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European Productivity Gaps: Is R&D the Solution?

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1. Introduction

Industrialization, and the association between technological advance and economic growth, brought Europe world economic leadership in the 19th century. However, in the course of the 20th century, European leadership was lost to the United States, as well as a number of dynamic Asian economies, of which Japan was the first to emerge in the process of modern economic growth. This loss of European leadership is commonly associated with another major technological change: the rise of the mass production system in the United States (e.g., David, 1975).

The process of European integration, started after the Second World War primarily as a way of achieving political stability and peace, became a major force towards the realization of economies of scale in the European economies, and hence as a way for Europe to benefit more than it had done before from the mass production system. This had its highpoint in the realization of the 'Europe 1992' program, which created a single European market, without limitations or the free trade of goods and services or the free mobility of people (Tsoukalis, 1997).

As a result of this and other factors related to the diffusion of technology, Europe was able to catch-up to the United States over the long postwar period (e.g., Abramovitz, 1979, Nelson and Wright, 1992, Pavitt and Soete, 1982), and close some of the productivity gap that had emerged in the first half of the 20th century (especially during the 1930s and 1940s). However, as we will document below, at the dawn of the 21st century Europe still faces a major productivity gap relative to

the U.S.A. and other world economic leaders, such as Japan.

- This fact of a European backlog relative to especially the U.S.A. and the dynamic Asian economies, led European political leaders to formulate an ambitious goal for the first ten years of the new millennium. At the Lisbon Summit in 2000 the governments of the European Union (EU) agreed on the goal of the EU to become by 2010 "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion".[1] This overall goal of the Lisbon Process has been embedded in a set of policy guidelines that include the following elements:
- Preparing the transition to a knowledge-based economy through better polices for the information society and R&D;
- Stepping up the process of structural reform for competitiveness and innovation and completion of the single market;
- Combating social exclusion and modernizing the European social model by investing in people;
- Sustaining the healthy economic outlook and favourable growth prospects by continuing with an appropriate macroeconomic policy mix and improving the quality of public finance.

To realize these goals, the review of the Lisbon Process at the Barcelona Summit in 2002 has explicitly emphasized the importance of Research and Development (R&D). One of its main recommendations calls for an increase in European R&D expenditure with the target to reach 3% of European GDP by 2010, two thirds of this to take the form of business R&D.[2] The main argument behind this target appears to be the concern that even if in the EU knowledge-intensive industries have been partially successful in creating employment over the last decade, productivity developments have been far less favorable (especially if measured against the U.S.A.). This underperformance is seen as a threat for European competitiveness and economic growth in general and, more specifically, for the achievement of the Lisbon goals and for the growth of national incomes and living standards. A related concern is the fact that the EU performs relatively low in input (business R&D) and output indicators (such as patents) of innovative activity. Public policy, with the aim to promote investment in business R&D, is therefore

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[1] Presidency Conclusions, Lisbon European Council, 23 and 24 March 2002, para. 5.

[2] Cf. Presidency Conclusions, Barcelona European Council, 15 and 16 March 2002 para. 47. For a review of the progress of the Lisbon Process up to then see *The Lisbon Strategy. Making Change Happen*, Communication from the Commission to the Spring European Council in Barcelona, COM(2002) 14 final, 15.1.2002.

seen as a key measure to prevent long-term economic decline (European Commission, 2002, Economic Policy Committee, 2002).[3]

As we argue below there is indeed major evidence that links R&D to productivity performance. Also, the adoption of the Barcelona target should contribute to close the gap in R&D intensities between the EU and the U.S. economies. However, the extent to which it can contribute to offset the productivity gap between the EU and the U.S.A. remains to be seen. On the one hand, as pointed out in the official documents as well, regulatory and other institutional differences might play important roles. On the other hand, the EU's trading partners will also benefit from increased European R&D by a higher R&D content of exports. Thus, for relative productivity, achieving the Barcelona target is not a zero-sum game. Based on a simulation exercise, which uses results from the literature and from a longitudinal dataset, the paper tries to assess this issue. It starts with a short discussion on the link between R&D and productivity growth. Section 3 presents an overview of the existing productivity gap between the EU and the U.S.A. and its development over time and sectors. Section 4 provides and discusses the simulation results. A conclusion sums up the main findings and puts them into the perspective of the debate.

2. The Link between R&D and Productivity

Economic theorists have accepted the positive link between technological change, productivity and economic growth for a long time. Process innovation provides opportunities for cost reduction. Product innovation enhances either the range of available intermediate inputs for the production process, increasing real output, or increases the availability of consumer products with corresponding welfare gains. Indeed, in modern economies, the inputs of capital and labor alone cannot account for a large part of output growth in modern economies (Solow, 1957). The concept of 'total factor productivity' (TFP) has been widely used as a measure to explain this residual (see Nadiri, 1970).

In a rich empirical tradition of work on productivity growth (e.g., Griliches, 1979), the total factor productivity residual has been related to the accumulation of a 'knowledge stock', which is not accounted for in the measurement of the conventional capital stock but increases output via innovation and technological change. R&D expenditures have been suggested as a way of measuring this knowledge stock, and this has led to a range of works relating R&D expenditures

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[3] See also *Productivity. The Key to Competitiveness of European Economies and Enterprises*, Communication from the Commission to the Council and the European Parliament COM(2002) 262 final, 21.05.2002.

to total factor productivity growth. This is consistent with the notion in 'new growth theory' of non-convexities of R&D and knowledge in output, which results in self-sustaining growth (as in Romer, 1986, 1990).

