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R&D in WorldScan[1]

This memorandum analyses the R&D version of WorldScan, the CGE model for the world economy of the CPB Netherlands Bureau for Economic Policy Analysis. We check whether the effect of R&D on total factor productivity (TFP) as modelled in WorldScan is consistent with the empirical estimates used for the calibration of the model. We find that the model deviates from these empirical estimates in two ways: i) the effect of R&D in WorldScan differs considerably over countries and sectors. Some validation for this sectoral pattern is found in the empirical literature; and ii) in WorldScan, R&D not only generates spillovers, but is also treated as a production factor. There is thus a potential for double-counting the effects of private R&D. We find that this risk is only partly realized.

In addition, we have considered the effectiveness of an R&D tax credit in WorldScan and find that such a tax credit raises both R&D expenditures and welfare. The degree of effectiveness of the tax credit in raising R&D expenditures is broadly consistent with the empirical literature: €1 extra R&D credit raises total R&D expenditures by an equal amount.

[1] I am indebted to Gerard Verweij, Stefan Boeters Bas Straathof, and Paul Veenendaal for their invaluable comments and discussions. Bas Straathof provided appendix 2. I claim full responsibility for any remaining errors.

1 Introduction

In March 2000, the European Union's Lisbon Agenda identified the low level of R&D as an important reason for Europe's lacking economic growth. Seven years later, innovation still has the full attention of policy makers around Europe. Given the prominent role of innovation in economic policy, the analysis of innovation is also important for policy-oriented economic research. A CGE model is a choice vehicle for the analysis of the long-term economic consequences of innovation policy. So far, attempts of such an analysis have however been rather scarce. In addition, in models that do incorporate innovation, R&D is frequently modelled as an exogenous rather than an endogenous event. Exceptions are the models Quest III, Mesemet and International Futures.[2]

WoldScan, the CGE model for the world economy of CPB Netherlands Bureau for Economic Policy Analysis, includes endogenous R&D, thus providing a flexible instrument for evaluating the effect of innovation policy. Obviously, this is quite relevant for policy makers and the model has, for example, already been used to evaluate the economic effects of reaching the Lisbon targets on R&D expenditures, see Gelauff and Lejour (2006). As an instrument for policy evaluation, a CGE model also has some drawbacks. One prominent drawback is that a model, by definition, is an abstract representation of a much more complex economic system. This abstraction limits the applicability of the model. It is important to understand the model's fundamentals in order to assess which topics can and cannot be analysed within the confines of the model's framework. In addition, in order to be useful in policy analyses, the model must be consistent with relevant empirical evidence.

This memorandum analyses the R&D version of WorldScan. We contrast the main model outcomes with the empirical estimates that inspired the specification of the model and with the empirical literature on R&D in general. We focus on the effect of R&D on total factor productivity (TFP) and on the effectiveness of a tax credit in stimulating R&D expenditures and welfare. With regard to the first issue, we observe that the two roles played by private R&D in WorldScan (as a factor of production and as a determinant of TFP-growth through intra-sectoral spillovers) create the potential for double-counting the effects of private R&D. In previous model exercises, the second role was therefore disabled, see Gelauff and Lejour (2006). One of the aims of this paper is to asses whether this practice has been entirely warranted. The second issue that we focus on, the effectiveness of a tax credit, relates to the potential of a government to increase R&D and to the welfare effect associated with such a policy intervention.

This paper is structured as follows. Section 2 briefly discusses the basic specification of the R&D version of WorldScan. It builds on Lejour *et al*. (2006) who provide a detailed and

[2] The Quest III model and the Mesemet model are described in respectively Apaya *et al.* (2007) and Bergeijk et al. (1997). Finally, for extensive documentation on the International Futures model, the reader is referred to http://mysite.du.edu/~bhughes/ifswelcome.html

comprehensive description of the model. It discusses the model's most salient features and possible avenues for an extension of the R&D version of WorldScan. Section 3 describes the effect of R&D on TFP and analyses how the effect generated by the model relates to the empirical estimates that inspired the model's specification. Section 4 covers the effect of government intervention with regard to R&D. It describes to what extent a tax credit on R&D is effective in raising R&D expenditures and welfare, and whether this effectiveness is mitigated by decreasing returns. Finally, section 5 summarizes the main results of the paper and recapitulates possible extensions to WorldScan that were identified in the main text.

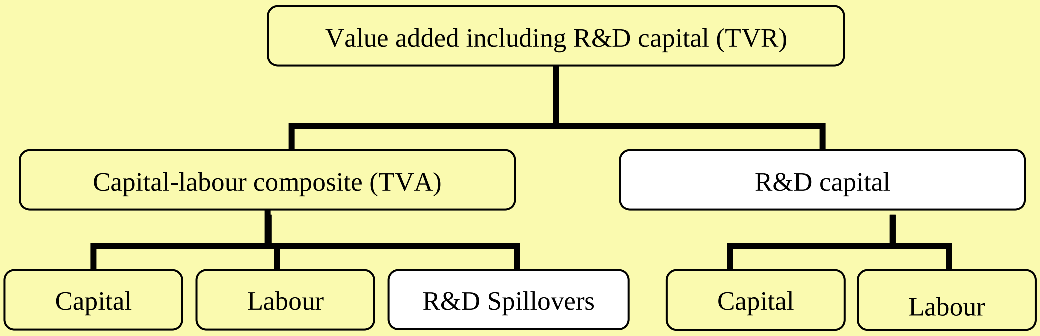
2 The current set-up: R&D in WorldScan

In theory, R&D can have an effect on the economy either through cost reduction, quality improvement or product differentiation. The focus of WorldScan lies on the first effect; the productivity effect of R&D.[3] R&D enters in two guises: as a factor of production and as a determinant of productivity in the form of R&D spillovers. While the introduction of R&D spillovers is not uncommon in economic modelling (see for example Bayoumi *et al.* (1999) and Diao *et al.* (1999)), the inclusion of R&D as a factor of production is more traditional (e.g. Bergeijk *et al*. (1997)). The rationale behind the introduction of R&D as a factor of production is to introduce a straightforward decision moment regarding the level of R&D through cost minimization. We will discuss both roles of R&D in turn in the subsequent section. The calibration of the R&D version of WorldScan is discussed in section 2.2.

[3] There also exists a version of WorldScan that features imperfect competition and in which product variety is endogenous.

Box 1: Value added in WorldScan's R&D version

For clarity, this box gives a schematic representation of the most relevant part of the production tree in WorldScan. For completeness, a schematic representation of the full production structure of WorldScan is given in appendix 1. We see that R&D affects production in two roles: as a factor of production (R&D capital) and through R&D spillovers. Distinguishing a separate role of R&D as a factor of production complicates the definition of value added. What do we mean by value added? Do we refer to value added in its traditional form, i.e. value created by capital and labour, or the value created by all the primary production factors that are distinguished by the model, i.e. value added created by capital, labour and R&D? For the remainder of the paper, when we refer to value added, we mean the (TVR) nest in which R&D capital is combined with the capital-labour composite.



