods production depends on the sector's technological level after innovation activities and foreign entry have occurred. This reflects our assumption that the foreign intermediate firms bring with them leading technology from abroad, but produce the intermediate goods within the country. Accordingly, we need to know how the sector states evolve during the period, in order to determine the second integral in (18). The following scheme displays the probabilities of technological levels reached by an intermediate sector. The illustration also shows the resulting market structure in terms of the mode of competition and of whether intermediate firms are domestic or foreign.

$$s_1^{BR} \quad \longrightarrow \quad \begin{cases} \rho_1^{BR} & : \ \bar{A}, \quad \text{local,} \quad \text{monopoly} \\ (1-\rho_1^{BR})\sigma & : \ \bar{A}, \quad \text{foreign,} \quad \text{monopoly} \\ (1-\rho_1^{BR})(1-\sigma) & : \ \bar{A}_{-1}, \quad \text{local,} \quad \text{monopoly} \end{cases}$$

$$s_1^{N} \quad \longrightarrow \quad \begin{cases} \sigma & : \ \bar{A}, \quad \text{foreign,} \quad \text{monopoly} \\ (1-\sigma) & : \ \bar{A}_{-1}, \quad \text{local,} \quad \text{monopoly} \end{cases}$$

$$s_2^{BR} \quad \longrightarrow \quad \begin{cases} \sigma & : \ \bar{A}, \quad \text{foreign,} \quad \text{monopoly} \\ (1-\sigma)\rho_2^{BR} & : \ \bar{A}_{-1}, \quad \text{local,} \quad \text{monopoly} \\ (1-\sigma)(1-\rho_2^{BR}) & : \ \bar{A}_{-2}, \quad \text{local,} \quad \text{perfect competition} \end{cases}$$

$$s_2^{N} \quad \longrightarrow \quad \begin{cases} \sigma & : \ \bar{A}, \quad \text{foreign,} \quad \text{monopoly} \\ (1-\sigma) & : \ \bar{A}_{-2}, \quad \text{local,} \quad \text{perfect competition} \end{cases}$$

$$s_3 \quad \longrightarrow \quad \begin{cases} \sigma & : \ \bar{A}, \quad \text{foreign,} \quad \text{monopoly} \\ (1-\sigma) & : \ \bar{A}_{-2}, \quad \text{local,} \quad \text{perfect competition} \end{cases}$$

Consequently, making use of (4) and (5) the total intermediates' demand for production workers is given by

$$\begin{aligned} \int_0^1 L^x(i)\, di = & \left[\sigma\left(s_1^{BR}(1-\rho_1^{BR}) + s_1^N + s_2^{BR} + s_2^N + s_3\right) + s_1^{BR}\rho_1^{BR}\right] L^{xm}(\bar{A}) + \\ & \left[s_1^{BR}(1-\sigma)(1-\rho_1^{BR}) + s_1^N(1-\sigma) + s_2^{BR}(1-\sigma)\rho_2^{BR}\right] L^{xm}(\bar{A}_{-1}) + \\ & \left[s_2^{BR}(1-\sigma)(1-\rho_2^{BR}) + s_2^N(1-\sigma) + s_3(1-\sigma)\right] L^{xc}(\bar{A}_{-2}). \end{aligned} \tag{20}$$

Inserting (19) and (20) into (18) determines the equilibrium wage level. In general, the equilibrium wage is not unique. Inserting (19) and (20) into the labor market clearing condition and assuming $\alpha = \frac{1}{2}$ and $\bar{L} = 1$, we obtain basic-research labor as a function of the wage w:

$$L^B(w) = w^2 \frac{w^2 - \mathcal{A}}{w^4 + \mathcal{B} + \mathcal{C}}, \tag{21}$$

with

$$\mathcal{A} = \frac{\bar{A}}{16\gamma^2}\left[\sigma\gamma^2 + (1-\sigma)\big(s_1\gamma + 4(s_2+s_3)\big)\right] \quad > \quad 0 \tag{22}$$

$$\mathcal{B} = \frac{\bar{A}^2}{256\gamma^2}\theta^2\phi[s_1^{BR}(\gamma - 1 + \sigma)^2 + s_2^{BR}(1-\sigma)^2] \quad > \quad 0 \tag{23}$$

$$\mathcal{C} = \frac{\bar{A}^2}{128\gamma^3}\theta^2\phi(1-\sigma)[s_1^{BR}\gamma(\gamma-1)(\gamma-1+\sigma) + s_2^{BR}(\gamma-4)(1-\sigma)]. \tag{24}$$

As the number of researchers can never be negative, the equilibrium wage must be higher than $\sqrt{\mathcal{A}}$. Further, we slightly restrict our parameter space in accordance with the following assumption:

Assumption 1
$\mathcal{B} + \mathcal{C} > -\mathcal{A}^2$.

We are now in a position to state

Lemma 1
Under Assumption 1 there exists a unique equilibrium wage.

Proof: See Appendix A.1.

From the equilibrium wage we obtain the equilibrium prices for intermediate goods from which the equilibrium quantities and the firms' profits follow. To simplify notation, we will henceforth use w to denote the equilibrium wage associated with a particular level of basic research.

3.6 Government

The government chooses the amount of basic-research labor L^B for an exogenously given sectoral concentration of basic research, s_1^{BR} and s_2^{BR}, in order to maximize aggregate consumption c of the current generation. The expenditures wL^B are financed by a tax $\tau \in [0, 1]$ on the household income. Households earn wages, and obtain profits from final good and domestic intermediate goods production. Consequently, the budget constraint of the government is

$$wL^B = \tau(w\bar{L} + s_1^{BR}\pi_1^{BR} + s_1^N\pi_1^N + s_2^{BR}\pi_2^{BR} + \pi^y). \tag{25}$$

π_1^N stands for the prospective profits of the state 1 firms that get no basic-research support. It equals π_1^{BR} when no basic research is performed. Thus, these firms only earns profits when the foreign firms do not enter the market. We remember that π^y denotes the profits of the final good sector, and it is given by:

$$
\begin{aligned}
\pi^y = & \left[\sigma\left(s_1^{BR}(1-\rho_1^{BR}) + s_1^N + s_2^{BR} + s_2^N + s_3\right) + s_1^{BR}\rho_1^{BR}\right]\bar{A}_t\left(\frac{\alpha^2}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)+ \\
& \left[s_1^{BR}(1-\sigma)(1-\rho_1^{BR}) + s_1^N(1-\sigma) + s_2^{BR}(1-\sigma)\rho_2^{BR}\right]\bar{A}_{t-1}\left(\frac{\alpha^2}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)+ \\
& \left[s_2^{BR}(1-\sigma)(1-\rho_2^{BR}) + s_2^N(1-\sigma) + s_3(1-\sigma)\right]\bar{A}_{t-2}\left(\frac{\alpha}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha).
\end{aligned} \tag{26}
$$

Aggregate consumption c equals total income after taxes:

$$
c = (1-\tau)\left(w\bar{L} + s_1^{BR}\pi_1^{BR} + s_1^N\pi_1^N + s_2^{BR}\pi_2^{BR} + \pi^y\right). \tag{27}
$$

With uniqueness of the equilibrium wage w for given L^B, the government's problem can also be solved via the control w. Technically, we choose this way as it allows for an explicit solution for L^B as a function of w. Economically, this approach could be interpreted as a wage offer by the government for doing basic research in order to attract the corresponding (equilibrium-) number of researchers.

Inserting $L^B(w)$ from equation (21) and the budget constraint (25) into (27), we obtain the overall consumption solely as a function of the equilibrium wage level w:

$$
c(w) = \frac{w^4(2\mathcal{A} + 2\mathcal{D} + \mathcal{E}) + w^2(2\mathcal{B} + 3\mathcal{C} + \mathcal{F}) + (\mathcal{B} + \mathcal{C})(2\mathcal{D} + \mathcal{E}) - \mathcal{A}(\mathcal{C} + \mathcal{F})}{w(w^4 + \mathcal{B} + \mathcal{C})}, \tag{28}
$$

with

$$
\mathcal{D} = \frac{\bar{A}}{16\gamma}s_1(1-\sigma) \quad > \quad 0 \tag{29}
$$

$$
\mathcal{E} = \frac{\bar{A}}{16}\sigma \quad > \quad 0 \tag{30}
$$

$$
\mathcal{F} = \frac{\bar{A}^2}{32\gamma^3}\theta^2\phi s_2^{BR}(1-\sigma)^2 \quad > \quad 0. \tag{31}
$$

This is the objective function, which the government maximizes with respect to the wage w.

Lemma 2
Under Assumption 1 there exists a unique maximum consumption level.

Proof: See Appendix A.2.

However, it is impossible to derive an analytical solution to the problem.[8] Accordingly, we will derive our results on the basis of numerical simulations. To determine the optimal basic-research concentration we look at comparative statics of the consumption level with respect to s_1^{BR} and s_2^{BR} in section 5.

4 Effects of Basic-Research Concentration

Before turning to comparative statics, we now introduce the different direct and indirect effects that sectoral concentration of basic research has on aggregate consumption.

4.1 Direct Effects

As can be seen from equation (27), the concentration of basic research affects aggregate consumption directly in the following way:

Beneficiary Size Effect The more concentrated basic research is, the smaller the amount of firms that benefits from basic research is.