An important issue in this literature is the idea that R&D not only provides productivity benefits for the firms that undertake it, but also for other firms in similar or somehow related lines of business. This is the notion of R&D spillovers, indicating that the impact of innovation and technology is felt widely rather than being a private pay-off. In this context, Griliches (1979, 1993) pointed to the distinction between knowledge and rent spillovers. **Pure '**knowledge spillovers' are externalities arising from the public goods characteristics of technology and research without the need to engage in economic transactions. These externalities can arise from learning, observation and copying such as 'reverse engineering' and 'patenting around'. Other transmission channels result from formal and informal contacts and networks of scientists, professionals, clients and customers, which go beyond market transactions (Mansfield, 1985). Rent spillovers, on the other hand, are defined by a shift of innovation rents from the producer to the user of a certain technology due to competitive market pressures. From the perspective of the whole economy, this constitutes an unwanted measurement error in attributing productivity increases to the wrong entity and can in principle corrected by using adjusted output deflators (Triplett, 1996). Yet for an individual firm, industry or country, such effects result in real benefits with corresponding productivity increases. Empirically, however, both notions are somewhat difficult to separate, as market interaction can facilitate the exchange of technological knowledge. To reflect the different mechanisms of spillover transmission and absorption the empirical literature uses basically three different weighting schemes to aggregate a stock of indirect, spillover-related R&D. Tansaction-based weights emphasise to some extent the rent spillover component. Usually these are derived from interindustry sales (e.g. van Meijl, 1995), investment flows (e.g. Sveikauskas, 1981) or from a full input-output framework (e.g. Terleckyj, 1974, 1982, Wolff and Nadiri, 1993 or Sakurai *et al.*, 1996). In contrast, weighting by technological distance measures accounts for the fact that the absorption of knowledge spillovers is mediated by the technological proximity between receiver and transmitter. Such distance may be measured by the type of performed R&D (Goto and Suzuki, 1989), the qualifications of researchers (Adams, 1990), the distribution of patents between patent classes (Jaffe, 1986) or patent classifications and citations (Verspagen, 1997a,b). Technology flow matrices in a sense combine the two concepts of technological and 'market' proximity by identifying originators and (potential) users of a technology or an innovation. Scherer's user-producer matrix as well as the Yale matrix have been derived from patent statistics (Scherer, 1982,

Putnam and Evenson, 1994).[4] Many empirical studies have found indeed a relatively high influence of R&D and related spillovers to productivity growth but the results depend in some measure on the construction of the spillover variable.[5] The findings that market transactions and technological closeness matter for productivity imply an extension of any meaningful empirical analysis to the global level, at least to the major trading partners. There is no *a priori* reason why international spillovers should be modelled differently than domestic spillovers. The total technology content of a product or a sector that matters for productivity contains the R&D performed by itself as well as the technology acquired by inputs from both domestic and foreign sources. For that reason, besides the more static advantages of getting an expanded set of inputs at lower cost (including frontier-technology), international trade is an important source for long-term development and catching-up (Fagerberg, 1987, Abramovitz, 1986). Especially small open economies can benefit disproportionately from international spillovers, not only in a development context (Coe et al., 2002) but also amongst developed countries as shown by Coe and Helpman (1995).[6] In fact it may be argued that the potential of the global R&D stock for catching-up should be *relatively* high for developed economies that already have a high level of absorptive capacities and would yield *comparatively* marginal benefits from investment in education and other social capabilities (Archibughi and Mitchie, 1998).

3. European Performance Relative to the World Economic Leaders

The eagerness of European policy makers to bring Europe to the economic frontier of the world is obviously rooted in the feeling that Europe is behind relative to the U.S.A. and other leading countries in the world in terms of technology and productivity. The aim of this section is to document the European gap in this respect. We focus on the manufacturing industry, which we subdivide into 21 sectors, documented in Table 1. The sources of the data are the OECD STAN database, and various parts of the Groningen Growth and Development database. The newest version of the STAN database, using the ISIC rev. 3 classification,

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[4] The intermediate position of technology flow matrices is confirmed by van Pottelsberghe (1997), who applies the different weights to the same dataset. Moreover, these results vindicate the approach of most empirical studies to use one and the same matrix across different countries.

[5] See Cincera and van Pottelsberghe (2001), Mohnen (2002) and Los and Verspagen (2003) for recent in-depth reviews of the empirical spillover literature.

[6] Also the simulation results of Verspagen (1997b) exhibit to some degree a relatively high contribution to productivity growth for the smaller economies in the sample.

covers the period from1980 to 1998, while the older version of it, using the ISIC rev. 2 classification covers the period from1970 to 1994. Merging these editions and accounting for the different classification schemes we obtain a dataset that covers the period from 1973 from 1997. We derive the growth rates of total factor productivity from this database, in the way that is described in more detail below. We use additional data on hours worked per person, unit value ratios (for value added) and value added deflators from the GGDC database to set up a benchmark of total factor productivity *levels relative to the U.S.A.* for 1997 (on the general nature of the data, see, e.g., Van Ark, 1996).[7] The TFP growth rates derived from STAN are used to retrapolate this benchmark on a yearly basis to the early 1970s. Because the STAN database has some serious holes in terms of the coverage for some countries, we focus on only four European countries, and compare these to the U.S.A.. The four European countries are Germany, France, Italy and the United Kingdom. We use employment (in number of jobs) as our indicator of labor input in the total factor productivity growth rate calculations. In this part of the calculations, no correction for hours worked is made, because the data on hours in the GGDC database is not available for a large part of the period we are interested in. Value added is our output indicator, and a constructed capital stock is taken as the only other production factor. The capital stock is constructed on the basis of the investment time series, using a perpetual inventory method (with a depreciation rate equal to 0.15). We have to resort to using aggregate purchasing power parities for the capital stocks supplied by the Penn World Tables, because the GGDC database does not supply sectoral data on capital stocks (or investment flows). In summary, the 1997 benchmark of total factor productivity levels is based on state-of-the art methods that take into account differences between sectors in terms of unit value ratios and hours worked, but the growth rates that are used to retrapolate this benchmark are based on more rough measures.

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[7] The specific way in which this is done involves retrapolating the 1997 unit value ratios in the GGDC database to 1990 by means of the value added deflators.

Table 1: Sectors in the Analysis

| ISIC rev.2	ISIC rev.3	Short description
31	15-16	Food, beverages & tobacco
32	17-19	Textiles, apparel & leather
33	20	Wood products & furniture
34	21-22	Paper, paper products & printing
351+352	24	Industrial chemicals, drugs & medicines
353+354	23	Petroleum & coal products
355+356	25	Rubber & plastic products
36	26	Non-metallic mineral products
37	27	Iron & steel, non-ferrous metals
381	28	Metal products
3825	30	Office & computing machinery
382-3825	29	Non-electrical machinery
3832	32	Radio, TV & communication equipment
383-3832	31	Electrical apparatus, nec
3841	351	Shipbuilding & repairing
3843	34	Motor vehicles
3845	353	Aircraft
3842+3844+3849	352, 359	Other transport
385	33	Professional goods
39	36-37	Other manufacturing

Chart 1 describes the evolution of total factor productivity gaps (ratios) in manufacturing sectors between the European countries and the U.S.A. A value larger than one indicates a European lead. The vertical axis of these figures gives the frequency of sectors with the specific value of the gap displayed on the horizontal axis. Thus, a peak in the plotted surface points to a cluster of sectors at the specific value of the productivity gap. The distribution displayed in the figure is smoothed using a so-called kernel density estimation method (see Härdle, 1990).[8] The raw data consist of the value of the productivity gap for each of the 21 sectors in the four countries (hence there are 84 observations for each year) for the period specified in the graphs. The kernel density estimates can be seen as smoothed histograms (one for every year) of these values. Peaks in the figure indicate that relatively many sectors cluster at the value of the productivity gap displayed on the horizontal axis below. The value 1 on the horizontal axis demarcates the difference