2.1 Model setup

R&D as a production factor

In its role as a production factor, the stock of R&D is combined with physical capital and labour to produce value added in the various production sectors that are distinguished in WorldScan:[4]

$$Y_s = f\left(A_s, K_s, L_s, R_s\right) \tag{2.1}$$

where Y stands for value added, A represents a productivity term and L, K and R stand for labour, the stock of physical capital and the R&D stock. The subscript s denotes the sector. This role highlights the long-term potential of R&D to increase productivity: producers substitute between investing in R&D and investing in the traditional factors of production, capital and labour. If they invest more in R&D, they can consequently produce more with the same amount of capital and labour. Alternatively, they can raise production given the current stock of R&D by employing more capital and labour inputs.

[4] Apart from the R&D producing sector, this version of WorldScan distinguishes nine other sectors which are listed in section 2.2, which describes the calibration of WorldScan. It also gives the values of the most important R&D parameters used in the calibration. The production set-up of WorldScan is a nested CES-function, a schematic representation of which is included in appendix 1.

There are a few features of the current WorldScan specification that deserve notice. Firstly, the function *f(.)* in (2.1) is homogenous of degree one in K, L and R, which means that for a given R&D stock, it is not possible to double total value added simply by doubling the primary production factors capital and labour. Actually, the current model has implications that reach slightly further than this. In WorldScan, R&D is modelled as a stock variable, similar to the stock of capital with a constant rate of depreciation (see also box 2). The R&D stock (R) increases with R&D investments (I) and falls with depreciation:

$$R_{s,t} = (1-\delta)R_{s,t-1} + I_{s,t} \tag{2.2}$$

where δ is the depreciation rate and t is the time index. Due to the depreciation of R&D stock, producers ultimately have to invest in R&D to maintain their production capacity even in steady state. In the limit, depreciation will drive the R&D stock to zero and production will cease in the absence of investments in R&D. In practical applications however, this implication has proven hypothetical: gross investments generally exceed the depreciation of R&D capital.

A second feature of the modelling that stands out is that the R&D version of WorldScan assumes perfect competition. This feature is exceptional because much of the literature on R&D is framed in a world of imperfect competition subject to rents that enable producers to recuperate the costs of R&D investments. In these models, imperfect competition is therefore generally a precondition, introducing an incentive for investing in R&D. In our current model set-up, this incentive is already provided for by the modelling of R&D as a production factor: As noted earlier, without R&D there can be no production.[5] In order to be able to use the model for analysing other facets of innovation, such as the effect of R&D on product differentiation or quality improvement, the model would have to be recast into an imperfect competition framework.

[5] The incentive in the model is however also not perfect; underinvestment from a social point-of-view arises due to the presence of R&D spillovers.

Box 2: Conceptual disadvantages of treating R&D as capital

In WorldScan, as in most empirical and theoretical work, the construction of the R&D stock is approached analogously to the construction of the stock of physical capital. The R&D stock is the sum of all previous R&D investments corrected for depreciation (Nadiri (1993), see also equation (2.2)).[6] Thereby, R&D expenditures can be interpreted as investments, whose effects extend beyond the period in which the expenditures are made.[7] This method for constructing R&D stocks is called the perpetual inventory method (PIM). A number of authors (e.g. Branstetter (1998) and Bitzer (2005)) have criticized this approach as being insensitive to the special nature of investments in R&D. Unlike machines, that rust, break and age, knowledge can in principle be maintained throughout time.[8] Nonetheless, some form of depreciation of R&D capital is warranted as part of the knowledge obtained during past R&D efforts becomes obsolete as it is being replaced with newer technologies (creative destruction) and firms loose the ability to appropriate private rents from previous R&D efforts. It is however not evident that this depreciation should occur at a constant and exogenous rate. All the more as a constant rate of depreciation has the implication that if all R&D activities were to cease, the R&D stock would converge to zero implying that all knowledge would be lost and as Bitzer (2005) pointedly puts it: “mankind would revert back to its Stone Age”.[9] Bitzer (2005) proposes an alternative way to model R&D stocks in which the depreciation rate of the R&D stock is dependent on past levels of R&D investments. His empirical implementation is however not quite convincing and this literature needs further development before it can be incorporated in WorldScan.[10] Shanks and Zheng (2006) also criticize the use of the PIM on the basis of the heterogeneous nature of knowledge that is acquired from R&D efforts. For example, not all knowledge is equally easy to use, transfer or spill over as it is tacit (i.e. in the mind of the researcher). Simply adding up heterogeneous R&D activities and outcomes into one general stock therefore poses conceptual problems.

Thirdly, firms buy their R&D inputs from a separate R&D producing sector. Obviously, such a separate R&D producing sector is an artefact as in practice much of business R&D takes places within the company. The introduction of a separate R&D sector however simplifies the modelling and is of no major consequence to the model outcomes. The decision on how much R&D to purchase (or invest in) is made by the firm and is based on cost minimization. This means that WorldScan features a straightforward and simple decision criterion regarding the size of the R&D stock. The R&D producing sector uses a constant returns to scale production function, combining capital and high- and low-skilled labour. Noteworthy is the absence of the R&D stock in the production of R&D, which sidesteps the debate in the theoretical literature on endogenous growth about the extent to which previous R&D efforts influence the production of new R&D.[11] In addition, the role of uncertainty in the production of R&D is ignored; more

[6] The rate of depreciation is set at 11%, see section 2.2.

[7] The investments in R&D are not necessarily ‘fixed’ in the traditional sense. Each period, firms decide on the optimal stock of R&D. There are no restrictions on selling off superfluous R&D stocks to other sectors. This feature however only comes into play if the necessary decline in the R&D stock exceeds the depreciation. In practical applications of the model, such an event is unlikely to arise.

[8] Formally stated, there is no technical depreciation of R&D capital. There is however economic depreciation as the ability of firms to appropriate private rents from the R&D capital falls (Pakes and Schankerman (1986)).

[9] Bitzer (2005), p.380.

[10] In particular, unlike in his theoretical model, Bitzer (2005) imposes a lag structure on the displacement of innovation to construct R&D capital stocks in his empirical implementation. It is not immediately clear why this imposed structure is to be preferred over the more conventional PIM-method.

[11] See for example the discussion in Romer (2006 - chapter 3) on the returns to knowledge in knowledge production.

resources devoted to R&D generate more R&D output fit to be used as inputs to production. This abstraction can be justified by the fact that we analyze long-term scenarios in which uncertainty plays a less prominent role.