- The concentration in the state 1 sectors ($s_1^{BR} \downarrow$) - henceforth we call it simply s_1^{BR}-concentration - affects the economy negatively through this channel. First, intermediate firms of state 1 that benefit from basic research have the possibility to innovate, and thus, earn higher profits ($\pi_1^{BR} > \pi_1^N$). Second, also the final good sector realizes higher profits if it is supplied by state 1 beneficiaries, as their goods are technologically more advanced.
- The effect that s_2^{BR}-concentration ($s_2^{BR} \downarrow$) has on the economy is ambiguous. On the one hand, only those intermediate firms of state 2 that are beneficiary of basic research are able to maintain their monopoly status by innovating successfully, and thus, earn profits. On the other hand, eventhough the technological level of the state 2 beneficiaries is higher, the final sector realizes higher profits if supplied by non-benefited state 2 firms, as

[8] The optimal wage w^* is given by the derivative of equation (28), which is a polynomial of degree eight.

they hold no monopoly. Which of the two effects dominates depends on the parametrization.[9]

Research Effectivity Effect The more concentrated basic research is, the more effective it is for the firms benefiting from it. This effect is pointed out by the measure of sectoral concentration of basic research $\phi = \frac{1}{s_1^{BR}+s_2^{BR}}$. As s_1^{BR}- and s_2^{BR}-concentration ($s_1^{BR} \downarrow$ and $s_2^{BR} \downarrow$) affect ϕ in the same positive way, it is straightforward that the *Research Effectivity Effect* is identical for both:

The effect is manifold. First, the profits of the state 1 intermediates that are basic-research beneficiaries, denoted by π_1^{BR}, increase with ϕ respectively with basic-research concentration. Second, also the intermediate state 2 beneficiaries realize higher profits π_2^{BR} with increasing ϕ. Third, the profits of the final sector increase with the innovation probability of the state 1 intermediates, as they benefit from the technological advance. And fourth, the profits of the final sector decreases with the innovation probability of the state 2 intermediates, because the supply by non-innovating state 2 firms prevents the final sector to pay monopoly rents. This is the only negative influence of the *Research Effectivity Effect* on consumption.

Lemma 3
s_1^{BR}-concentration ($s_1^{BR} \downarrow$) has a negative direct effect on consumption, whereas s_2^{BR}-concentration ($s_2^{BR} \downarrow$) increases consumption through the direct effects.

Proof: See Appendix A.3.

The intuition of Lemma 3 can be explained as follows. The magnitude of the direct effects aiming at the state 2 part of the economy are secondary compared to those aiming at the state 1 part. This has several reasons. First, due to monopoly distortion the effect on the state 2 intermediates' profits and on the final sector's profit are oppositional. Thus, they cancel eachother out to some extent. Second, the state 2 intermediates are not competitive against the foreign firms. And third, the technological level of the state 2 intermediates is lower. As a consequence, how s_1^{BR}- and s_2^{BR}-concentration affect the state 1 part of the economy determines the direction of the direct effects. As discussed previously, s_1^{BR}-concentration affects the state 1 part negatively through the *beneficiary size effect* and positively through the *research effectivity effect*. However, as the *research effectivity effect* is dispersed on both, the state 1 and the state 2 part of

[9] It is straightforward to show that s_2^{BR}-concentration influences aggregate consumption positively with respect to the *beneficiary size effect* as long as $\gamma < \frac{8}{5}$.

the economy, and the *beneficiary size effect* targets exclusively on the important state 1 part, the latter always dominates.[10] Thus, s_1^{BR}-concentration has a negative direct effect on consumption. s_2^{BR}-concentration affects the state 1 part only through the positive *research effectivity effect.* And consequently, s_2^{BR}-concentration has a positive direct impact on consumption.

As already mentioned, we later extend our model with the two openness factors, σ^o and σ^c. In this case the patterns of the *Beneficiary Size Effect* and the *Research Effectivity Effect* remain the same. Hence, the above description for s_1^{BR}-concentration also applies to s_1^{oBR}- and s_1^{cBR}-concentration. Accordingly, what holds for s_2^{BR}-concentration also holds for s_2^{oBR}- and s_2^{cBR}-concentration. This, however, does not imply that the magnitude of the effects are unchanged. Hence, Lemma 3 does not hold here. How the direct effects in this framework affect consumption will be illustrated and discussed when we introduce the two openness factors in the comparative-statics analysis.

4.2 Indirect Effects

The indirect effects derive from the fact that the degree of basic-research concentration through the direct effects affects the government's decision on the optimal amount of basic research. And this in turn, influences total consumption, as can be derived from equation (27). To get an understanding of the indirect effects, we dissect the effects basic research L^B has on consumption. This constitutes also a good illustration of what the incentives to invest in basic research are.

Escape Entry Effect: State 1 monopolists will avoid foreign entry and retain the domestic market, if they innovate successfully so to keep up with the technological frontier. As basic research facilitates innovation, it helps state 1 monopolists to retain domestic profits, which increases the consumption of households as shareholders. It is straightforward, that the *escape entry effect* increases with openness σ, as the entry threat of foreign firms increases. And as s_1^{BR}-concentration (s_2^{BR}-concentration) is detrimental (beneficial) to the state 1 intermediates, it lowers (amplifies) the *escape entry effect.*

Monopoly Effect: State 2 monopolists can only preserve their technological advantage and retain their monopoly position, if they innovate successfully (and no foreign entry takes place). Otherwise they will lose their competitive edge as the

[10] The dominance of the *beneficiary size effect* can be seen mathematically from $\frac{\partial(s_1^{BR}\phi)}{\partial s_1^{BR}} \geq 0$.

competitive fringe will catch up technologically. In this way, basic research helps state 2 leaders to make profits. However, the state 2 monopoly lowers the profits of the competitive final-good sector caused by higher intermediate-goods prices. The second effect dominates as a result of the well-known monopoly distortion factor. The net effect is what we call the *monopoly effect*. Using the reasoning in the intuition of Lemma 3 with respect to the state 2 part of the economy, it is clear that s_1^{BR}-concentration (s_2^{BR}-concentration) is detrimental (beneficial) for the state 2 intermediates. Thus, it amplifies (lowers) the *monopoly effect*.

Productivity Effect: Basic research increases the probability of successful innovation, and thus, enhances technological growth. Higher technology raises profits for both the intermediate firms and the final-good sector. Consequently this effect on consumption is positive. By definition, it is obvious that the size of the *productivity effect* is primarily determined by the innovation size γ. How s_1^{BR}- and s_2^{BR}-concentration affect the level of the *productivity effect* is ambiguous. On the one hand, s_1^{BR}-concentration (s_2^{BR}-concentration) lowers the aggregate technological level of the state 1 (state 2) sectors due to the *beneficiary size effect's* dominance over the *research effectivity effect*. On the other hand, s_1^{BR}-concentration (s_2^{BR}-concentration) increases the aggregate technological level of the state 2 (state 1) sectors due to the *research effectivity effect*.

Wage Effect: Higher labor employment in the basic-research sector reduces the labor supply for the intermediate firms. Consequently the equilibrium wage increases. This has several implications for consumption. First, wage income increases, which affects consumption positively. Second, labor becomes more expensive, which lowers the profits of the intermediate firms as well as those of the final sector. This impact on consumption is negative. Third, also the costs for labor in the basic-research sector rise. That is why a higher tax rate has to be levied, and consumption is lowered. The aggregate impact of the *wage effect* on consumption is generally negative.[11] The magnitude of the *wage effect* is decreased (increased) by s_1^{BR}-concentration (s_2^{BR}-concentration). The intuition is as follows. s_1^{BR}-concentration (s_2^{BR}-concentration) reduces (increases) the demand for production workers L^x and total demand for private researchers in the state 1 sectors $s_1^{BR}L_1^I$, but it increases (reduces) total demand for private researchers in

[11]It is possible that the *wage effect* gets positive for a very small parameter range. s_1, σ and γ have to be low. See Appendix A.4. The intuition is that in these circumstances the wage's impact on the final sector's profit is positive. The final sector benefits from the fact that the state 2 leaders' innovation probability decreases with wage, and thus, they have to pay less monopoly rent.

the state 2 sectors $s_2^{BR} L_2^I$. The first two shifts in demand always dominate the third. Thus, total labor demand decreases (increases) with s_1^{BR}-concentration (s_2^{BR}-concentration).[12] This implies that the equilibrium wage is lower (higher) for a given amount of basic research.

5 Comparative Statics

In what follows we run a comparative-statics analysis to examine what sectoral concentration of basic research yields the highest consumption level. We consider three different frameworks. We start with a benchmark case in which we look at a high-technology country with an unitary openness factor. We proceed with an economy that features sectors of different technological levels, but still assume an unitary openness factor. Finally, we consider a country with diversified technological level and openness across sectors.

5.1 Benchmark Case: High-Technology Country ($s_1 = 1$) with Unitary Openness

We first analyze the simplest scenario. We assume an economy with an unitary openness parameter σ and where all sectors are in state 1, i.e. an economy which is technologically most advanced. This provides us a benchmark for the following discussion of the more general scenarios and helps us to better understand all the effects that underlie basic-research concentration.

Figure 1 illustrates how total consumption and optimal basic research change with the degree of basic-research concentration in the considered scenario. Interestingly, it does not matter how much the government concentrates basic research as long as concentration is not too strong. This is due to the fact that the *research effectivity effect* equals the *beneficiary size* provided that $s_2^{BR} = 0$. This condition is illustrated in the proof of Lemma 3. The *research effectivity effect* is normally dominated by the *beneficiary size effect*, as the impact of the former is dispersed on several sector types. However, in this scenario we assume only one sector type s_1, which implies $s_2^{BR} = 0$. Thus, the *research effectivity effect* affects exclusively the s_1-sectors, which causes it to have the same size than the *beneficiary size effect*.

[12]It is straightforward to show.

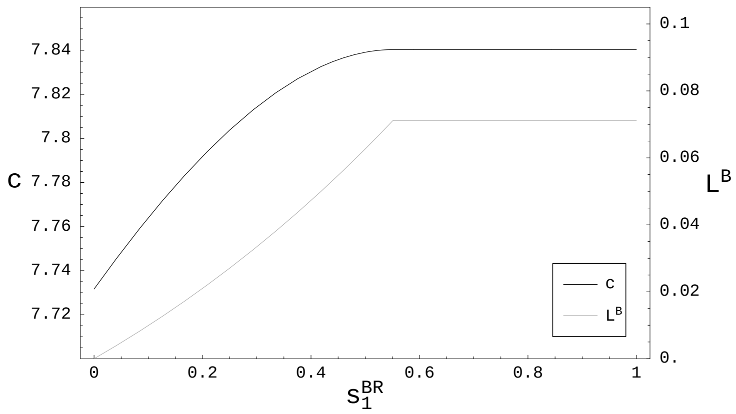

Figure 1: Effect of Basic-Research Concentration: Benchmark Case ($\bar{A} = 100$, $\gamma = 1.4$, $\theta = 2.5$, $\sigma = 0.7$, $s_1 = 1$, $s_2 = 0$, $s_2^{BR} = 0$, $s_3 = 0$)

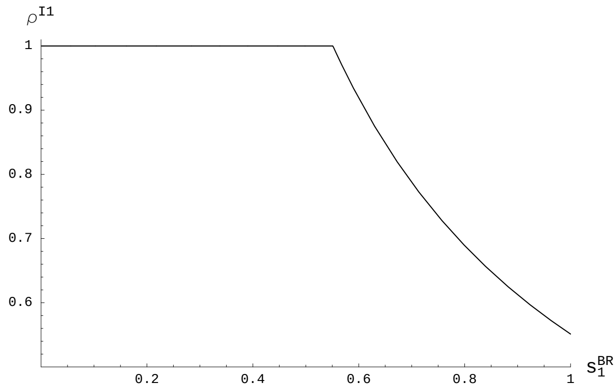

Figure 2: Innovation Probability ρ_1^{BR} in the Benchmark Case ($\bar{A} = 100$, $\gamma = 1.4$, $\theta = 2.5$, $\sigma = 0.7$, $s_1 = 1$, $s_2 = 0$, $s_2^{BR} = 0$, $s_3 = 0$)

Moreover, as the direct effects are zero in aggregate, there is no incentive to change the amount of basic-research investments. However, at a certain degree of concentration optimal basic research and total consumption start to fall. As illustrated in Figure 2 this is due to the fact the the innovation probability ρ_1^{BR} reaches one, and hence, we do not have interior solutions anymore. In order for ρ_1^{BR} not to exceed one the amount of basic research has to be narrowed down, which obviously has a negative effect on total consumption. As we are not interested in the corner solutions, we will in the following stop our simulations as soon as any innovation probability reaches one.