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[8] We use Stata's kdensity function, with the default Epanechnikov kernel.

between European productivity leadership (>1) and a European productivity backlog (<1). In chart 1, it is obvious that on average, the European countries indeed face a productivity gap relative to the U.S.A., although it is a relatively small one.[9] The peak (modal value) of the density plot in 1997 lies at a value of 90% (0.9), i.e., where the European countries trail 10% behind U.S. productivity. 53% of the total density (sectors) has a 10% or higher backlog, i.e. is found to the left of the peak for 1997. 36% of the density is found in the right tail that represents European sectors leading over the U.S.A. in terms of total factor productivity (values larger than 1).

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[9] Our four European countries display above-EU average productivity, so that the results in this section must be seen as a lower boundary to the gap of the total EU.

Chart 1: Kernel Density Estimates of the Distribution of Total Factor Productivity Gaps of four European Countries vs. the United States (The Horizontal Axis Indicates the Ratio of European Productivity over U.S. Productivity.)
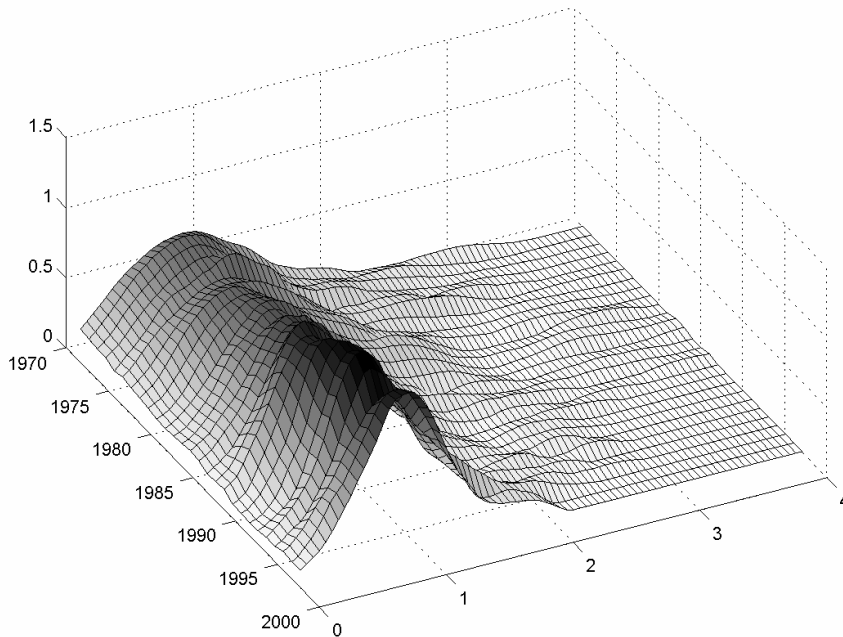

Over time, the evolution is one in which the distribution becomes more narrow and peaked, but the overall centre of the distribution does not shift very much. In the early 1970s, the peak lies at 85%, i.e., a somewhat larger European backlog, but at the same time, a larger fraction (48%) of the total density is found at values larger than one (i.e., a European lead). The early periods also show a relatively long trail of sectors on the right hand side, which corresponds to a limited number of European sectors that operate at the 'leading edge' of productivity. This 'leading edge' largely disappears over the 30-year period in the graph, until we have the relatively narrow and peaked distribution of the late 1990s.

4. R&D in Europe and the Global Economy: Reality and the Barcelona R&D Target

The large majority of R&D in the world is carried out by firms, universities and public or semi-public research organizations. Chart 2 shows the total R&D intensity in Europe, on the one hand, and U.S.A. on the other hand. R&D intensity is defined as total R&D as a % of GDP. Over the period 1980-2000, this value fluctuates between 2 ½percent and 3% in the U.S.A., while it is almost a full percentage point lower in the European Union[10] (all averages across countries are calculated as weighted averages). For the four European countries identified in the previous section, the value is slightly higher than the EU-average: it fluctuates around 2%. Chart 2 thus supports the impression of European backlog in R&D that led to the Barcelona target of a 3 % R&D intensity. In order to achieve this target, and given the value of GDP in the year 2000, Europe's R&D effort in that year would need to be expanded by (roughly) one third. Obviously, this is a large increase, and one may put question marks to the possibility to achieve this, especially so in times of a downturn in the world business cycle, as well as more than a year having passed since the Barcelona meeting, without clear policy measures aimed at stimulating R&D extra having been undertaken in many European countries.

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[10] The European Union is defined as EU-16 over the complete period.

Chart 2: R&D Intensity (Total R&D as Percents of GDP)
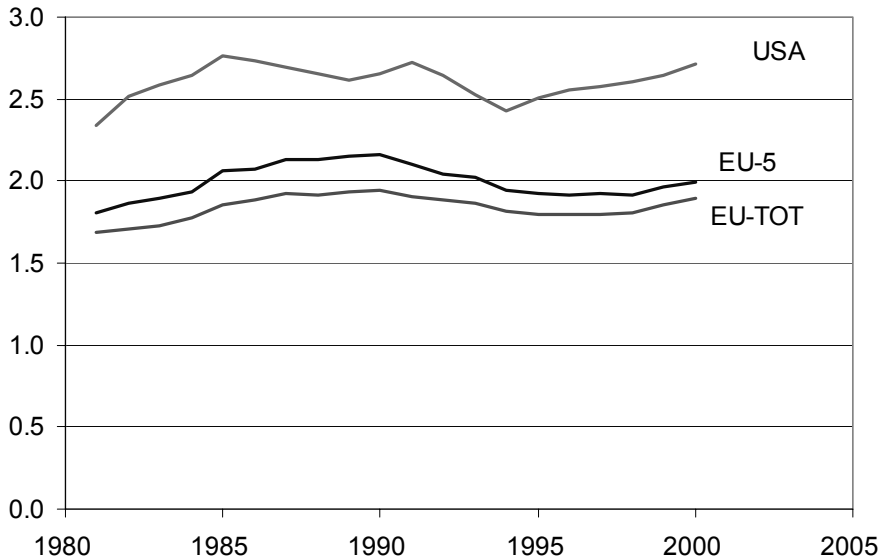
While we believe that the Barcelona R&D targets will be rather hard to achieve, we undertake the analysis in the remainder of this paper under the assumption that it will indeed be possible to achieve these targets. The aim of this analysis is to assess the impact that increased R&D intensity may have on the productivity gaps facing the European economy.