A fourth feature of the model which stands out is the fact that R&D is generic, i.e. its production technology does not depend on the sector in which it will meet its final use. For example, R&D on manufacturing goods is not distinguishable from R&D in services. Furthermore, no distinctions are made between applied and fundamental research, process- and product R&D or between R&D undertaken in firms, government research facilities or universities. These different forms of R&D are likely to differ in terms of e.g. spillover potential and rate of return (see Cameron (1998)). Treating R&D as a homogeneous good however greatly simplifies the analysis. As it were, it averages out the effects of different types of R&D, allowing us to focus on the overall effect of R&D on productivity and growth. Nevertheless, introducing more heterogeneity in R&D seems a constructive avenue for future extensions to the R&D version of WorldScan. In particular an extension with public R&D seems a viable option, since there is data available on public R&D expenditures and there exists a wide body of empirical literature on the effects of public R&D (e.g. Guellec and Van Pottelsberghe de la Potterie (2001)).[12] An example of a model that distinguishes a private and public R&D stock is the MESEMET model (see van Bergeijk *et al* (1997)). In this model, public R&D features as an input, which, in a set-up similar to that of WorldScan, is combined with *inter alia* private R&D, physical capital, and labour to determine a country's production capacity. An extension to WorldScan with public R&D could follow a similar approach. An important decision would then be whether to treat private and public R&D as substitutes or complements. A further complication is that WorldScan, unlike MESEMET, has a sectoral structure and data at the sectoral level may not be available. An alternative approach is to limit the effect of public R&D to generating spillovers, which requires only the construction of a country-level R&D stock.[13] The size of the spillover effect would have to be determined by way of an empirical analysis or a meta-analysis of the available empirical evidence.

A final feature of WorldScan that is noteworthy is that R&D is produced for the domestic market only. There is no trade in R&D capital. In reality, one can observe international flows of R&D, for example within multinational enterprises, parallel to foreign direct investment, or through patent licensing agreements. In addition, one of the more interesting strands of the recent empirical literature has been investigating to what extend R&D is geographically mobile, in the sense that R&D responds to interstate or international cost differences. Wilson (2007) for example finds that tax incentives in other states negatively affect a state's R&D spending and that this effect is of a similar size as the response to a tax incentive

[12] On the country-level, data on government and industry-performed R&D can be obtained from the OECD, see http://www.oecd.org/dataoecd/49/45/24236156.pdf

[13] Possibly one uses a different rate of depreciation for the private and public R&D stock.

in the own state - suggesting a high degree of R&D mobility. In more technical terms, the magnitude of the internal and external user cost elasticities of R&D are of similar magnitude, but opposing sign. Modelling the mobility of R&D opens the door to analysing interesting phenomena such as tax competition and cooperation on R&D. Unfortunately, data and empirical studies on international trade and mobility of R&D services are very scarce, which impedes the introduction of international trade in R&D services.[14] Furthermore, modelling patent licensing in WorldScan is complicated by the fact that within the current framework, R&D is modelled as a private good. Unlike reality in which multiple users can simultaneously use the knowledge obtained from R&D (i.e. there is non-rivalry), the use of R&D in WorldScan is exclusive: only one producer can use the same R&D stock at any given moment in time. We must therefore interpret the R&D stock in WorldScan as exclusively patented. In WorldScan, flows of knowledge across international (and sectoral) borders are accounted for by the introduction of R&D spillovers (see below). For current applications of the model, which focus on the long-run effect of R&D on growth, this feature of WorldScan is an asset. But, as noted in Lejour *et al*. (2006), it will need amendment if issues such as outsourcing of R&D, international cooperation or tax competition in R&D become the object of analysis. Given our previous remarks, one could wonder to what extent WorldScan is the most appropriate vehicle for the analysis of these phenomena.

R&D as a determinant of productivity of capital and labour

The second role in which R&D appears in WorldScan is in the form of spillovers. As is well documented (e.g. Jaffe *et al*. (1993) and Keller (2002, 2004)), R&D can generate spillovers: innovations in one firm or sector may lead to productivity improvements in other firms or sectors (both domestic and foreign) without any remuneration by the receiving sectors. The prime example of such spillovers are innovations in Information and Communication Technologies (ICT) whose effects are not limited to productivity improvements of the ICT-sector alone.

Spillovers in WorldScan affect the productivity of capital and labour, see box 1. Growth of this productivity is comprised of two parts: exogenous growth ($\overset{\circ}{a x_s}$) and endogenous growth ($\overset{\circ}{a n_s}$), see equation (2.3). For a description of the exogenous growth component, the reader is referred to Lejour *et al*. (2006).[15] The endogenous productivity growth arises due to spillovers from the own sector (intrasectoral spillovers) in addition to spillovers from other domestic ($\overset{\circ}{s}_s^D$ - intersectoral spillovers) or foreign sectors ($\overset{\circ}{s}_s^F$ - international spillovers):

[14] The only available dataset known to us is for the United States compiled by the Bureau of Economic Analysis, see http://www.nsf.gov/statistics/infbrief/nsf06326/nsf06326.pdf

[15] It is also comprised of two different components, namely a historical relative growth rate based on historical time series to account for historical differences in sectoral TFP growth rates and a term that ensure that GDP growth reaches its targeted value in the baseline, see Lejour *et al*. (2006).

$$\overset{\circ}{A}_S = g\left(\overset{\circ}{a}x_S, \overset{\circ}{a}n_S\left(\overset{\circ}{R}_S, \overset{\circ}{S}_S^{D}, \overset{\circ}{S}_S^{F}\right)\right) \tag{2.3}$$

An important thing to note about this equation is that the variable on the left-hand side is productivity growth and not growth in value added. The direct effect on the firm's own output is already accounted for by the first role of R&D in WorldScan: the role of R&D as an input. Spillovers from other domestic and foreign sectors increase with the accumulation of those sectors' R&D stocks. However, not all R&D undertaken in those sectors is equally important in creating spillovers. Instead the increases in the R&D stocks are weighted by the degree in which these sectors interact with the sector receiving the spillovers. As weights are used the share in intermediate deliveries of the sending sector and the import share of the sending country (see Lejour *et al*., 2007). The rationale for this weighting scheme is one of economic proximity: more intensive trade relations provide more opportunities to become familiar with the knowledge that is used in other sectors, whereby the spillover potential increases. An alternative to this method (apart from applying no weighting scheme) is to use a weighting scheme based on technological proximity (for a more extensive discussion see Cincera (2005)).

With the introduction of spillovers, WorldScan partly incorporates the non-rivalrous nature of knowledge that was not captured in its role as a factor of production. While R&D in the form of spillovers is not exactly "used" by other producers (non-rivalry in the true sense), it does create benefits for them without hindering the owner of the R&D capital, i.e. there are so-called externalities to R&D. These externalities in turn introduce market failures as the returns from R&D arising from spillovers are not taken into account in the private R&D decisions of the firms that determine the total size of R&D investments. An important distinction between the two roles of R&D in the model is further that unlike in its previous role as a factor of production, R&D in its capacity of spillovers is exogenous to the individual firm: it does not influence how many R&D spillovers it receives. Appendix 2 examines these issues in detail and gives a microfoundation of sectoral production and spillovers, deriving the relation between WorldScan's sectoral production function and a firm-level production function.