5.2 Technology Diversification and Unitary Openness

We depart from the benchmark case, and analyze economies, which have a positive share of sectors that are not leading technologically. Though, we still assume an unitary openness factor σ. We start by analysing how s_1^{BR}-concentration affects welfare, and then turn to the evaluation of s_2^{BR}-concentration.

s_1^{BR}-Concentration

How s_1^{BR}-concentration affects consumption is illustrated in Figure 3. It is increasing with s_1^{BR}, implying that no s_1^{BR}-concentration maximizes welfare. When remembering the preceding discussion of the effects this result is not surprising. We know from Lemma 3 that s_1^{BR}-concentration decreases total consumption through the direct effects, as the *beneficiary size effect* exceeds the *research effectivity effect.* Thus, it seems that in general the outcome's direction is in line with the direct effects. Figure 3 also suggests that s_1^{BR}-concentration tends to decrease optimal basic research. This can be explained by the fact that s_1^{BR}-concentration reduces the positive *escape entry effect* and increases the negative *monopoly effect.*

Robustness checks show that this result holds for a wide range of parameters. However, for parametrizations comprising low values of σ and γ, and high values of s_1 we obtain the opposite result, i.e. consumption as well as optimal basic research increase with s_1^{BR}-concentration for interior solutions.[13] This implies that in these circumstances the indirect effects are positive, and dominate the negative direct effects. The intuition is as follows. The direct effects are weak as research is not that efficient for two reasons. First, the technological progress obtained by innovation is small (low γ). And second, the domestic firms do not need to fear foreign firms' entry (low σ). Thus, even when not innovating the domestic firms will most likely retain their profits. The indirect effects are dominated by the *wage effect* as the *escape entry effect* is low for low σ, the *productivity effect* is unimportant when γ is low, and the *monopoly effect* is low for high s_1. And because the negative *wage effect* decreases with s_1^{BR}-concentration, consumption is affected positively by s_1^{BR}-concentration in this special case. Thus we can state, that in the scenario with low σ and γ, and high s_1, basic research is very expensive. The reason is twofold: One the one hand basic research is not that

[13]Given a positive amount of basic research, $s_1^{BR} = 0$ can never be optimal (See Gersbach et al. (2008) for a detailed analysis why state 1 sectors are necessary.). In the discussed case consumption increases with s_1^{BR}-concentration but at some point innovation probability reaches one, and consumption starts to fall again in the area, where we have no interior solutions.

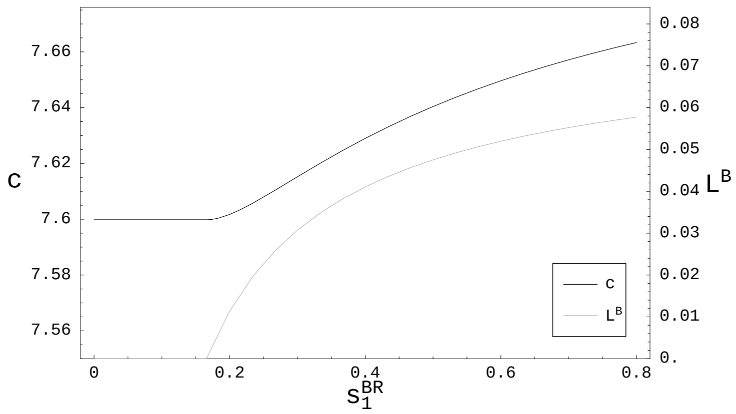

Figure 3: Effect of s_1^{BR}-Concentration ($\bar{A} = 100$, $\gamma = 1.4$, $\theta = 2.5$, $\sigma = 0.7$, $s_1 = 0.8$, $s_2 = 0.2$, $s_2^{BR} = 0.2$, $s_3 = 0$)

efficient. On the other hand, the distortion on the labor market (*wage effect*) is strong. By increasing s_1^{BR}-concentration the distortion on the labor market is softend, which renders basic research less costly, allows to invest more in basic research, and enhances consumption.

s_2^{BR}-Concentration

Unlike s_1^{BR}-concentration, s_2^{BR}-concentration for the most part has a positive effect on total consumption and on optimal basic research, as is depicted in Figure 4. It implies that $s_2^{BR} = 0$ maximizes total consumption. Or in other words, the government should exclude the state 2 sectors from the basic-research programme. The explanation is in line with the one for s_1^{BR}-concentration. The result is primarily determined by the direct effects. And we know from Lemma 3 that the direct effects of s_2^{BR}-concentration are consumption enhancing. s_2^{BR}-concentration has to be chosen in order to support the state 1 part of the economy in the highest possible way. This is achieved by choosing $s_2^{BR} = 0$, so that the research effectivity of the state 1 intermediates is maximized. The tendency that s_2^{BR}-concentration increases optimal basic research is established by the following conditions: s_2^{BR}-concentration enlarges the positive *escape entry effect*, and it lowers the negative *monopoly effect*.

In accordance with s_1^{BR}-concentration, robustness checks support this result except when σ and γ are low, and s_1 is high. Then the result turns around caused on the one hand by the dominance of the indirect effects, and on the other hand by negativity

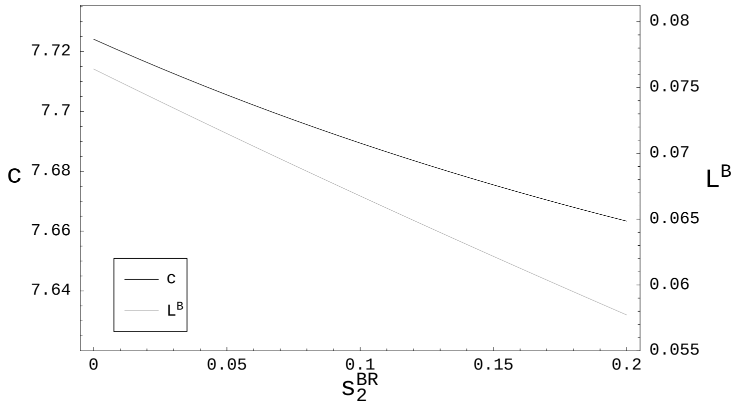

Figure 4: Effect of s_2^{BR}-Concentration ($\bar{A} = 100$, $\gamma = 1.4$, $\theta = 2.5$, $\sigma = 0.7$, $s_1 = 0.8$, $s_1^{BR} = 0.8$, $s_2 = 0.2$, $s_3 = 0$)

of the indirect effects for these parameter values. We already discussed that the *wage effect* is a key factor under these circumstances. And as s_2^{BR}-concentration increases the negative *wage effect*, it affects consumption negatively. Hence, no s_2^{BR}-concentration is optimal, as it lowers the cost of basic research by reducing the distortion that it has on the labor market. This enables the government to invest more basic research. Hence, in this case choosing $s_2^{BR} = s_2$ in order to diminish the labor market distortion is more beneficial to the state 1 part of the economy than increasing the research effectivity by setting $s_2^{BR} = 0$.

5.3 Technology and Openness Diversification

So far we had an unitary openness parameter within our modeled economy. However, reality shows that openness diverges across sectors (e.g. Lee and Swagel (2000) and Koyama and Golub (2006)). The government, for instance, protects some sectors more from globalization than others. In the following, we introduce this feature in our model by broadening our sector diversification. We now differentiate between two openness factors, σ^o and σ^c, whereas $\sigma^o > \sigma^c$. This implies that the sectors exhibiting σ^o are more open than those holding σ^c. The new sector diversification is thus given by s_j^{ok}, s_j^{ck} ($j = 1, 2, 3$; $k = BR, N$), whereas the indices o and c indicate which openness factor the sectors exhibit. The adjusted concentration parameter is given by $\phi = \frac{1}{s_1^{oBR}+s_1^{cBR}+s_2^{oBR}+s_2^{cBR}}$.[14] We will omit the discussion of s_2^{oBR}- and s_2^{cBR}-concentration, as we have already shown in section 5.2 that in general it is welfare enhancing to renounce investing in basic research in the backward sectors. This result does also apply here.[15] Thus, we only inspect how s_1^{oBR}- and s_1^{cBR}-concentration affects the consumption level and hereby assume $s_2^{oBR} = s_2^{cBR} = 0$.

What effect s_1^{oBR}- and s_1^{cBR}-concentration have on consumption depends primarily on the innovation size γ. Figure 5 and 6 illustrate the relationship for lower values of γ. Basic research should then be concentrated on the high technological sectors with a higher level of openness s_1^o. When γ is low the technological progress obtained by research is low, thus it makes sense to run a basic-research policy that focus on protecting the domestic markets from foreign entry. As the s_1^c-sectors are less threatend by foreign competition it is advantageous to forgo basic research there in order to support the more threatend s_1^o-sectors by increasing their research effectivity.