5. Assessing the Impact of "Barcelona" on European Productivity Gaps

The empirical and theoretical literature on R&D and productivity provides a practical framework to assess the impact of increased R&D efforts in Europe on technology gaps between Europe and the U.S.A.. In this assessment, account will have to be taken of the fact that R&D does not only have an impact in the firm/sector where it is undertaken, but also, partly spills over to other sectors in the domestic and foreign economy. Viewed in this way, much of the increased R&D efforts as a result of 'Barcelona' will be absorbed within the EU itself due to the nature of the integration of European economies. However, it will also add to the technology content of exports to the main non-European competitors with the potential to generate productivity increases there. The aim of this section is to

employ a simulation exercise to assess the net effect of the mechanisms on the productivity gaps identified in Section 3 above.

The methodology that will be used in this section is based on a theoretical framework in which scale economies play no role. An important debate in the "new growth" literature is about the role of technology in scale effects. The early endogenous growth models in, e.g., Romer (1986, 1990) or Grossman and Helpman (1991) lead to the conclusion that an increase in the knowledge stock of a country (in whichever way we may measure this) will lead to an increase in the growth *rate*. This represents a mechanism of strong scale economies, in which, *ceteris paribus*, large countries are at an advantage. Jones (1995) argues that the empirical data do not support such strong effects of scale economies related to knowledge and R&D stocks. Instead, Jones (1995) proposes a model in which the growth rate of an economy depends on the growth rate of population, i.e., the growth of (human) resources that can be put into the development of new knowledge (so called semi-endogenous growth).

Although the so called Jones-Critique of strong scale effects has led to a debate in which the possibility of some form of scale economies related to knowledge and R&D has not been ruled out, we proceed here to implement a model that is rooted in an earlier empirical approach (e.g., Griliches, 1979) in which the level of total factor productivity depends on the level of the knowledge stock, and the rate of growth of total factor productivity thus depends on the growth of a knowledge (or R&D capital) stock. The reason for adopting this relatively conservative approach is that this model can still be considered as the main theoretical workhorse for the empirical work in this area. Moreover, since an important part of our calculations will take the form of extrapolating on the basis of increased R&D stocks in Europe, a model incorporating scale effects that have not been empirically verified over a large range of the relevant variables may be too optimistic in assessing the increased productivity effects.

For the calculation of productivity effects we use the concept of 'direct and indirect' R&D from the spillovers literature. We take the same sectors as above, and focus on business R&D only. The method we employ will be to add one-third to the R&D stocks of European sectors. The 3% Barcelona R&D intensity target actually implies a somewhat larger multiplication factor, but in light of the above discussion, we feel that this is a too ambitious target.[11] This implies that current R&D levels in Europe increase by (roughly) 33% (taking GDP as given, something we will do for all analysis in this section). We assume that the distribution of R&D over private and non-private sources does not change, i.e., that the one-third increase applies to both types of R&D.

We take 1997 as the reference year (this is the most recent year for which disaggregated R&D stocks can be calculated for the countries in our sample).

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[11] The calculated effects are linear in the growth rates.

Because our R&D stocks are simply summations over time (taking into account also knowledge depreciation), a once-and-for-all multiplication of R&D investment by 1.33 also implies a multiplication of the R&D stocks by 1.33. We therefore perform a simulation in which all European R&D stocks are multiplied by 1.33 and compare the total factor productivity levels implied by this to the levels implied by the actual 1997 R&D stocks.

From the 'direct' R&D stocks, we calculate domestically and internationally acquired 'indirect' R&D stocks (see appendix for mathematical details). For the construction of these we rely on a weighting scheme developed by Verspagen (1997a). This scheme uses patent statistics, and is based on co-classification of patents in terms of their technological class. When a patent is classified in more than a single technology class, and these classes 'belong to' different industries, this is taken as a spillover from one sector (where the main technology class of the patent is) to another sector (where the supplementary technology class of the patent is). In this way, a matrix can be set up that gives the share of all patents generated in a sector that spillover to all other sectors. In Verspagen (1997b) these weights were used to construct domestic and foreign indirect R&D stocks, and the results were applied to an estimation of the impact of R&D and R&D spillovers on total factor productivity. We use the elasticities obtained in Verspagen (1997b), and documented in table 3, in the simulation exercises in this section. In addition to these 'technology weights', domestic indirect R&D is weighted by the share of domestic producers on the market; 'imported' R&D is weighed by the share of foreign producers (broken down at the country level). TFP growth is simply given as the sum of the three components (own sector R&D, domestic indirect R&D from other sectors, foreign indirect R&D), weighted by their output elasticities.

Table 2: Empirical Coefficients (Output Elasticities) used in the Simulations

|	OwnR&D	Domestic indirect R&D	Foreign indirect R&D
High-tech (Radio, TV & communication equipment; office & computing machinery; professional goods; aircraft)	0.177	0.025	0.061
Medium-tech (Industrial chemicals, drugs & medicines; non-electrical machinery; electrical apparatus)	0.078	0.022	0.032
Low-tech (Food, beverages & tobacco; textiles, apparel & leather; wood products & furniture; paper, paper products & printing; petroleum & coal products; rubber & plastic products; non-metallic mineral products; iron & steel, non-ferrous metals; metal products; shipbuilding & repairing; motor vehicles; other transport; other manufacturing)	0.084	0.040	0.045

Table 3 documents the productivity effects in the four European countries and the U.S.A. for the various simulation experiments. Our first experiment, described above, is to multiply all European R&D stocks by 1.33, the value associated with the Barcelona target. This corresponds to an 'untargeted' or uniform R&D impulse, i.e., one in which all sectors increase R&D expenditures by the same proportional rate. The effect of this is to raise total factor productivity levels in Europe across the 21 sectors of our analysis by an average of 4.4%, with a relatively narrow variation (standard deviation equal to 1.0%-points) over the sectors. The U.S.A. also benefits from this European R&D policy, and realizes a projected 0.6% increase in total factor productivity levels (with a standard deviation equal to half this value). Thus, both European and U.S.A. levels of productivity may be expected to rise across the board of manufacturing sectors as a result of the Barcelona targets, if and when successfully achieved.