2.2 Calibration

WorldScan is calibrated on the GTAP database version 6 (Dimaranan and McDougall (2005)). This database for example contains information on income from physical capital and high- and low-skilled labour on a sectoral basis. The R&D version of WorldScan recognizes the following ten sectors: Agriculture, oil and minerals (AGO), Energy carriers (ENG), low technology manufacturing (LTM), medium-low technology manufacturing (MLM), medium-high technology manufacturing (MHM), high technology manufacturing (HTM), transport (TRA), commercial services (OCS), government- and other services (OSR) and the R&D producing sector (R&D). Unfortunately, the GTAP database does not distinguish an R&D producing sector and also does not contain information on R&D expenditures. Data on R&D expenditures (as a % of GDP) are instead taken from OECD (2003) and UNESCO (1998). The cost structure of the R&D producing sector is calibrated on data taken from the US national accounts, which are the only national accounts to explicitly recognise an R&D sector.

As described in Fraumeni and Okubo (2002), the rules for classifying R&D expenditures in national accounts, which form the basis of the GTAP database, are rather opaque. The most common practice in national accounts appears to be counting R&D expenditures as intermediate inputs rather than value added.[16,17] In order to avoid the situation in which R&D expenditures are doubly accounted for (namely both in value added and intermediate inputs)[18], we subtract R&D expenditures from expenditures on capital and labour (see box 3).

[16] As a consequence, R&D expenditures are not capitalized and hence are not treated as investments, which may lead to biased figures of total value added (Fraumeni and Okubo (2002). This problem is referred to as the expensing bias. See also Marrano *et al*. (2007). The first revision of the 1993 SNA has a provision for the capitalization of R&D expenditures but this revision is unlikely to be adopted in the EU before 2013-2014 (see OECD (2006)).

[17] As described in Fraumeni and Okubo (2002), the rules of classifying R&D expenditures in national accounts may even be more complicated. In the US national income and product accounts (NIPA), R&D expenditures by nonprofit or government agencies are treated as final consumption, while software is treated as an investment. In the ANBERD dataset of the OECD, software is also treated as an investment, while R&D expenditures are again treated as intermediate inputs.

[18] This problem has long been recognised in empirical and modelling exercises using R&D data (Schankerman (1981)) and is appropriately referred to as the double-counting bias.

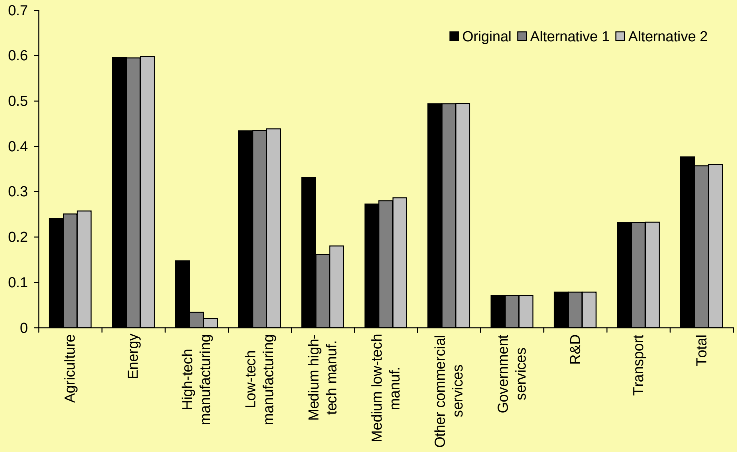
Box 3: Avoiding double-counting R&D expenditures

In the current calibration of WorldScan, the expenditures on R&D are subtracted in equal amounts from expenditures on physical capital and expenditures on high-skilled labour to avoid double-counting the expenditures on R&D. No corrections are made on the expenditures on low-skilled labour. This rule for attributing R&D expenditures over the other factors of production is rather ad hoc and lacks a clear empirical foundation.[19] Moreover in some industries this rule results in negative values for expenditures in physical capital in a few industries where the capital share is low prior to the correction for R&D expenditures. This, in turn, requires further ad hoc adjustments.

In this box, we examine whether the results in WorldScan are robust to the way that R&D expenditures are allocated over capital- and labour expenditures by applying two alternative rules for attributing R&D over the different factors of production: 1) We subtract total R&D expenditures from total value added. The residual value added is subsequently attributed over capital and both high- and low-skilled labour using the sectors' value shares calculated from the original GTAP data. This method ensures that the value shares of the different production factors are strictly nonnegative; 2) We subtract the R&D expenditures from capital, high- and low-skilled labour using the original value shares of capital, high- and low-skilled labour in the R&D sector. This method results in a negative value share of high-skilled labour in a few sectors, which is corrected for.

The figure shows the capital shares of the various sectors resulting from the different attribution rules. As is evident, the differences are relatively minor. The most important differences occur in the sectors high-tech and medium-high tech manufacturing.

Resulting capital shares using different attribution rules for R&D expenditures in Germany (2001)



In order to analyse whether the results of WorldScan are robust to this aspect of its calibration, we run an R&D scenario that was used in a previous study (Gelauff and Lejour (2006) - described in more detail in section 3.2) using these different attribution rules in the calibration. We find only minor differences in the estimated effect of the policy change. Qualitatively, the results are identical. The quantitative differences are shown in the table below for a selected number of variables.

[19] It is shown in for example Peeters and Ghijsen (2000) and Dougherty *et al*. (2007) that the share of labour compensation in R&D expenditure is somewhere between 40% and 80%. However, Dougherty *et al*. (2007) also show that this share differs over countries.

Box 3 (continued)

Effect of a 10% increase of R&D expenditures in Germany in 2020, baseline vs. scenario (no spillovers)

	Value Added	GDP per capita	Consumption per capita	R&D stock	User cost of capital	Wage low-skilled as % of wage high-skilled
Current calibration	0.69	0.42	– 0.30	17.68	0.52	– 0.93
Alternative 1	0.68	0.42	– 0.30	18.48	0.49	– 0.99
Alternative 2	0.71	0.43	– 0.31	19.18	0.52	– 1.00

The most important differences occur in the results for the wage rate and the R&D stock. For most variables, the final results differ more markedly for the second alternative calibration. Still, even using the second alternative calibration, the results are qualitatively identical and show only relatively minor quantitative differences. This also holds true when we include various spillovers, administer shocks in different countries or with different scenarios. The differences in the results increase slightly as we include more spillovers. Overall, the quantitative differences however remain relatively minor and in qualitative terms, the results are the same. Nonetheless, we have a slight preference for alternative 1, i.e. subtracting R&D expenditures from total sectoral value added and subsequently distributing the residual value added over the expenditures on other factors of production. The basis of this preference is rooted in the fact that this method prevents the occurrence of negative value shares of capital or labour whereby preventing the need for ad-hoc corrections.

The values of the other R&D parameters are listed in table 2.1. We use a depreciation rate of R&D capital of 11%, which is substantially higher than the depreciation rate of physical capital (2.7%). Depreciation of knowledge or R&D is defined as “the rate at which appropriable revenues of R&D decline.”[20] This thus reflects the private depreciation of R&D capital. The social rate of depreciation is likely to be much lower. Shanks and Zheng (2006) offer an overview of the empirical estimates of the depreciation rate of knowledge[21] or R&D stocks. The estimates range between 5 and 30%. The value of 11% is based on Carson *et al.* (1994) and falls well within this range. A number of studies indicate that the rate of depreciation of R&D capital varies across countries (Pakes and Schankerman (1986)), sectors (Goto and Suzuki (1989) and Bernstein and Mamuneas (2006)) or over time (Bosworth and Jobome (2001)).[22] These patterns are not incorporated in WorldScan as the empirical evidence is still rather scarce.