We obtain the opposite result for higher values of γ as illustrated in Figure 7 and 8. Here, it is optimal to target basic research at the high technological sectors with a lower level of openness s_1^c. A high γ implies that technological progress is important. Thus, the government should run a basic-research policy that guarantees the highest possible technological progress in the economy. This involves to abstain from defending the domestic profits with any basic-research support in the open sectors. The reason is twofold: First, it allows for a free technology boost in the open sectors by importing the high technology from foreign firms. Second, it maximizes research effectivity in those sectors that are more closed, where technological progress has to be provided domestically.

The resulting trade-off is also well apparent when considering the direct effects presented in section 4.1.

Lemma 4
For $\gamma < \frac{5}{4}$, the direct effect of s_1^{oBR}-concentration (s_1^{cBR}-concentration) on consumption is negative (positive). If we increase γ up to a certain level we obtain the reversal of the direct effects' signs.

Proof: See Appendix A.6.

[14]This extension does not alter the tractability of the model, and thus, we can derive the maximum consumption level in the same manner as in the unitary openness model. This is illustrated in Appendix A.5.

[15]We obtain the same special case as in the preceding section when γ and σ^o are low, and s_1 is large. Then $s_2^{oBR} = s_2^o$ and $s_2^{cBR} = s_2^c$ is optimal, and s_1^{oBR}- as well as s_1^{cBR}-concentration increases consumption for interior solutions. The intuition is the same as before.

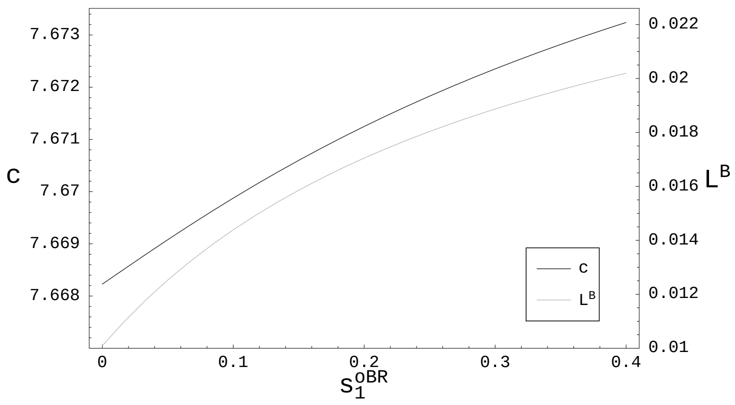

Figure 5: Effect of s_1^{oBR}-Concentration with Low Innovation Size ($\bar{A} = 100$, $\gamma = 1.4$, $\theta = 2$, $\sigma^o = 0.7$, $\sigma^c = 0.3$, $s_1^o = 0.4$, $s_1^c = 0.4$, $s_1^{cBR} = 0.4$, $s_2^o = 0.1$, $s_2^{oBR} = 0$, $s_2^c = 0.1$, $s_2^{cBR} = 0$, $s_3^o = 0$, $s_3^c = 0$)

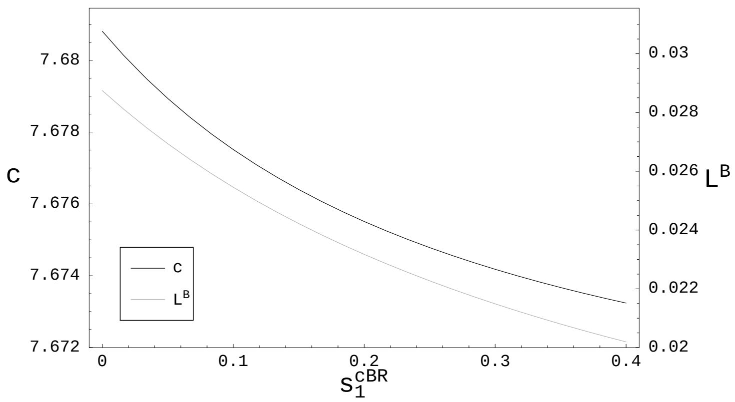

Figure 6: Effect of s_1^{cBR}-Concentration with Low Innovation Size ($\bar{A} = 100$, $\gamma = 1.4$, $\theta = 2$, $\sigma^o = 0.7$, $\sigma^c = 0.3$, $s_1^o = 0.4$, $s_1^{oBR} = 0.4$, $s_1^c = 0.4$, $s_2^o = 0.1$, $s_2^{oBR} = 0$, $s_2^c = 0.1$, $s_2^{cBR} = 0$, $s_3^o = 0$, $s_3^c = 0$)

On the one hand, s_1^{oBR}-concentration (s_1^{cBR}-concentration) affects only the s_1^o-sectors (s_1^c-sectors) negatively through the *beneficiary size effect*. On the other hand, the *research effectivity effect* of s_1^{oBR}- and s_1^{cBR}-concentration has a positive impact on both, the s_1^o- and the s_1^c-sectors. Whether s_1^o- or s_1^c-sectors are more important is the determinant of the focus basic-research concentration should have. γ scales the importance of the different sector-types. If it is low, protecting domestic profits is the major concern, and thus, s_1^o-sectors are more important. s_1^{cBR}-concentration has a

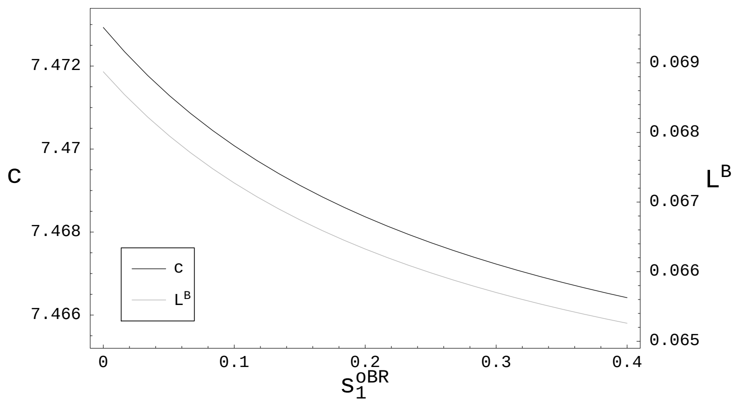

Figure 7: Effect of s_1^{oBR}-Concentration with High Innovation Size ($\bar{A} = 100$, $\gamma = 1.6$, $\theta = 2$, $\sigma^o = 0.7$, $\sigma^c = 0.3$, $s_1^o = 0.4$, $s_1^c = 0.4$, $s_1^{cBR} = 0.4$, $s_2^o = 0.1$, $s_2^{oBR} = 0$, $s_2^c = 0.1$, $s_2^{cBR} = 0$, $s_3^o = 0$, $s_3^c = 0$)

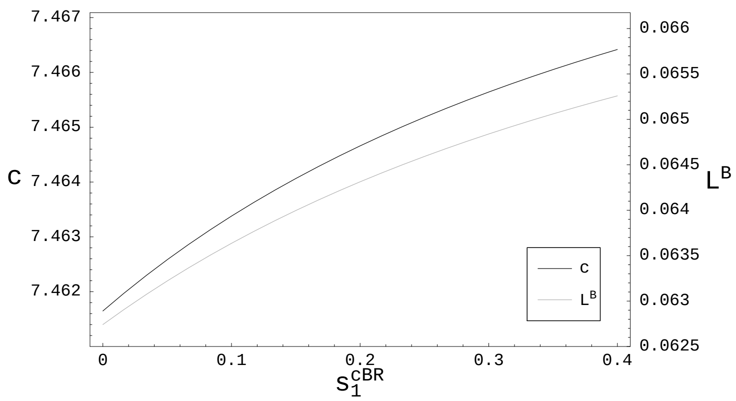

Figure 8: Effect of s_1^{cBR}-Concentration with High Innovation Size ($\bar{A} = 100$, $\gamma = 1.6$, $\theta = 2$, $\sigma^o = 0.7$, $\sigma^c = 0.3$, $s_1^o = 0.4$, $s_1^{oBR} = 0.4$, $s_1^c = 0.4$, $s_2^o = 0.1$, $s_2^{oBR} = 0$, $s_2^c = 0.1$, $s_2^{cBR} = 0$, $s_3^o = 0$, $s_3^c = 0$)

positive direct impact on consumption as it affects the s_1^o-sectors only positively through the *research effectivity effect*. The direct effect of s_1^{oBR}-concentration is ambiguous cause of the opposing *research effectivity* and *beneficiary size effect*. The latter is dominant as it focuses exclusively on the s_1^o-sectors. Thus, consumption declines with s_1^{oBR}-concentration through the direct effects. If γ is large, technological progress is important which lays the focus on the s_1^c-sectors. As a consequence, the direct effect of s_1^{oBR}- and s_1^{oBR}-concentration on consumption goes in the opposite direction.

Robustness checks support this result for most parameter values. Noticeably, it is sufficient for σ^o and σ^c to differ minimally to obtain the presented pattern. Though, if the sum of σ^o and σ^c is very low, we obtain a different result. Then basic research should be concentrated on the s_1^o-sectors independently of the size of γ. However, this is primarily due to our assumption of $\gamma \leq 2$. In such a context γ would need to increase more than allowed to obtain the reversal of the results. The reason is that with a lower sum of σ^o and σ^c the free technological progress that can be imported from foreign firms is not important. Consequently, the weight of technological progress must be increased by rising γ excessively in order for a basic-research policy, that aims at maximizing technological progress, to be optimal. This condition is also illustrated in the proof of Lemma 4 in Appendix A.6.

6 Discussion and Extensions

The results in the preceding section suggest that in most cases it is optimal to concentrate basic research only on the most important sector type (either s_1^{BR}, s_1^{oBR} or s_1^{cBR}). It implies that given this optimality all these cases are theoretically comparable to the benchmark case in section 5.1, i.e. basic-research concentration within this sector type has no effect on consumption.[16] The reason is in accordance with the explanation in section 5.1. When basic research is excluded from all sector types except one, the *research effectivity effect* of basic-research concentration only affects this one sector type just like the *beneficiary size effect*, and thus, they both cancel eachother out.

One might argue that this situation is unlikely, as the government might not be able to guarantee the complete exclusion of some sector types from basic research. For instance, the sectors' level of technology and openness might not be known for sure, leading to unintentional investment in less important sectors. Or, the government might want intentionally to support some unimportant sectors because of some other political reasons, like redistribution issues or voter favour.