Table 3: Average Growth Rates over Sectors of Total Factor Productivity in Simulation Experiments (Standard Deviations between Brackets)

	Growth of productivity relative to base case (1997 real data)		
Description of simulation experiment	EU-4	U.S.A.	Ratio increase EU to U.S.A.
Uniform R&D impulse in EU	4.4% (1.0%)	0.6% (0.3%)	7.3
Targeted high-tech R&D impulse in EU	8.0% (12.5%)	1.5% (1.9%)	5.3
Targeted medium-tech R&D impulse in EU	8.9% (4.1%)	2.5% (1.1%)	3.6
Targeted low-tech R&D impulse in EU	13.3% (11.6%)	0.4% (0.6%)	33.3

The result is, obviously, a reduction in European technology gaps. This is documented in chart 3, which gives the kernel density estimations for the first simulation experiment and the real data for 1997. The latter is taken from chart 1 (last year), but is now reproduced in a 2-dimensional format. The evenness of the impact of increased R&D across sectors is evident from the almost parallel shift of the density curve. The peak (modal value) of the distribution shifts to the right, and is now found at a value of 0.95, i.e., where European productivity lags behind US productivity 5%-points. 41% of the total density is now found in the domain where European productivity leads over U.S.A. productivity (to the right of 1 on the horizontal axis). Although this is a clear improvement of the European situation, it does not represent a very clear take-over of the U.S.A. by Europe. In other words, although the increased R&D levels as a result of the Barcelona targets are beneficial for European industry, they do not seem to lead to the targeted European productivity leadership.

Chart 3: Kernel Density Estimates for real Productivity Gaps (1997) and Simulated Gaps (a European R&D Impulse Uniformly distributed over Sectors)
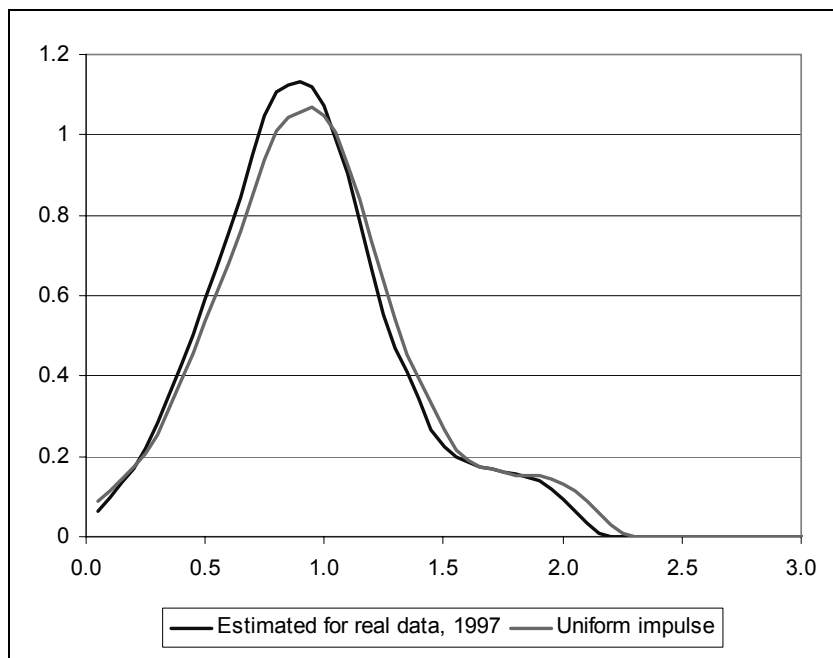
In order to compare the impact of the different sectoral R&D stocks on the distribution of European productivity gaps, we also document the results of some other thought-experiments, in which only a number of sectoral R&D stocks are varied at the same time. In these experiments, we employ the commonly used distinction between high-tech, medium-tech and low-tech sectors. This classification is based on average R&D intensity across the OECD countries, and is documented in Table 2 in the specific way in which it was used here. Note that because our level of disaggregation of sectors does not completely correspond to the usual scheme, we had to change some of the usual definitions. The most notable of these changes is that we merge pharmaceuticals (normally considered as a high-tech sector) with chemicals (normally considered as a medium-tech sector), and treat the resulting sector as a medium-tech sector.

In the sectoral experiments, we employ a broad reasoning that corresponds to "putting all money on one card". This means that we still start from a one-third increase in total R&D efforts (stocks), but now put these additional expenditures into a single of the three broad sectoral classifications (low-, medium or high-tech). In order to find the multiplication factor of R&D stocks that corresponds to this, we

use the following formula:

$$\frac{R_{L,t+1} + R_{M,t+1} + R_{H,t+1}}{R_{L,t} + R_{M,t} + R_{H,t}} = \frac{R_{L,t+1}}{R_{L,t}}\sigma_{L,t} + \frac{R_{M,t+1}}{R_{M,t}}\sigma_{M,t} + \frac{R_{H,t+1}}{R_{H,t}}\sigma_{H,t} = 1.33,$$

where R represents R&D stocks, the subscripts *H, M* and *L* indicate high-tech, medium-tech and low-tech, respectively, the subscripts *t* and *t+1* indicate before and after experiment periods, and σ indicates a share in total R&D. A 'focused' R&D impulse is calculated using this formula, by setting the ratio $R_{i,t+1}/R_{i,t}$ to 1 (i.e., no change) for the two sectoral classes on which the R&D impulse is *not* focused, and then solving for the same ratio for the sectoral class on which the R&D is focused. For example, in case of an R&D impulse focused on low-tech, this yields

$$\frac{R_{L,t+1}}{R_{L,t}} = \frac{0.33}{\sigma_{L,t}} + 1.$$

This shows that we can calculate the ratio at which R&D stocks in the focused sectoral class must be increased as a function of the targeted overall increase (one third, or 0.33) and the share of the sectoral class in total R&D stocks. For sectoral classes that represent a small (large) share in total stocks, a large (small) proportionate increase is necessary to accommodate the increase of total R&D by one third.

Chart 4 and 5 document the sectoral distribution of total R&D stocks for the broad aggregates used in the experiments. Obviously, the low-tech R&D stocks make up the smallest part of total R&D stocks in both the EU-4 and the U.S.A., accounting for approximately 10% at the end of the period. In the U.S.A., the medium-tech sectors are somewhat smaller than in Europe, and the reverse holds (by implication) for the high-tech sectors. We use the EU-4 shares in 1997 to calculate the implied multiplication factors for the high-, medium and low-tech sectors according to the above formula. This yields a factor of 5.0, 3.5 and 11.4, respectively. It must be noted that these factors are quite high, especially so for low-tech sectors, and hence it is not very realistic to assume that such a focused R&D strategy could ever be actually implemented. The calculations using these multiplication factors are, however, intended to illustrate the differences in sectoral impact, rather than to make actual predictions of what could happen.