The substitution elasticity between R&D and the capital-labour aggregate is 0.9, implying that the substitution possibilities between R&D and the capital and labour composite are limited. Gelauff and Lejour (2006) experiment with a lower elasticity of substitution to allow for complementarities between R&D and capital, but find that the quantitative differences

[20] Nadiri and Purcha (1996), p. 51. See also box 1 for a discussion of the conceptual difficulties of using a constant rate of depreciation.

[21] Some of the estimates use patent data rather than data on R&D.

[22] For a more extensive treatment of this subject, the reader is referred to Shanks and Zheng (2006).

in the outcomes are slight. The substitution possibilities between capital and labour are also limited; the elasticity in the TVA nest is set at 0.85.

Table 2.1 Calibration of the R&D parameters of WorldScan

Parameter		Value in calibration year
Depreciation rate of R&D capital	δ_{RDE}	0.11
Substitution parameter TVR nest[1]	σ_{TVR}	0.9
Substitution parameter TVA nest[1]	σ_{TVR}	0.85
Own sector R&D spillover parameter	β_R	0
Domestic sectoral R&D spillover parameter	β_D	0.325
Foreign R&D spillover parameter	β_F	0.868

[1] Note that the substitution elasticity is calculated as $\sigma = 1/(1-\rho)$

The endogenous productivity growth due to spillovers (see equation 2.3) is specified as follows:

$$\overset{\circ}{a} n_s = \beta_R \overset{\circ}{R}_s + \beta_D \overset{\circ}{S}{}_s^D + \beta_F \overset{\circ}{S}{}_s^F \qquad (2.4)$$

The specification is based on Lejour and Tang (2004), who estimate the following TFP-growth equation using dynamic OLS, based on pooled data of 14 OECD countries and 12 sectors for the period 1980 to 1999:[23]

$$\overset{\circ}{TFP}_{sr,t} = \gamma_R \overset{\circ}{R}_{sr,t} + \gamma_D \overset{\circ}{S}{}_{sr,t}^D + \gamma_F \overset{\circ}{S}{}_{sr,t}^F + \sum_r D_r + \sum_t D_t + \varepsilon_{sr,t} \qquad (2.5)$$

where D_r and D_t are country and time dummies, and ε is the disturbance term. $\dot{S}_{sr,t}^D$ and $\dot{S}_{sr,t}^F$ again represent increases in the spillover potential of other sectors (both domestic and foreign). Using data from the STAN-database, TFP growth was constructed as the difference between the increase in value added and the increase in the primary production factors, labour and capita, weighted by their respectively cost shares. Their findings are summarized in table 2.2. The estimated elasticity of TFP growth with respect to private R&D efforts equals 4.9%, this means that a 1% increase in a sector's R&D stock results in a 0.049 percent increase in TFP. The interpretation of the other results follows by analogy.

Even though the estimated equation (2.5) shows great similarities with the model equation (2.4), ample differences remain that make the translation of the empirical relation into model parameters less than straightforward. Most importantly, unlike in the model, there is no separate role for R&D as an input of production in the empirical specification, so that the estimated coefficient γ_R captures the effect of R&D in both its guises. This harbours a danger of double-counting the effect of private R&D investments in WorldScan, as they feature both as an

[23] See Lejour and Tang (2007) for more details.

input in production while also having an effect on productivity through spillovers. For this reason, the effect of R&D spillovers to firms in the same sector (intra-sectoral spillovers) has been set equal to zero in previous model exercises (Gelauff and Lejour (2006)). In the next section, we will analyze the effects of R&D in WorldScan. In the process we will consider whether setting the intra-sectoral spillovers equal to zero has been entirely warranted.

Table 2.2 R&D spillovers on TFP growth

Coefficient	Parameter estimate	Standard error	Elasticity (%)[A]
Own sector R&D spillover	0.049**	0.022	4.9
Domestic sectoral R&D spillover	0.325***	0.107	7.4
Foreign R&D spillover	0.868***	0.233	5.6
Total elasticity			18.0

***, ** significant at 1% and 5% respectively

[A] For own sector spillovers, the elasticity equals the parameter estimate. For the intersectoral and international spillovers however, in order to obtain the elasticity, the parameter is multiplied by the weighted average of the share of own intermediate deliveries (0.226) and foreign intermediate deliveries (0.065) respectively. Data are taken from the OECD ANBERD and Stan database.

Source: Lejour & Tang (2006)

2.3 Conclusion

In the modelling of WorldScan, R&D has a dual impact on output, namely as a factor of production and in the form of spillovers. The first was introduced to provide a straightforward decision criterion regarding the optimal amount of R&D. Possible scope for extensions of the model has been identified in 1) the generic nature of R&D; and 2) the national dimension of the market for R&D inputs. In the calibration of WorldScan, we propose a different method of distributing R&D expenditures over the expenditures on capital and labour so as to avoid inflating the figures for value added. In this new method, R&D expenditures are first subtracted from total sectoral value added. The residual value added is subsequently distributed over labour and capital expenditures in proportion to their value shares. The most important advantage of this method is that it avoids negative value shares of capital and labour. Finally, the calibration of the spillover effects is based on empirical estimates which, unlike WorldScan, do not distinguish the dual role of R&D. Directly translating these empirical estimates into model parameters harbours the danger of double-counting the effects of private R&D. In the next section we will analyze to what extent this danger occurs and can be corrected for.

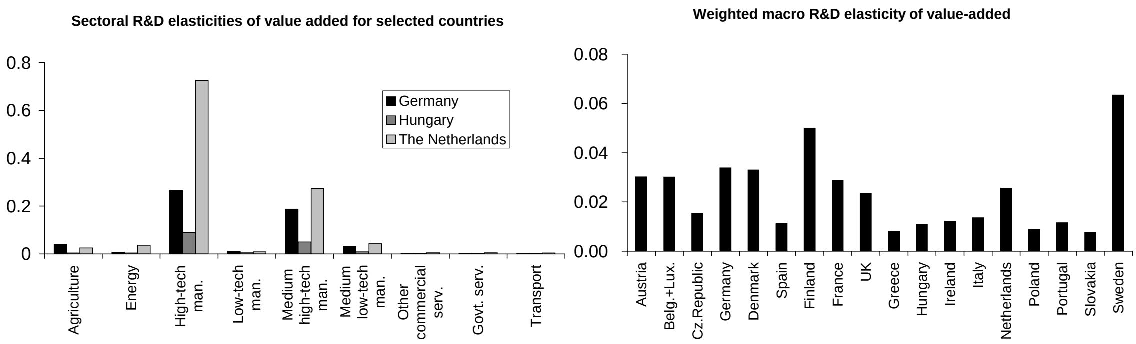
3 The effect of R&D in the model

So how do the effects of R&D in the model, which recognizes a separate role of R&D as an input in production, relate to the empirical estimates that inspired the specification of the spillover parameters, which did not explicitly discern the role of R&D as a production factor. What is the additional effect that arises by distinguishing the role of R&D as an input in production? The effect of R&D in WorldScan is captured by the elasticity of TFP growth with respect to growth in the R&D stock. In this section we will subsequently analyze this elasticity in a partial and general equilibrium framework.