Even so, basic-research concentration is modeled such that given (almost) optimality of excluding all the less important sector types, we obtain the mentioned borderline case. The positive effects of basic-research concentration within the most important sector type exactly (almost) cancel out the negative effects. Hence, let us analyze the concentration parameter ϕ more precisely. For given amount of basic research and

[16] At some level of concentration within this sector type, innovation probability reaches one and concentration starts to be detrimental for consumption.

demand for private researchers, ϕ defines to which extent basic-research concentration enlarges the innovation probability of a firm that is a basic-research beneficiary. Every slight change in the weight of ϕ would imply a deviation from the irrelevance of basic-research concentration within the sector type which should be focused on. Thus, it is a straightforward exercise to expand ϕ with a weighting parameter. For instance in the benchmark case, we can give ϕ the following extended form: $\phi = \left(\frac{1}{s_1^{BR}}\right)^{\beta}$, whereas $\beta > 0$. So far we assumed $\beta = 1$. Hence it is obvious, that for $\beta < 1$ s_1^{BR}-concentration is detrimental to consumption, as the positive *research effectivity effect* is scaled down. If we have $\beta > 1$ the opposite holds. In similar fashion, the inclusion of β changes the results in the extended frameworks. Given the optimality to focus basic research only on the most important sector type[17], basic-research concentration within this sector type has a positive (negative) effect on consumption for $\beta > 1$ ($\beta < 1$). Accordingly, if $\beta < 1$, it is optimal to spread basic research across all sectors of the most important sector type. For $\beta > 1$ basic research should be focused only at a fraction of the sectors from the most important sector type.

The concluding question is what possible features of an economy with a low β respectively a high β are. A low β implies that basic-research concentration has weak positive effects. Research synergies or spillovers across sectors, which are not modeled explicitly, could be determinants of β's size. Strong research synergies or spillovers across all sectors of the most importan type would then explain a low β. For instance, the research fields biology, chemistry and medicine are very complementary. Thus, if these fields belong to the most important sector type in an economy, it makes no sense to skip one and concentrate on the others.

7 Conclusion

Within a Schumpeterian growth framework, we have analyzed how a country should concentrate basic research optimally across sectors dependent on openness and technological level. Our results suggest that first, the backward sectors should be excluded from the basic-research programme in order to increase research effectivity in the more important leading sectors. And second, basic research should be targeted at a fraction of the technologically leading sectors if openness diverges across sectors. Then, given a small innovation step, it is optimal to concentrate basic research on the high-

[17]With the inclusion of β we might obtain additional types of results that suggest to target basic research on more than one sector type. However, this goes beyond the scope of the presented results, and thus, it will not be considered here.

technological sectors that feature a higher degree of openness. The main aim is to protect the sectors that are most threatend by foreign high technological firms. If we have higher innovation steps, basic research should be concentrated on the high-technological sectors with a lower degree of openness. The policy's aim here is to maximize technological progress. Thus, it should allow the entrance of foreign firms in the more open sectors to benefit from the free import of high technology.

There remain several interesting open issues which are left for future research. First, a straightforward extension would be to differentiate sectors also with respect to the important innovation-step size. It would then be possible to control for the sectors' difference in technological growth speed. However, it is very complex to implement this in our model framework. Second, it may be interesting to endogenize the behavior of foreign countries and to examine the issue of targeting basic research from a global perspective. This would increase the strategic scope of basic research, as taking over foreign markets would constitute an additional incentive to invest in basic research. Third, it might be useful, but by no means trivial, to establish the dynamics of our model in order to examine a social planner's solution for basic-research investment across many generations.

A Proofs

A.1 Proof of Lemma 1

We show that the function $L^B(w)$ strictly increases in w, hence the inverse function exists. As $L^B < 0$ is not feasible, wages lower than $\sqrt{\mathcal{A}}$ are not possible in equilibrium. Rewriting equation (21) as

$$L^B(w) = \frac{1 - \frac{\mathcal{A}}{w^2}}{1 + \frac{\mathcal{B}+\mathcal{C}}{w^4}} \tag{32}$$

reveals that L^B will be zero for $w = \sqrt{\mathcal{A}}$, and converges to 1 for $w \to \infty$. No equilibrium exists for $w < \sqrt{\mathcal{A}}$. For $w \geq \sqrt{\mathcal{A}}$, it is convenient to replace w by $\sqrt{z\mathcal{A}}$, where $z \geq 1$. We obtain

$$L^B(z) = \frac{1 - \frac{1}{z}}{1 + \frac{\mathcal{B}+\mathcal{C}}{z^2\mathcal{A}^2}}. \tag{33}$$

We now need to show that $L^B(z)$ is strictly increasing in z, i.e. that

$$\frac{\partial L^B(z)}{\partial z} = \frac{\frac{1}{z^2}\left(1 + \frac{\mathcal{B}+\mathcal{C}}{z^2\mathcal{A}^2}\right) + 2\frac{z-1}{z}\frac{\mathcal{B}+\mathcal{C}}{z^3\mathcal{A}^2}}{\left(1 + \frac{\mathcal{B}+\mathcal{C}}{z^2\mathcal{A}^2}\right)^2} > 0. \tag{34}$$

This condition can be rewritten as

$$1 - \frac{\mathcal{B}+\mathcal{C}}{z^2\mathcal{A}^2} + 2\frac{\mathcal{B}+\mathcal{C}}{z\mathcal{A}^2} > 0. \tag{35}$$

If $\mathcal{B}+\mathcal{C} > 0$, we can estimate the left-hand side from below by multiplying the last term with $\frac{1}{z}$. This gives us

$$1 + \frac{\mathcal{B}+\mathcal{C}}{z^2\mathcal{A}^2} > 0,$$

which is obviously satisfied.

We now consider the case where $\mathcal{B}+\mathcal{C} < 0$. As the left hand side of (35) is increasing in z, we know that if condition (35) is satisfied for $z = 1$, it will also be satisfied for $z > 1$. By inserting $z = 1$, we obtain

$$1 + \frac{\mathcal{B}+\mathcal{C}}{\mathcal{A}^2} > 0. \tag{36}$$

This holds under Assumption 1, i.e. if $\mathcal{B}+\mathcal{C} > -\mathcal{A}^2$.

A.2 Proof of Lemma 2

To prove that we have a unique maximum consumption level in the relevant space $w \geq \sqrt{\mathcal{A}}$, we show that $c(w)$ is either always decreasing in w or increasing in w, reaching a local maximum, and then decreasing in w.

To analyze the slope of $c(w)$, we differentiate with respect to w:

$$\begin{aligned}\frac{\partial c(w)}{\partial w} =& \frac{-w^8(2\mathcal{A}+2\mathcal{D}+\mathcal{E}) - 3w^6(2\mathcal{B}+3\mathcal{C}+\mathcal{F}) + w^4(\mathcal{B}+\mathcal{C})(6\mathcal{A}-4\mathcal{D}-2\mathcal{E})}{w^2(w^4+\mathcal{B}+\mathcal{C})^2} + \\ & \frac{5w^4\mathcal{A}(\mathcal{C}+\mathcal{F}) + w^2(\mathcal{B}+\mathcal{C})(2\mathcal{B}+3\mathcal{C}+\mathcal{F})}{w^2(w^4+\mathcal{B}+\mathcal{C})^2} + \\ & \frac{(\mathcal{B}+\mathcal{C})\big(\mathcal{A}(\mathcal{C}+\mathcal{F}) - (\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E})\big)}{w^2(w^4+\mathcal{B}+\mathcal{C})^2}.\end{aligned}$$

It is obvious that the denominator is positive. Hence, to determine the slope it is sufficient to focus on the numerator only. As we are interested in the relevant space $w \geq \sqrt{\mathcal{A}}$, it is convenient to replace w by $\sqrt{z\mathcal{A}}$, whereas $z \geq 1$. The numerator takes the form

$$\begin{aligned}&\underbrace{-z^4\mathcal{A}^4(2\mathcal{A}+2\mathcal{D}+\mathcal{E})}_{U}\underbrace{-3z^3\mathcal{A}^3(2\mathcal{B}+3\mathcal{C}+\mathcal{F})}_{V}\underbrace{+5z^2\mathcal{A}^3(\mathcal{C}+\mathcal{F})}_{W}+ \\ &\underbrace{z^2\mathcal{A}^2(\mathcal{B}+\mathcal{C})(6\mathcal{A}-4\mathcal{D}-2\mathcal{E})}_{X}\underbrace{+z\mathcal{A}(\mathcal{B}+\mathcal{C})(2\mathcal{B}+3\mathcal{C}+\mathcal{F})}_{Y}+ \\ &\underbrace{(\mathcal{B}+\mathcal{C})\big(\mathcal{A}(\mathcal{C}+\mathcal{F}) - (\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E})\big)}_{Z}.\end{aligned}$$

We note that $\mathcal{A}, \mathcal{B}, \mathcal{D}, \mathcal{E}, \mathcal{F} > 0$, $\mathcal{F} > -\mathcal{C}$, and $\mathcal{A} > \mathcal{D}+\mathcal{E}$. The analysis can be simplified by distinguishing four cases.

1. $\mathcal{B}+\mathcal{C} > 0$ and $(\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E}) - \mathcal{A}(\mathcal{C}+\mathcal{F}) < 0$
   U and V, the terms with the highest exponents of z, are negative, while all the remaining terms, W, X, Y, and Z, are positive. Hence, it is obvious that in this case $c(w)$ either falls straightaway in z or w, or it rises first and falls after reaching its maximum.

2. $\mathcal{B}+\mathcal{C} > 0$ and $(\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E}) - \mathcal{A}(\mathcal{C}+\mathcal{F}) > 0$
   U and V are negative, W, X, and Y are positive, and Z is again negative. If Y dominates Z for $z = 1$, it is always dominating and as in the preceding case the exponents of z can be used to state the uniqueness of a maximum consumption

level. Inserting $z = 1$ in $Y + Z > 0$ leads to

$$\begin{aligned}\mathcal{A}(\mathcal{B}+\mathcal{C})(2\mathcal{B}+4\mathcal{C}+2\mathcal{F}) - (\mathcal{B}+\mathcal{C})^2(2\mathcal{D}+\mathcal{E}) > 0 \\ \mathcal{A}(2\mathcal{B}+4\mathcal{C}+2\mathcal{F}) > (\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E}) \\ 2\mathcal{A}(\mathcal{C}+\mathcal{F}) + 2\mathcal{A}(\mathcal{B}+\mathcal{C}) > (2\mathcal{D}+\mathcal{E})(\mathcal{B}+\mathcal{C}).\end{aligned}$$

As $\mathcal{A} > \mathcal{D} + \mathcal{E}$, the inequality holds, and the existence of a unique maximum is shown.