Table 3 shows that the largest productivity effects of increased R&D are to be expected from the medium-tech sectors. For the focused low-tech R&D impulse, an average 13.3% total factor productivity increase in Europe is found, while this value is almost 0.4% in the U.S.A. (as a result of increased European R&D).

Moreover, the effects of increasing high-tech R&D are highly variable over sectors, as indicated by the fact that standard deviation is larger than the mean (this is less so the case for medium- and low-tech sectors). The ratio of the increase of productivity in Europe and the U.S.A. is highest for the focused low-tech impulse, indicating that in this sectoral class, increased European R&D efforts are 'appropriated' to the largest extent.

Chart 4: Percentual Distribution of R&D Stocks in High-, Medium- and Low-Tech Sectors
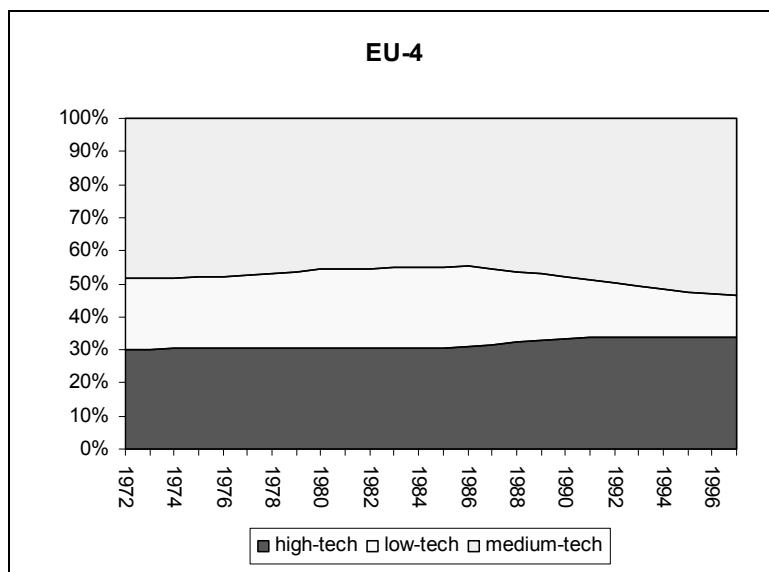

Chart 6 shows the effects in terms of the distribution of total factor productivity gaps over sectors for the focused high-tech impulse. The latter is compared against two different baseline cases, i.e., the kernel density estimate of the productivity gaps resulting in the first experiment (uniform R&D impulse), and the empirical observation for 1997. While the uniform R&D impulse shifts the kernel estimate almost in a parallel fashion, this is much less the case for the focused high-tech R&D impulse. For the focused high-tech R&D impulse, the peak of the distribution actually shifts slightly to the left, to a value of 0.85 (15% European productivity backlog). 42% of the total density lies to the right of the value 1 in case of the focused high-tech R&D impulse, indicating that, overall, there is a rightward shift of the distribution (the value is 36% for the empirically observed distribution). But what is most striking in the case of the focused high-tech impulse is that a small number of sectors on the right hand side of the distribution benefits most. This

'leading edge' of European sectors gains relatively much as a result of a targeted high-tech impulse.

The focused medium-tech impulse is displayed in chart 7. Here we note a shift of the kernel density that is almost equal to the case of a uniform R&D impulse, and almost exactly parallel to the empirically observed density. The peak of the distribution stays, however, at a value of 0.9 (10% productivity back log for Europe), which is also the empirically observed peak. In this case, 44% of the total density lies to the right of 1 (European productivity lead).

Chart 5: Percentual Distribution of R&D Stocks in High-, Medium- and Low-tech Sectors, EU-4
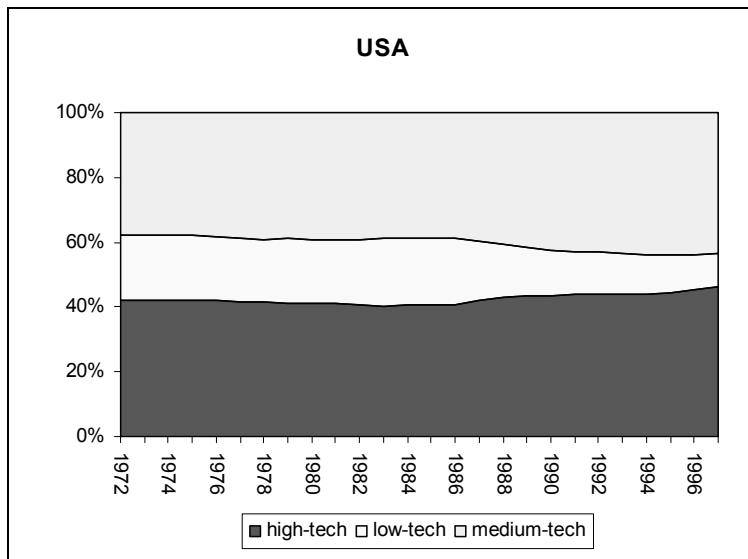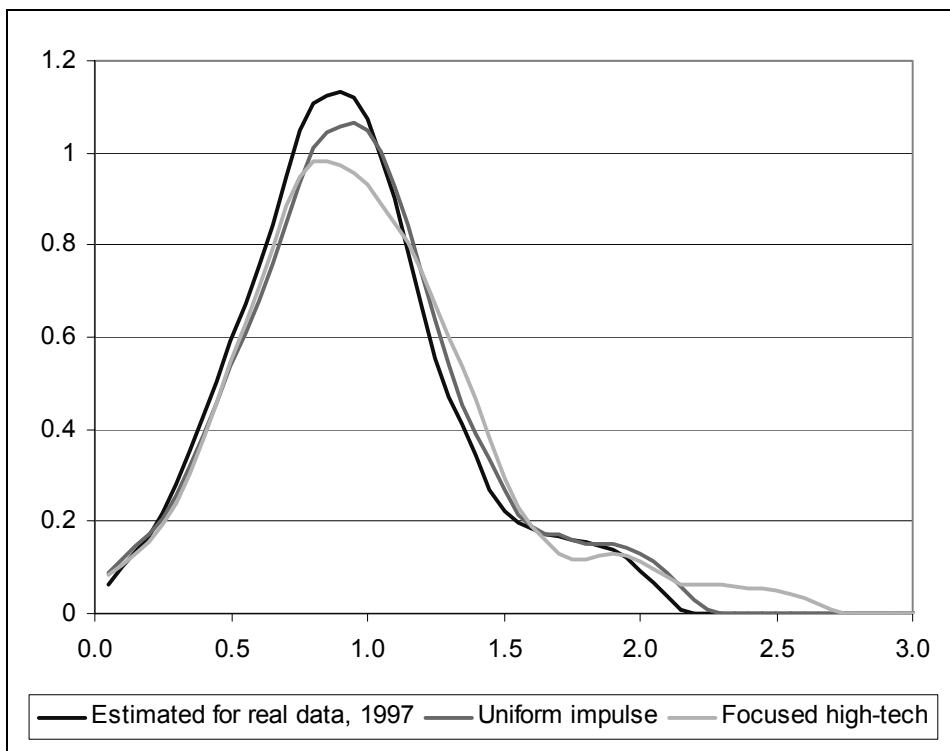
Chart 6: Kernel Density Estimates for Simulated Productivity Gaps (a European R&D Impulse Focused on High-Tech Sectors