3.1 Partial equilibrium

As a first approximation, we calculate the elasticity of value added with regard to the private R&D stock in the absence of any general equilibrium effects. This elasticity isolates the effect of R&D in its role as an input, as it describes the contribution of an increase in the R&D stock on sectoral value added. The elasticity of value added with regard to the private R&D stock can be calculated as the ratio of the cost value of R&D in a particular sector and the cost value of the total value added nest.[24] The derivation is given in appendix 3. In addition, we calculate a country-wide macro-elasticity by weighting the sectoral elasticities with the relative size of the sector in terms of value added. A selection of the results is shown in figure 3.1 below.

Figure 3.1 The effect of private R&D in partial equilibrium



As is evident from the left graph and unlike the empirical estimates, there are substantial differences in the size of the elasticities between different sectors, ranging from close to zero in the transport sector in almost all countries to 0.725 for the sector high-tech manufacturing in the Netherlands. Differences also exist in the weighted country-level elasticities (as shown in the right panel). In comparison to the sectoral differences however the differences between countries are much smaller, ranging from 0.01 in Greece to 0.06 in Sweden.

[24] We use the values in the base year.

Box 4: Is the sectoral pattern in R&D elasticities justified?

The previous analysis shows that there are clear sectoral differences in the response of TFP to increases in R&D. Is such a pattern realistic? A number of empirical studies has shown that the R&D elasticity of TFP is not equal across sectors (e.g. Hall (1993), Englander *et al*. (1988) and Cameron (2004)). Most of these studies limit themselves to data on manufacturing industries. Though the point estimate of the elasticity varies across studies, a rather consistent finding is that the R&D elasticity of output or value added is higher in high-tech manufacturing than in low-tech manufacturing (see for example Verspagen (1997), Greenhalgh and Longland (2002), Meister and Verspagen (2004) and Tsai and Wang (2004)). This is in accordance with the sectoral pattern produced in WorldScan. Finally, Rogers (2006) finds that the R&D elasticities of TFP of non-manufacturing firms fall in a lower range than the elasticities of manufacturing firms, which is again consistent with the sectoral pattern produced by WorldScan. Note that the studies cited here vary in their approach and underlying assumptions. For example, the studies differ in whether they investigate the elasticity of value added or TFP or whether they measure this elasticity in growth rates or levels. However, the results of these studies indicate that a sectoral pattern in the response to changes in R&D-behaviour is not without an empirical basis.

On average, the weighted macro-elasticity equals 0.023. This means that an increase in a country's R&D stock of 100% leads to a 2.3% increase in total value added. This gives us a first indication of the effect of recognizing R&D as an input in production. Note that the effect we are considering is not identical to the effects that were empirically estimated in table 2.2, as those measure the effect of R&D on TFP, while here we consider the effect of R&D on value added. Under assumptions, the two elasticities are however comparable (see appendix 4). Our partial equilibrium analysis shows that the effect of private R&D in the absence of spillovers in the model (on average 2.3%) appears to fall short of the empirically estimated effect of private R&D efforts (4.9%). As mentioned before, previous model exercises only considered the effect of private R&D as a production factor, i.e. the effect of private R&D through spillovers was set equal to zero so as to avoid double-counting the effects of private R&D. At first glance, these results suggest that this might not be necessary. In addition, the partial equilibrium analysis reveals differences in the effects between sectors and countries that are not taken into account in the empirical estimates.

3.2 General equilibrium

To obtain a fuller understanding of the effects of R&D in its two different guises, we conduct a number of simulations of the effects of an increase in R&D expenditures in a general equilibrium setting. In each of the simulations, starting in 2005 the yearly R&D expenditures of a country (as a percentage of GDP) are gradually increased until in 2010 they have reached a level that is 10% higher compared to the baseline. To allow for this increase in expenditures, the tax credit on R&D is adjusted (effectively lowering the investment price of R&D). Between 2011 and 2020, the R&D expenditures are held constant at this level and after 2020 the level of R&D expenditures is allowed to fluctuate while keeping the tax credit rate constant. In the first simulation, we ignore the role of R&D as a determinant of productivity growth and focus solely on the effects of R&D as an input in production. In short, we set all the spillover parameters in equation (2.6) equal to zero. In the second simulation, we incorporate the second role of R&D in WorldScan, i.e. we include spillovers.

No intrasectoral spillovers

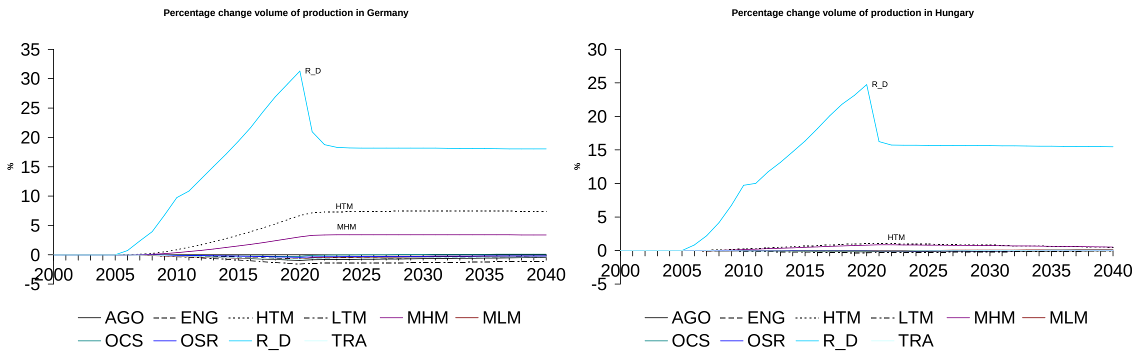
The results of the simulations in the absence of spillovers are reported in table 3.1 for a selection of countries. These countries were selected to represent economies that differ in terms of size, sectoral composition and openness-to-trade to allow for a fuller range of effects.

Table 3.1 **The effects of a 10% increase in R&D expenditures in the absence of spillovers in 2020 (with $\beta_V=\beta_D=\beta_F=0$). Change in %.**

	Consumption	Real wages	Exports	Value added	R&D stock
Germany	– 0.3	0.6	1.2	0.7	17.68
Hungary	– 0.1	0.2	0.4	0.2	15.87
The Netherlands	– 0.1	0.4	1.0	0.5	19.57

Table 3.1 shows that an increase in the R&D expenditures leads to an increase in total value added, the export volume, real wages and the R&D stock, and a decrease in consumption. In the general equilibrium setting, an additional effect occurs that was not present in the partial equilibrium framework: the influx of R&D causes a shift in the sectoral composition of the countries, see figure 3.2.