3. $\mathcal{B} + \mathcal{C} < 0$ and $2\mathcal{B} + 3\mathcal{C} + \mathcal{F} > 0$
U and V are still negative, W is positive, and the remaining terms X, Y, and Z, are negative. Thus it is sufficient to show that $W + X + Y + Z > 0$ holds for $z = 1$. Arguing with the exponents of z again, $c(w)$ is then either falling all along or rising before falling continuously. Next we prove that $W + X + Y + Z > 0$ for $z = 1$:

$$\begin{aligned}5\mathcal{A}^3(\mathcal{C}+\mathcal{F}) + \mathcal{A}^2(\mathcal{B}+\mathcal{C})(6\mathcal{A}-4\mathcal{D}-2\mathcal{E}) + \mathcal{A}(\mathcal{B}+\mathcal{C})(2\mathcal{B}+3\mathcal{C}+\mathcal{F}) + \\ \mathcal{A}(\mathcal{B}+\mathcal{C})(\mathcal{C}+\mathcal{F}) - (\mathcal{B}+\mathcal{C})^2(2\mathcal{D}+\mathcal{E}) > 0.\end{aligned}$$

Estimating $W + X + Y + Z$ from below by using Assumption 1, the inequality reduces to

$$\begin{aligned}4\mathcal{A}^3(\mathcal{C}+\mathcal{F}) + \mathcal{A}^2(\mathcal{B}+\mathcal{C})(6\mathcal{A}-4\mathcal{D}-2\mathcal{E}) + \mathcal{A}(\mathcal{B}+\mathcal{C})(2\mathcal{B}+3\mathcal{C}+\mathcal{F}) + \\ -(\mathcal{B}+\mathcal{C})^2(2\mathcal{D}+\mathcal{E}) > 0 \\ 4\mathcal{A}^3(\mathcal{C}+\mathcal{F}) + \mathcal{A}^2(\mathcal{B}+\mathcal{C})(6\mathcal{A}-2\mathcal{D}-\mathcal{E}) + \mathcal{A}(\mathcal{B}+\mathcal{C})(2\mathcal{B}+3\mathcal{C}+\mathcal{F}) > 0 \\ 3\mathcal{A}^3(\mathcal{C}+\mathcal{F}) + \mathcal{A}^2(\mathcal{B}+\mathcal{C})(6\mathcal{A}-2\mathcal{D}-\mathcal{E}) + 2\mathcal{A}(\mathcal{B}+\mathcal{C})^2 > 0 \\ 3\mathcal{A}^3(\mathcal{C}+\mathcal{F}) + 2\mathcal{A}(\mathcal{B}+\mathcal{C})^2 - \mathcal{A}^2(\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E}) + 6\mathcal{A}^3(\mathcal{B}+\mathcal{C}) > 0.\end{aligned}$$

The second and third terms are positive. Hence, again estimating the LHS from below by neglecting them gives us

$$\begin{aligned}3\mathcal{A}^3(\mathcal{C}+\mathcal{F}) + 6\mathcal{A}^3(\mathcal{B}+\mathcal{C}) > 0 \\ 3(\mathcal{C}+\mathcal{F}) + 6(\mathcal{B}+\mathcal{C}) > 0 \\ 2\mathcal{B}+3\mathcal{C}+\mathcal{F} > 0.\end{aligned}$$

This inequality holds by the definition of the case we are dealing with.

4. $\mathcal{B}+\mathcal{C}<0$ and $2\mathcal{B}+3\mathcal{C}+\mathcal{F}<0$
In this case, U is negative, V and W are positive, X is negative, Y is positive, and finally Z is negative. It is thus slightly more complicated to show the existence of a unique maximum of $c(w)$. We have to take two steps. First, we show that X dominates Y at $z=1$.

$$\mathcal{A}^2(\mathcal{B}+\mathcal{C})(6\mathcal{A}-4\mathcal{D}-2\mathcal{E})+\mathcal{A}(\mathcal{B}+\mathcal{C})(2\mathcal{B}+3\mathcal{C}+\mathcal{F})<0$$
$$\mathcal{A}(6\mathcal{A}-4\mathcal{D}-2\mathcal{E})+2\mathcal{B}+3\mathcal{C}+\mathcal{F}>0.$$

The fact that $\mathcal{A}>\mathcal{D}+\mathcal{E}$ allows us to reduce the inequality to

$$2\mathcal{A}^2+2\mathcal{B}+3\mathcal{C}+\mathcal{F}>0.$$

Furthermore, omitting the positive term $\mathcal{C}+\mathcal{F}$ leads to

$$2\mathcal{A}^2+2(\mathcal{B}+\mathcal{C})>0$$
$$\mathcal{A}^2>-(\mathcal{B}+\mathcal{C}).$$

According to Assumption 1 the inequality holds. Consequently, $X+Y+Z$ is negative along the whole relevant interval because of $z\geq 1$ and X having the larger exponent of z. The next step is to prove that $V+W+Y+X+Z>0$ for $z=1$.

$$-3\mathcal{A}^3(2\mathcal{B}+3\mathcal{C}+\mathcal{F})+5\mathcal{A}^3(\mathcal{C}+\mathcal{F})+\mathcal{A}^2(\mathcal{B}+\mathcal{C})(6\mathcal{A}-4\mathcal{D}-2\mathcal{E})+$$
$$\mathcal{A}(\mathcal{B}+\mathcal{C})(2\mathcal{B}+3\mathcal{C}+\mathcal{F})+(\mathcal{B}+\mathcal{C})\big(\mathcal{A}(\mathcal{C}+\mathcal{F})-(\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E})\big)>0$$
$$2\mathcal{A}^3(\mathcal{C}+\mathcal{F})+2\mathcal{A}(\mathcal{B}+\mathcal{C})(\mathcal{B}+2\mathcal{C}+\mathcal{F})+$$
$$-2\mathcal{A}^2(\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E})-(\mathcal{B}+\mathcal{C})^2(2\mathcal{D}+\mathcal{E})>0.$$

Making use of Assumption 1, we can reduce the inequity in the following way:

$$2\mathcal{A}^3(\mathcal{C}+\mathcal{F})+2\mathcal{A}(\mathcal{B}+\mathcal{C})(\mathcal{B}+2\mathcal{C}+\mathcal{F})-\mathcal{A}^2(\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E})>0$$
$$2\mathcal{A}(\mathcal{B}+\mathcal{C})^2-\mathcal{A}^2(\mathcal{B}+\mathcal{C})(2\mathcal{D}+\mathcal{E})>0.$$

As both terms are positive, the inequity is correct. Considering the exponents of z and the two facts that $X+Y+Z<0$ always holds and that $V+W+X+Y+Z>0$ at $z=1$, we can state the validity of $V+W+X+Y+Z>0$ along the whole relevant interval. Furthermore, we know that U is negative and that it has the highest exponent of z. Thus in this case as well, $c(w)$ either falls continuously or rises first to reach a maximum and falls subsequently.

A.3 Proof of Lemma 3

By using equation (25) in equation (27) we obtain the following expression for overall consumption

$$c = (1 - L^B)w + s_1^{BR}\pi_1^{BR} + s_1^N\pi_1^N + s_2^{BR}\pi_2^{BR} + \pi^y. \tag{37}$$

We now have to show that the derivative with respect to s_1^{BR} is positive.

$$\begin{aligned}
\frac{\partial c}{\partial s_1^{BR}} =& \frac{\partial(s_1^{BR}\pi_1^{BR})}{\partial s_1^{BR}} + \frac{\partial s_1^N}{\partial s_1^{BR}}\pi_1^N + s_2^{BR}\frac{\partial \pi_2^{BR}}{\partial s_1^{BR}} + \frac{\partial \pi^y}{\partial s_1^{BR}} \\
=& \left[\phi - \frac{s_1^{BR}}{(s_1^{BR}+s_2^{BR})^2}\right] L^B\theta^2(\gamma-1+\sigma)^2\frac{\bar{A}^2}{256\gamma^2 w^3} + (1-\sigma)\frac{\bar{A}}{16\gamma w} - \\
&(1-\sigma)\frac{\bar{A}}{16\gamma w} - \frac{s_2^{BR}}{(s_1^{BR}+s_2^{BR})^2}L^B\theta^2(1-\sigma)^2\frac{\bar{A}^2}{256\gamma^2 w^3} + \\
&\left[\phi - \frac{s_1^{BR}}{(s_1^{BR}+s_2^{BR})^2}\right] L^B\theta^2(1-\sigma)(\gamma-1+\sigma)(\gamma-1)\frac{\bar{A}^2}{64\gamma^2 w^3} - \\
&\frac{s_2^{BR}}{(s_1^{BR}+s_2^{BR})^2}L^B\theta^2(1-\sigma)^2(\gamma-2)\frac{\bar{A}^2}{64\gamma^3 w^3} \\
=&\phi^2 s_2^{BR}L^B\theta^2\frac{\bar{A}^2}{256\gamma^3 w^3}\Big\{\gamma(\gamma-1+\sigma)^2 - \gamma(1-\sigma)^2 + \\
&4\gamma(1-\sigma)(\gamma-1+\sigma)(\gamma-1) - 4(1-\sigma)^2(\gamma-2)\Big\} \\
=&\phi^2 s_2^{BR}L^B\theta^2\frac{\bar{A}^2}{256\gamma^3 w^3}\Big\{\gamma(\gamma-1+\sigma)\big(\gamma-1+\sigma+4(1-\sigma)(\gamma-1)\big) - \\
&(1-\sigma)^2(5\gamma-8)\Big\} \geq 0.
\end{aligned} \tag{38}$$

It is obvious to see that the direct effect of s_1^{BR}-concentration is neutral when $s_2^{BR} = 0$. It means that in this case the *beneficiary size* and the *research effectivity effect* cancel eachother out.