Finally, chart 8 displays the result of a focused low-tech R&D impulse. In comparison to the two earlier focused R&D impulses (high-tech and medium-tech), the effects are more dramatic for low-tech. We observe a relatively strong shift of the part of the distribution that is immediately to the right of the peak, while the peak itself (by implication, because the total density is constant) shifts downwardly relatively much. Also the 'leading edge' European sectors (to the far right) shift relatively much as a result of the focused low-tech R&D impulse. The fraction of the density that lies to the right of the value 1 is 51% in case of the focused low-tech impulse, and the peak of the distribution occurs at 0.95 (5% European productivity backlog).

Summarizing, it seems indeed to be the case that R&D policies aimed at different sectors may have different effects in terms of the distribution of productivity effects over sectors. Perhaps surprisingly, the most dramatic effects

are associated to R&D in low-tech, while medium-tech sectors have the most evenly distributed impact.

Chart 7: Kernel Density Estimates for Simulated Productivity Gaps (a European R&D Impulse focused on Medium-Tech Sectors)
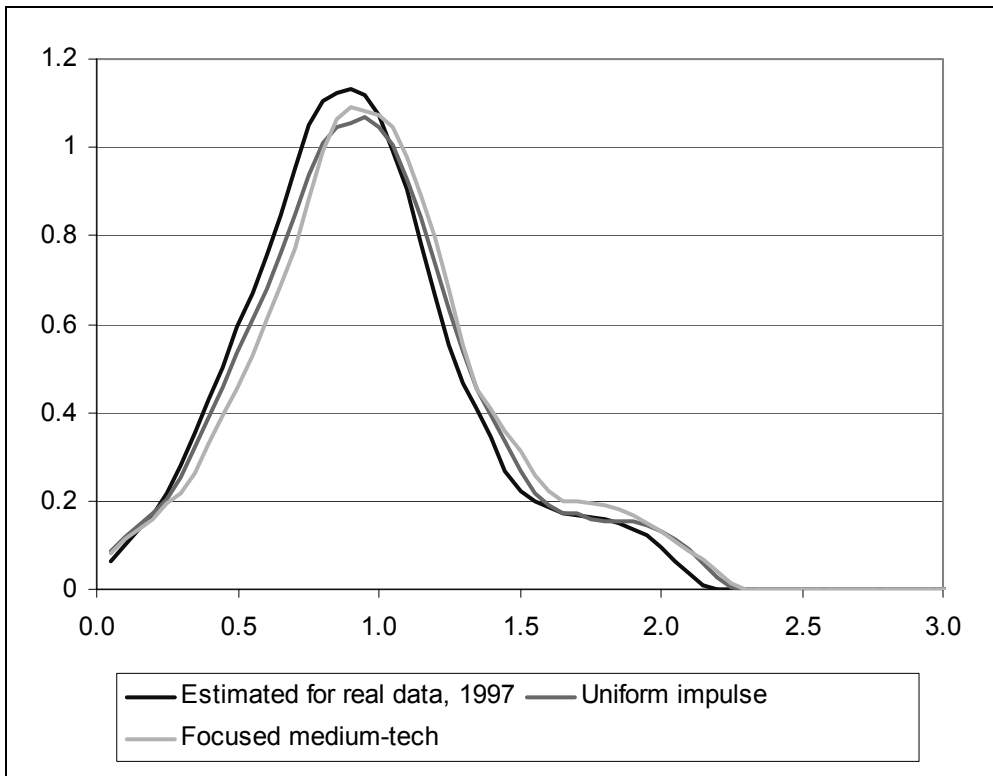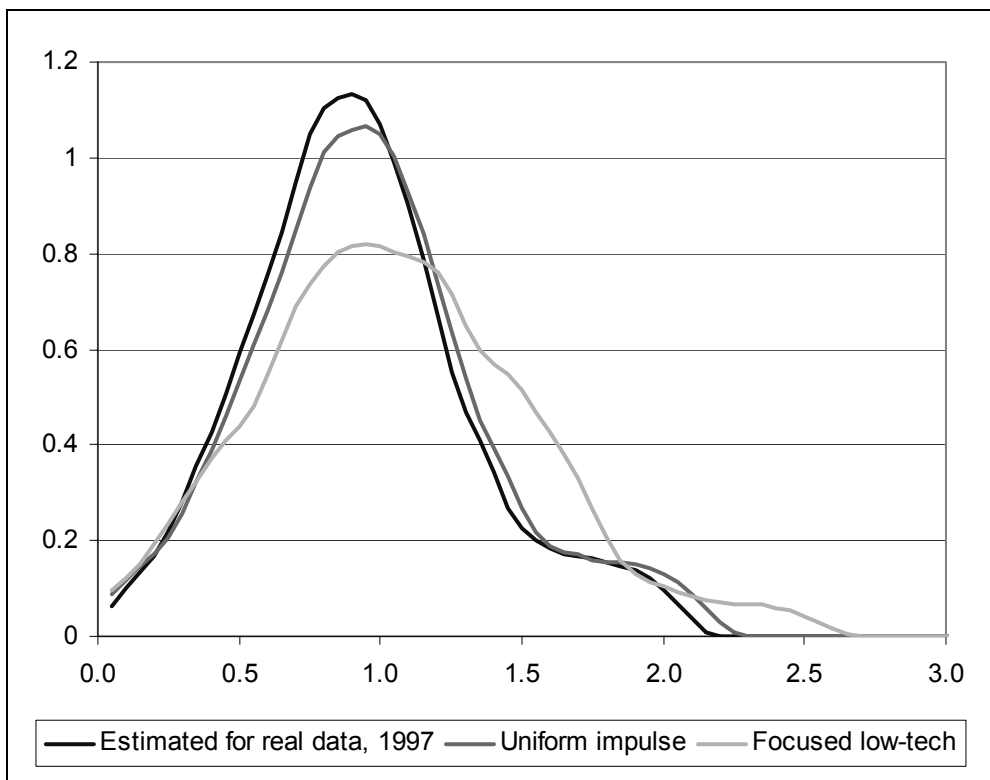
Chart 8: Kernel Density Estimates for Simulated Productivity Gaps (a European R&D Impulse Focused on Low-Tech Sectors)