Figure 3.2 **Change (%) in volume of capital labour composite**



Naturally, the R&D producing sector expands. In Germany (shown in the left panel of figure 3.2) we also observe a marked expansion of the sectors high-tech and medium high tech manufacturing, which use R&D relatively intensively. As these sectors have a relatively high level of productivity growth, this change in the sectoral composition allows total value added to increase above the level that would be expected in a partial equilibrium framework. Notice that the effects differ across countries. For example, as the initial difference in R&D intensities between sectors is much smaller in Hungary, the change in the sectoral structure is also much less pronounced in Hungary (as shown in the right panel of figure 3.2) and so is the effect on value added.

The shift in the sectoral structure is accompanied by a change in the relative prices of the sectors. The relative prices of the R&D intensive sectors high-tech and medium high-tech manufacturing decrease markedly, while the relative prices of R&D extensive sectors such as services rise. The change in the relative prices of production sectors translates into a change in the prices of consumption categories.[25] With the exception of the consumption category 'Housing apparel', about 70% of whose value is derived from the sectors high-tech and medium-high tech manufacturing, the prices of all consumption categories increase. With the sectors medium-high tech and high-tech manufacturing generally also constituting the largest sectors in terms of trade value, there is a negative overall terms-of-trade effect.[26] As a result, the export volume increases.

The policy experiment also has an effect on income. On the one had, real wages rise as the marginal product of labour increases with the influx of additional R&D. On the other hand, the R&D tax credit is financed by a lump-sum transfer from the households, reducing their disposable income. Overall, the effect on prices and on disposable income results in a fall of consumption per capita, as shown in table 3.1.[27] The R&D tax credit and the lump-sum tax required to finance the credit, thus introduce a distortion. The effects vary per country (as shown in table 2.1) as their initial R&D intensities differ.[28]

So to what extend does the effect of R&D in the model approach the empirical estimate of the relation between R&D stock and TFP in general equilibrium? In order to answer this question, we calculate the elasticity of TFP with respect to an increase in the R&D stock.[29] We define TFP as the difference between the increase in total value added (TVR) and the increase in the primary production factors, labour and capita, weighted by their respective cost shares. In terms of the model variables, we calculate:

$$\overset{\circ}{T} = \overset{\circ}{Y} - w_C \overset{\circ}{C} - w_L \overset{\circ}{L} \tag{3.2}$$

[25] For more information on the specification of the consumption structure of WorldScan, the reader is referred to Lejour *et al*. (2006).

[26] The negative terms-of-trade effect occurs in all countries. However, for countries with a relatively low overall R&D share (*inter alia* Greece, Poland and the Slovak Republic), the effect sets in relatively late compared to other countries.

[27] In the baseline, the R&D tax credit is equal to zero. Welfare measured in terms of equivalent variation also decreases.

[28] Of the three countries shown in table 2.1, Germany had the highest R&D intensity. It's weighted cost share of R&D in total value added (TVR) equals 34% in the 2001. The Netherlands and Hungary had an R&D intensity of respectively 26% and 11%.

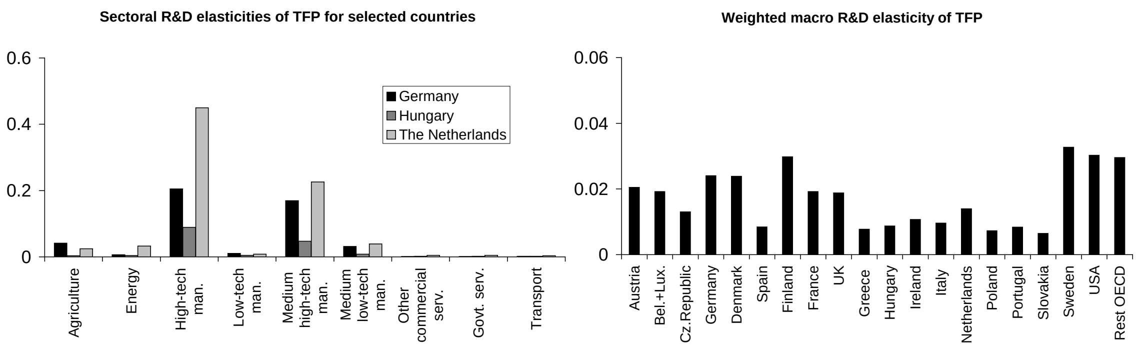
[29] Note that in the model, R&D influences the productivity in the capital-labour composite (TVA) through spillovers. Here, as in the empirical estimates, we consider the productivity in the entire value added nest, i.e. including R&D (TVR).

Where w_C and w_L are the respective cost shares of capital and labour in the capital-labour composite (TVA) and ◦ denotes relative change between the scenario and the baseline.[30] TFP increases in the scenario compared to the baseline with a bias towards those sectors that use R&D relatively intensively in their production process, i.e. high-tech and medium high-tech manufacturing. We calculate the elasticity of TFP growth with respect to a change in the growth rate of the R&D capital stock as follows:

$$\gamma_V = \frac{\overset{\circ}{T}}{\overset{\circ}{R}} \tag{3.3}$$

We calculate a macro-elasticity by weighting the sectoral TFP growth with the relative size of the sector in terms of total value added and dividing this by the growth of the R&D stock of the country. The results mirror those found in the partial equilibrium framework. Again, we clearly observe differences in the effects of private R&D across sectors and countries that are absent (or rather unaccounted for) in the empirical estimates.

Figure 3.3 The effect of private R&D in general equilibrium



When we compare figure 3.3 to figure 3.1, which shows the partial equilibrium effects, both the sectoral and the country pattern are nearly identical. These patterns can therefore almost entirely be attributed to differences in the initial value shares of R&D in value added. The correlation between the partial and general equilibrium macro-elasticities is 0.97. The average size of the elasticity is slightly smaller in general equilibrium than in partial equilibrium: 1.7% versus 2.3%. Overall, the results confirm that, in the absence of intersectoral spillovers, the effect of R&D in the model seems to fall short of the effects of R&D as estimated empirically.

[30] We use the cost shares in the capital-labour nest (TVA) instead of the cost shares in the total value added nest (TVR) as the latter do not add up to one.

Introducing intrasectoral spillovers

In consequence, we carry out a second simulation exercise in which we introduce intra-sectoral spillovers, i.e. spillovers to other firms within a sector. For analytical convenience, we ignore intersectoral and international spillovers.[31] The size of the intra-sectoral spillovers are set to 2.6%, which is equal to the difference between the empirical estimate of the effect of private R&D and the effect of R&D in partial equilibrium. In this set up, we find that the same increase in R&D expenditures results in a slightly larger increase in the R&D stock while, at the same time, it has a significantly larger effect on the size of value added. This is not surprising as, in the presence of intrasectoral spillovers, R&D has a direct effect on productivity (ad_{rs}). This allows value added to increase more rapidly and in addition, it allows consumption to grow instead of decline as in the previous simulation. In the presence of R&D spillovers, increasing the tax credit on R&D in order to increase R&D expenditures is not merely a distortion but also allows for positive welfare effects through spillovers. The sectoral composition still changes, but the change is less biased towards the R&D intensive sectors.