As the expression in (38) left of the brace is surely positive, it remains to show that the brace is positive.

$$\underbrace{\gamma(\gamma-1+\sigma)\big(\gamma-1+\sigma+4(1-\sigma)(\gamma-1)\big)}_{P}\underbrace{-(1-\sigma)^2(5\gamma-8)}_{Q} \geq 0.$$

P is always positive. For $\gamma \leq \frac{8}{5}$ also Q is positive, and hence, the inequality holds. In order to analyze the validity of the inequality for $\gamma > \frac{8}{5}$ we derivate it with respect to γ.

$$\underbrace{3\gamma^2}_{(+)} + \underbrace{12\gamma^2(1-\sigma) - 20\gamma(1-\sigma)}_{(+)\text{ for }\gamma>\frac{8}{5}} + \underbrace{8\sigma\gamma(1-\sigma)}_{(+)} > 0.$$

Thus, $P+Q$ increases in γ when $\gamma > \frac{8}{5}$ holds. And as we have shown that $P+Q \geq 0$ for $\gamma = \frac{8}{5}$, it will surely be positive for higher values of γ as well. To sum up, it is proven that s_1^{BR}-concentration has a negative direct effect on consumption.

With the same line of argumentation we can show that the derivative of (37) with respect to s_2^{BR} is negative. Hence, the positive direct effect of s_2^{BR}-concentration is proven.

A.4 The *Wage Effect's* Direction

By using equation (25) in equation (27) we obtain the following expression for overall consumption

$$c = (1-L^B)w + s_1^{BR}\pi_1^{BR} + s_1^N\pi_1^N + s_2^{BR}\pi_2^{BR} + \pi^y.$$

The wage effect's direction can be determined by taking the derivative with respect to w.

$$\frac{\partial c}{\partial w} = 1 - L^B + s_1^{BR}\frac{\partial \pi_1^{BR}}{\partial w} + s_1^N\frac{\partial \pi_1^N}{\partial w} + s_2^{BR}\frac{\partial \pi_2^{BR}}{\partial w} + \frac{\partial \pi^y}{\partial w}.$$

When writing out, the expression takes the following form:

$$\begin{aligned} 1 - L^B - 3s_1^{BR}\frac{\bar{A}^2}{256\gamma^2 w^4}L^B\phi\theta^2(\gamma-1+\sigma)^2 - s_1^{BR}\frac{\bar{A}}{16\gamma w^2}(1-\sigma) + \\ -s_1^N\frac{\bar{A}}{16\gamma w^2}(1-\sigma) - 3s_2^{BR}\frac{\bar{A}^2}{256\gamma^2 w^4}L^B\phi\theta^2(1-\sigma)^2 + \\ -\frac{\bar{A}}{8w^2}\sigma - 3s_1^{BR}\frac{\bar{A}}{64\gamma^2 w^4}L^B\phi\theta^2(1-\sigma)(\gamma-1+\sigma)(\gamma-1) - s_1\frac{\bar{A}}{8\gamma w^2}(1-\sigma) + \\ -3s_2^{BR}\frac{\bar{A}}{64\gamma^3 w^4}L^B\phi\theta^2(1-\sigma)^2(\gamma-2) - (s_2+s_3)\frac{\bar{A}}{4\gamma^2 w^2}(1-\sigma). \end{aligned}$$

This equals

$$
\begin{aligned}
1 - L^B - \frac{1}{w^2}\frac{\bar{A}}{16\gamma^2}\Big(2\sigma\gamma^2 + (1-\sigma)\big(3s_1\gamma + 4(s_2+s_3)\big)\Big) + \\
-3\frac{L^B}{w^4}\frac{\bar{A}^2}{256\gamma^2}\theta^2\phi\left(s_1^{BR}(\gamma-1+\sigma)^2 + s_2^{BR}(1-\sigma)^2\right) + \\
-6\frac{L^B}{w^4}\frac{\bar{A}^2}{128\gamma^3}\theta^2\phi(1-\sigma)\left(s_1^{BR}\gamma(\gamma-1)(\gamma-1+\sigma) + s_2^{BR}(\gamma-4)(1-\sigma)\right) + \\
-3\frac{L^B}{w^4}\frac{\bar{A}^2}{32\gamma^3}\theta^2\phi s_2^{BR}(1-\sigma)^2.
\end{aligned}
$$

Making use of (22), (23), (24), (29) and (30), and replacing L^B with (21), we get

$$
\begin{aligned}
1 - \frac{w^4 - \mathcal{A}w^2}{w^4 + \mathcal{B} + \mathcal{C}} - \frac{1}{w^2}(\mathcal{A} + 2\mathcal{D} + \mathcal{E}) - \frac{w^2 - \mathcal{A}}{w^2(w^4 + \mathcal{B} + \mathcal{C})}(3\mathcal{B} + 6\mathcal{C} + 3\mathcal{F}) = \\
w^2(w^4 + \mathcal{B} + \mathcal{C}) - w^2(w^4 - \mathcal{A}w^2) - (w^4 + \mathcal{B} + \mathcal{C})(\mathcal{A} + 2\mathcal{D} + \mathcal{E}) + \\
-(w^2 - \mathcal{A})(3\mathcal{B} + 6\mathcal{C} + 3\mathcal{F}) = \\
-\underbrace{(w^4 + \mathcal{B} + \mathcal{C})}_{H}\underbrace{(2\mathcal{D} + \mathcal{E})}_{I} - \underbrace{(w^2 - \mathcal{A})}_{J}\underbrace{(2\mathcal{B} + 5\mathcal{C} + 3\mathcal{F})}_{K}.
\end{aligned}
\tag{39}
$$

It is straightforward that H, I and J are positive. Hence, if K is also positive, the *wage effect* is surely negative. When writing out K we obtain

$$
\begin{aligned}
\frac{\bar{A}^2}{256\gamma^3}\theta^2\phi[2s_1^{BR}\gamma(\gamma-1+\sigma)^2 + 2s_2^{BR}\gamma(1-\sigma)^2 + \\
10s_1^{BR}\gamma(\gamma-1)(\gamma-1+\sigma)(1-\sigma) + 10s_2^{BR}(\gamma-4)(1-\sigma)^2 + 24s_2^{BR}(1-\sigma)^2] = \\
\frac{\bar{A}^2}{256\gamma^3}\theta^2\phi[s_1^{BR}\gamma(\gamma-1+\sigma)\{2(\gamma-1+\sigma) + 10(\gamma-1)(1-\sigma)\} + \\
s_2^{BR}(1-\sigma)^2\{12\gamma - 16\}].
\end{aligned}
$$

We see that K is surely positive for $\gamma > \frac{4}{3}$. Thus, a small γ is needed to obtain a negative K. Additionally, a small σ and s_1^{BR} and a high s_2^{BR} support this outcome.

We now assume K to be negative. In order for (39) to be positive, I must be as small as possible, which is given for low s_1 and σ. For the extreme case $s_1 = 0$ and $\sigma = 0$, $I = 0$ and the *wage effect* is positive given $K < 0$.

Thus, we have shown that for the *wage effect* to get positive, γ, σ and s_1 have to be low.

A.5 Derivation of Maximum Consumption Level with Two Openness Factors

When extending the model with two openness factors σ^o and σ^c, the maximum consumption level can be derived in the exact same way. All the state 1 and state 2 monopolists still maximize their profits according to (8) and (12). However, as they consider different openness factors, we have to take into account more labor demands L_1^{oI}, L_1^{cI}, L_2^{oI}, L_2^{cI}, more innovation probabilities ρ_1^{oBR}, ρ_1^{cBR}, ρ_2^{oBR}, ρ_2^{cBR}, and more expected profits ϕ_1^{oBR}, ϕ_1^{cBR}, ϕ_2^{oBR}, ϕ_2^{cBR}. How this affects the remainig equations of the model is straightforward. Moreover, the central equations of the model (21) and (28) can be specified the same way

$$L^B(w) = w^2 \frac{w^2 - \mathcal{A}}{w^4 + \mathcal{B} + \mathcal{C}},$$

$$c(w) = \frac{w^4(2\mathcal{A} + 2\mathcal{D} + \mathcal{E}) + w^2(2\mathcal{B} + 3\mathcal{C} + \mathcal{F}) + (\mathcal{B} + \mathcal{C})(2\mathcal{D} + \mathcal{E}) - \mathcal{A}(\mathcal{C} + \mathcal{F})}{w(w^4 + \mathcal{B} + \mathcal{C})},$$

whereas here $\mathcal{A}$, $\mathcal{B}$, $\mathcal{C}$, $\mathcal{D}$, $\mathcal{E}$ and $\mathcal{F}$ take the extended form

$$\begin{aligned}
\mathcal{A} &= \frac{\bar{A}}{16\gamma^2}\big[\sigma^o(s_1^o + s_2^o + s_3^o)\gamma^2 + (1-\sigma^o)\big(s_1^o\gamma + 4(s_2^o + s_3^o)\big) + \\
&\quad \sigma^c(s_1^c + s_2^c + s_3^c)\gamma^2 + (1-\sigma^c)\big(s_1^c\gamma + 4(s_2^c + s_3^c)\big)\big] > 0 \\
\mathcal{B} &= \frac{\bar{A}^2}{256\gamma^2}\theta^2\phi\big[s_1^{oBR}(\gamma - 1 + \sigma^o)^2 + s_2^{oBR}(1-\sigma^o)^2 + \\
&\quad s_1^{cBR}(\gamma - 1 + \sigma^c)^2 + s_2^{cBR}(1-\sigma^c)^2\big] > 0 \\
\mathcal{C} &= \frac{\bar{A}^2}{128\gamma^3}\theta^2\phi\big[s_1^{oBR}\gamma(\gamma-1)(\gamma-1+\sigma^o)(1-\sigma^o) + s_2^{oBR}(\gamma-4)(1-\sigma^o)^2 + \\
&\quad s_1^{cBR}\gamma(\gamma-1)(\gamma-1+\sigma^c)(1-\sigma^c) + s_2^{cBR}(\gamma-4)(1-\sigma^c)^2\big] \\
\mathcal{D} &= \frac{\bar{A}}{16\gamma}\big[s_1^o(1-\sigma^o) + s_1^c(1-\sigma^c)\big] > 0 \\
\mathcal{E} &= \frac{\bar{A}}{16}\big[\sigma^o(s_1^o + s_2^o + s_3^o) + \sigma^c(s_1^c + s_2^c + s_3^c)\big] > 0 \\
\mathcal{F} &= \frac{\bar{A}^2}{32\gamma^3}\theta^2\phi\big[s_2^{oBR}(1-\sigma^o)^2 + s_2^{cBR}(1-\sigma^c)^2\big] > 0
\end{aligned}$$

and $\phi = \frac{1}{s_1^{oBR} + s_1^{cBR} + s_2^{oBR} + s_2^{cBR}}$.