6. Discussion and Conclusions

In this paper we have documented European total factor productivity gaps relative to the U.S.A. Although our method of calculating productivity levels in these countries is imperfect, it was shown that Europe indeed lags behind somewhat to the U.S.A. in terms of total factor productivity in many manufacturing industries. We discussed the European ambition, expressed at the Lisbon Summit, to become 'the most competitive and dynamic economy in the world'. For reason of the relationship between R&D and productivity, we were especially interested in the targets set in Barcelona for European R&D intensity. In an analysis of current R&D trends, it was concluded that these targets are indeed ambitious, implying an increase of European R&D intensity by one third.

We then proceeded to apply a simple simulation method, based on the empirical

literature on R&D and productivity, to estimate the impact of the Barcelona targets, assuming they can successfully be implemented, on the productivity gaps in manufacturing industry between Europe and the U.S.A.. Our model makes many simplifying assumptions, but its main virtue is that it does take into account the indirect impact of R&D, in terms of spillovers, in other sectors and countries than where the R&D effort is originally made. Thus, it was shown that also the U.S.A. may expect to benefit from increased European R&D, although at relatively low rates. The net effect on European productivity gaps is expected to be positive from the European perspective, i.e., will lead to a catch-up of total factor productivity levels relative to the U.S.A..

However, the results also indicate that the expected effects are relatively small compared to the size of existing productivity gaps facing European industries. According to our estimates, which are to be looked as a rough indication of orders of magnitude, achievement of the Barcelona targets in a purely quantitative sense (i.e., *ceteris paribus* raising R&D intensity to 3% of GDP) will not put the European economy clearly in the lead in terms of productivity relatively to the U.S.A.. According to our simulations, a focused R&D impulse in low-tech industries can be expected to have the strongest effect, but it is unrealistic to assume that these sectors alone can achieve the Barcelona R&D target.

These results imply that, according to the estimations of our model, a policy solely aimed at increasing R&D expenditures, without paying any attention to the broad institutional context in which innovation and technological development take place, is not likely to succeed. Raising R&D expenditures may be one part of the story behind the European backlog, but factors such as absorptive capacity, interaction between researchers in public and private organizations, finding the right level of intellectual property rights protection, etc., may be just as important in achieving the Lisbon ambition. Our model does not have to say much on these factors (which can be argued to represent changes in the R&D elasticities that our models takes as given), but it does point out that more research on these issues may be useful, and that the story of regaining European technological and economic leadership may be a more complicated one that the Lisbon and Barcelona summits want us to believe.

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Appendix – Data, Methods and Variables

The analysis draws on the OECD STAN, ANBERD and BITRA databases, merging their ISIC-Rev.2 and ISIC-Rev.3 versions for a longitudinal dataset, covering 21 industries in 7 countries for the period of 1973-1997 (table 1). These sectoral data are used to calculate both domestic and 'international', i.e. imported R&D stocks. To derive constant price series in U.S. dollars, implicit deflators from STAN and PPPs from the Penn World Tables were employed. The countries covered include the EU member states of France, Germany, Italy and the United Kingdom, as well as the United States. Japan is included as a country from/to which spillovers flow, but this country is not included in the productivity comparisons.

Following Verspagen (1997b) we start from an augmented Cobb-Douglas production function

$$Y_{ijt} = A_{ijt} K_{ijt}^{\alpha} L_{ijt}^{\beta} RD_{ijt}^{\rho} IRD_{ijt}^{\delta} IRF_{ijt}^{\phi} \tag{1.1}$$

where Y represents production, A the usual scale variable, and K and L capital and labour inputs respectively. RD is 'own', i.e. direct R&D, IRD is domestic indirect R&D, IRF is 'foreign', i.e. indirectly imported R&D. α, β, ρ, δ, ϕ are the relevant output elasticities. The indices i, j and t refer to country, sector and time. Neglecting indices, total factor productivity can be measured as a function of total R&D:

$$TFP \equiv Y / \left(K^{\alpha} L^{\beta} \right) \tag{1.2}$$

or, combining (1.1) and (1.2), in the form of growth rates:

$$\frac{\dot{TFP}}{TFP} = \rho \frac{\dot{RD}}{RD} + \delta \frac{\dot{IRD}}{IRD} + \phi \frac{\dot{IRF}}{IRF} \tag{1.3}$$

Capital stocks are constructed by applying the perpetual inventory method, that is

$$K_t = (1 - \psi) K_{t-1} + I_t \tag{1.4}$$

with I being investment in fixed capital, the depreciation rate ψ set to 0.15 and an initial capital stock of 5 times I_{t+1} (assuming an initial growth rate of 5 per cent). The 'own' R&D stocks are constructed similarly using R&D expenditures.

For indirect domestic R&D, the sectoral R&D stocks are weighted by coefficients from a patent citation matrix based on EPO statistics (Verspagen, 1997a). For domestically acquired R&D we set their diagonal elements to zero to avoid double-counting. Finally, we weight with the share of domestic inputs; that is

$$IRD_{ik} = \sum_j \omega_{jk} \left(1 - m_{ij} \right) RD_{ij}, \qquad\qquad j \neq k \qquad\qquad (1.5)$$

where ω_{jk} designates the share of sector j in sector k's citations and m_j stands for the import penetration of the domestic market. For imported R&D we keep the diagonal elements and aggregate as

$$IRF_{ik} = \sum_h \sum_j \omega_{jk} m_{ij} RD_{hj} s_{ihj} \qquad\qquad (1.6)$$

using import penetration-weighted input coefficients, and RD_{hj}, the R&D stock of the export country h, being weighted by its import share in country i, s_{ihj}. We take this variable as a proxy for the degree of interaction between two countries (Verspagen, 1997b). The simulation uses hypothetical R&D stocks as explained in the main text and calculates corresponding indirect R&D as in (1.5) and (1.6). To calculate hypothetical TFP growth the elasticity estimates (as in table 3) by Verspagen (1997b), who uses a comparable set of OECD countries and sectors, were employed and fed into (1.3).