As $\mathcal{A} - \mathcal{F}$ feature the same sign than the ones of the basic model, Lemma 1 and 2 and their proof are also valid for this case.

A.6 Proof of Lemma 4

We assume $s_2^{oBR} = s_2^{cBR} = 0$. Considering equations (25) and (27), the expression for overall consumption in the framework with two openness factors is given by

$$c = (1 - L^B)w + s_1^{oBR}\pi_1^{oBR} + s_1^{oN}\pi_1^{oN} + s_1^{cBR}\pi_1^{cBR} + s_1^{cN}\pi_1^{cN} + \pi^y,$$

whereas π^y takes the form

$$\begin{aligned}\pi^y = &\left[\sigma^o \left(s_1^{oBR}(1-\rho_1^{oBR}) + s_1^{oN} + s_2^o + s_3^o\right) + s_1^{oBR}\rho_1^{oBR}\right]\bar{A}_t \left(\frac{\alpha^2}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)+\\ &\left[\sigma^c \left(s_1^{cBR}(1-\rho_1^{cBR}) + s_1^{cN} + s_2^c + s_3^c\right) + s_1^{cBR}\rho_1^{cBR}\right]\bar{A}_t \left(\frac{\alpha^2}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)+\\ &\left[s_1^{oBR}(1-\sigma^o)(1-\rho_1^{BRo}) + s_1^{oN}(1-\sigma^o)\right]\bar{A}_{t-1}\left(\frac{\alpha^2}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)+\\ &\left[s_1^{cBR}(1-\sigma^c)(1-\rho_1^{cBR}) + s_1^{cN}(1-\sigma^c)\right]\bar{A}_{t-1}\left(\frac{\alpha^2}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha)+\\ &\left[(s_2^o + s_3^o)(1-\sigma^o) + (s_2^c + s_3^c)(1-\sigma^c)\right]\bar{A}_{t-2}\left(\frac{\alpha}{w}\right)^{\frac{\alpha}{1-\alpha}}(1-\alpha).\end{aligned}$$

By derivating c with respect to s_1^{oBR} and s_1^{cBR} we obtain the direct effects of s_1^{oBR}-respectively s_1^{cBR}-concentration. We start with s_1^{oBR}.

$$\begin{aligned}\frac{\partial c}{\partial s_1^{oBR}} =& \frac{\partial(s_1^{oBR}\pi_1^{oBR})}{\partial s_1^{oBR}} + \frac{\partial s_1^{oN}}{\partial s_1^{oBR}}\pi_1^{oN} + s_1^{cBR}\frac{\partial \pi_1^{cBR}}{\partial s_1^{oBR}} + \frac{\partial \pi^y}{\partial s_1^{oBR}}\\ =& \left[\phi - \frac{s_1^{oBR}}{(s_1^{oBR}+s_1^{cBR})^2}\right] L^B\theta^2(\gamma - 1 + \sigma^o)^2\frac{\bar{A}^2}{256\gamma^2 w^3} + (1-\sigma^o)\frac{\bar{A}}{16\gamma w} -\\ &(1-\sigma^o)\frac{\bar{A}}{16\gamma w} - \frac{s_1^{cBR}}{(s_1^{oBR}+s_1^{cBR})^2}L^B\theta^2(\gamma - 1 + \sigma^c)^2\frac{\bar{A}^2}{256\gamma^2 w^3} +\\ &\left[\phi - \frac{s_1^{oBR}}{(s_1^{oBR}+s_1^{cBR})^2}\right] L^B\theta^2(1-\sigma^o)(\gamma - 1 + \sigma^o)(\gamma - 1)\frac{\bar{A}^2}{64\gamma^2 w^3} -\\ &\frac{s_1^{cBR}}{(s_1^{oBR}+s_1^{cBR})^2}L^B\theta^2(1-\sigma^c)(\gamma - 1 + \sigma^c)(\gamma - 1)\frac{\bar{A}^2}{64\gamma^2 w^3}\end{aligned}$$

$$\frac{\partial c}{\partial s_1^{oBR}} = \phi^2 s_1^{cBR} L^B \theta^2 \frac{\bar{A}^2}{256\gamma^2 w^3} \Big\{ (\gamma - 1 + \sigma^o)^2 - (\gamma - 1 + \sigma^c)^2 +$$
$$4(\gamma - 1)(1 - \sigma^o)(\gamma - 1 + \sigma^o) - 4(\gamma - 1)(1 - \sigma^c)(\gamma - 1 + \sigma^c) \Big\}.$$

The sign of the expression in the brace determines wether the direct effect is positive or negative. We can write out the brace to obtain

$$(\sigma^o)^2 - (\sigma^c)^2 + 2(\gamma - 1)(\sigma^o - \sigma^c) + 4(\gamma - 1)[(2 - \gamma)(\sigma^o - \sigma^c) - (\sigma^o)^2 + (\sigma^c)^2] =$$
$$(\sigma^o - \sigma^c)\left[-(4\gamma - 5)(\sigma^o + \sigma^c) + (10 - 4\gamma)(\gamma - 1)\right].$$

As $(\sigma^o - \sigma^c)$ is positive the expression in the squared bracket is determinant. It is obvious that for $\gamma < \frac{5}{4}$ the direct effect of s_1^{oBR}-concentration is always negative.

We now show that the direct effect of s_1^{oBR}-concentration becomes positive if we increase the level of γ high enough. Therefore, we take the derivative of the expression in the squared bracket with respect to γ

$$-4(\sigma^o + \sigma^c) + 14 - 8\gamma.$$

For $(\sigma^o + \sigma^c) > \frac{3}{2}$ it is surely negative, and thus, the bracket expression falls monotonically in γ. For $(\sigma^o + \sigma^c) < \frac{3}{2}$, it is first positive and from a certain level of γ on it is negative. Consequently, the expression in the squared bracket starts to fall monotonically in γ at a certain level of γ. Thus, is is proven that the direct effect of s_1^{oBR}-concentration is positive with large enough γ. However, we assumed γ to be bounded according to $\gamma \leq 2$. By inserting $\gamma = 2$ in the squared bracket expression we can determine under which condition we do not obtain a reversal of the direct effect's sign.

$$-3(\sigma^o + \sigma^c) + 2 > 0$$
$$\frac{2}{3} > (\sigma^o + \sigma^c).$$

Doing the same exercise to calculate the direct effect of s_1^{cBR}-concentration, we rapidly see that it is the exact opposite of the direct effect of s_1^{oBR}-concentration.

References

Acs, Z. J., Audretsch, D. B. and M. Feldmann (1992): 'Real effects of academic research: Comment', *The American Economic Review*, 82: 363–367.

Aghion, P., Blundell, R., Griffith, R., Howitt, P. and S. Prantl (2006): 'The effects of entry on incumbent innovation and productivity'. *NBER Working Papers* 12027, National Bureau of Economic Research, Inc.

Ergas, H. (1987): 'The importance of technology policy'. In Dasgupta, P. and P. Stoneman (Eds.): *Economic Policy and Technological Performance*. Cambridge University Press, Cambridge. Pages 51–96.

Gersbach, H., Schneider, M. and O. Schneller (2008): 'On the design of basic research policy'. *CER-ETH Working Papers* 79, Center of Economic Research at ETH Zurich.

Giovanni Dosi, Silvia Fabiani, R. A. and M. Meacci (1994): 'The dynamics of international differentiation: A multi-country evolutionary model', *Industrial and Corporate Change*, 3(1): 225–242.

Jungmittag, A. (2004): 'Innovations, technological specialisation and economic growth in the eu', *International Economics and Economic Policy*, 1(2): 247–273.

Katz, J. S. (1994): 'Geographical proximity and scientific collaboration', *Scientometrics*, 31(1): 31–43.

Koyama, T. and S. Golub (2006): 'OECD's FDI regulatory restrictiveness index: Revision and extension to more economies'. *Economics Department Working Papers* 525, OECD.

Laursen, K. (2000): *Trade Specialisation, Technology and Economic Growth. Theory and Evidence from Advanced Countries*. Edward Elgar, Cheltenham.

Lee, J. W. and P. Swagel (2000): 'Trade barriers and trade flows across countries and industries', *The Review of Economics and Statistics*, 79(3): 372–382.

Lorentz, A. (2006): 'Sectoral specialisation and growth rate differences among integrated economies', *The Electronic Journal of Evolutionary Modeling and Economic Dynamics*.

Los, B. and B. Verspagen (2006): 'The evolution of productivity gaps and specialization patterns', *Metroeconomica*, 57(4): 464–493.

Meliciani, V. (2001): *Technology, Trade and Growth in OECD Countries. Does Specialisation Matter?* Routledge, London.

Morales, M. (2004): 'Research policy and endogenous growth', *Spanish Economic Review*, 6(3): 179–209.

Narin, F., Hamilton, K. S. and D. Olivastro (1997): 'The increasing linkage between u.s. technology and public science', *Research Policy*, 26(3): 317–330.

OECD (2002): *The Measurement of Scientific and Technological Activities: Proposed Standard Practice for Surveys on Research and Experimental Development.* OECD Publications.

OECD (2007): 'Research and development statistics', 2007 Edition.

Park, W. G. (1998): 'A theoretical model of government research and growth', *Journal of Economic Behavior & Organization*, 34(1): 69–85.

Pelloni, A. (1997): 'Public financing of education and research in a model of endogenous growth', *LABOUR*, 11(3): 517–539.

Salter, A. J. and B. R. Martin (2001): 'The economic benefits of publicly funded basic research: a critical review', *Research Policy*, 30(3): 509–532.

Shell, K. (1967): 'A model of inventive activity and captial accumulation'. In: *Essays on the Theory of Optimal Growth.* MIT Press, Cambridge, MA.

Verspagen, B. (1993): *Uneven Growth Between Interdependent Economies: an Evolutionary View on Technology Gaps, Trade and Growth.* Avebury, Aldershot.

Zellner, C. (2003): 'The economic effects of basic research: evidence for embodied knowledge transfer via scientists' migration', *Research Policy*, 32(10): 1881–1895.