We again estimate the R&D elasticity of TFP, now in the presence of positive intrasectoral spillovers. The sectoral and country patterns of the elasticities are largely retained. As before, these pattern can be attributed to difference in the initial R&D shares. The correlation between the results in the presence of spillovers and the initial value share of R&D has dropped slightly, but is still sizable at 0.9. The average elasticity in the OECD countries is about 4% and is therefore closer to its empirically estimated value of 4.9%. It therefore seems that the fear of double-counting the rewards to private R&D is only partially warranted. In setting the parameter of intrasectoral spillovers equal to zero, the effect of private R&D is underestimated and we would propose giving the parameter a positive value though smaller than the empirically estimated one, for example at 2.6%.

To obtain the total R&D elasticity of TFP, we have to add the elasticity of private R&D to the elasticity of R&D from other sectors and countries. These equal 7.4 and 5.6 respectively (see table 2.2)[32], such that the total elasticity equals about 17%. This implies a return to R&D of about 90%, see appendix 5. This is at the higher end of the spectrum of available empirical estimates.

[31] After all, these are not in danger of being doubly accounted for. International spillovers do not play a role in this particular simulation as the shocks are country-specific: the R&D stocks of other countries do not change such that there is no change in the degree of international spillovers.

[32] As shown in table 2.1 the parameters of intersectoral and international spillovers are set equal to those obtained in the empirical estimates. To arrive at the elasticities of these spillovers, this parameter is multiplied by the weighted average of the share of own intermediate deliveries (0.226) and foreign intermediate deliveries (0.065) respectively.

3.3 Conclusion

In conclusion, this section has shown that the effects of R&D in WorldScan vary considerably across countries and sectors. In this respect, the model differs importantly from the empirical estimates that inspired its specification (Lejour and Tang (2007)), which imposed a uniform effect. A short overview of the empirical literature revealed some validation for such a sectoral pattern. In general equilibrium, R&D has a positive effect on value added and TFP. In the absence of spillovers, the effect on consumption is negative. This is however mainly caused by the lump-sum transfer that is necessary to finance an increase in the R&D stock. An increase in the R&D stock causes a shift in the sectoral pattern of production and relative prices. The model exercise shows that the magnitude of the effect of private R&D, as encapsulated by the elasticity of value added with respect to the R&D stock, more closely resembles the empirical estimate when intra-sectoral spillovers are included. The danger of double counting the effects of private R&D are only partially realised in the model and therefore the practice of setting the parameter of intrasectoral spillovers equal to zero does not seem to be the optimal approach.

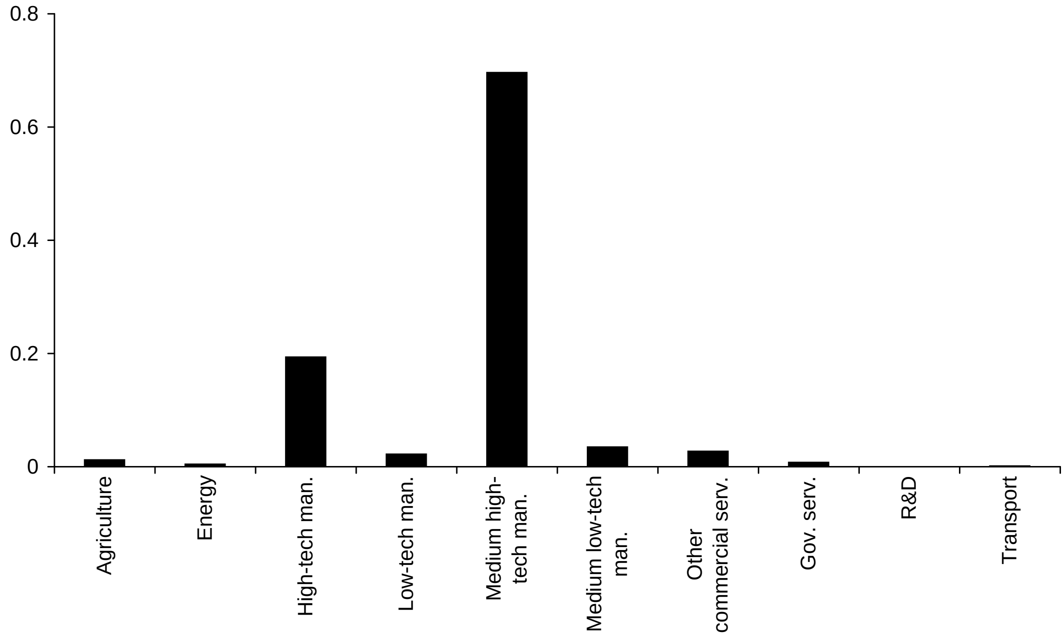
4 Mechanisms for raising WorldScan's R&D content and the effectiveness of an R&D tax credit

The ultimate goal of the model is to analyze what effect innovation and R&D have on the economy and answer questions such as: what happens to the economy when R&D expenditures are increased? In other words, we want to simulate changes in the R&D content of an economy. Two methods were explored in WorldScan's R&D version that would allow for a change in the R&D content. In an earlier version of the model, an increase in a countries' R&D expenditure was effected by raising the productivity with which R&D is made. A drawback of this approach was that this increased productivity came about for no reason. In other words, it came about without cost. This 'manna from heaven'-approach is somewhat unsatisfactory. As a result, a second method for raising R&D expenditures was introduced in the form of a universal tax credit on the price of R&D. Here, raising R&D expenditures comes at a cost in terms of government outlays to fund the tax. These outlays are financed by a lump sum tax from households. Section 4 analyzes the effect of the tax credit in WorldScan. Again, the model's correspondence to the empirical evidence on tax credits is evaluated by a short review of the empirical literature, based on both micro- and macro-level studies.

4.1 The effectiveness of an R&D tax credit in WorldScan

The tax credit is effective in stimulating R&D in WorldScan by lowering the price of R&D. In previous applications of the model, the tax credit applied equally to all R&D efforts. Technically, it would however be a straightforward exercise to develop a scenario in which a specific sector is targeted in the government's R&D policy, i.e. by introducing a sector-specific subsidy. Even with a universal tax credit, not all sectors receive an equal share of public money due to differences in the R&D intensities of different sectors. As shown in figure 4.1, the sectors high-tech and medium high-tech manufacturing, which are relatively R&D intensive, receive the lion's share (89%) of the R&D tax credit in Germany. This feature is quite credible: as described in Guellec and Van Pottelsberghe (2000), one of the distinguishing characteristics of a universal tax credit is that it is does not create a distortion; it does not change the relative R&D behaviour of one sector vis-à-vis other sectors.[33]

Figure 4.1 Share of the dollar amount of total tax credit per sector for Germany in 2005 (tax rate = 5%)



Effect of R&D expenditures and welfare

To gauge the effects of a tax credit in WorldScan, we introduce an R&D tax credit of 5% in Germany in the year 2005 which we maintain throughout the period of simulation. Unless otherwise stated, we use a setting that includes intra- and inter-sectoral spillovers.[34] Recall that all R&D in WorldScan is performed by firms in a separate R&D sector. We therefore do not

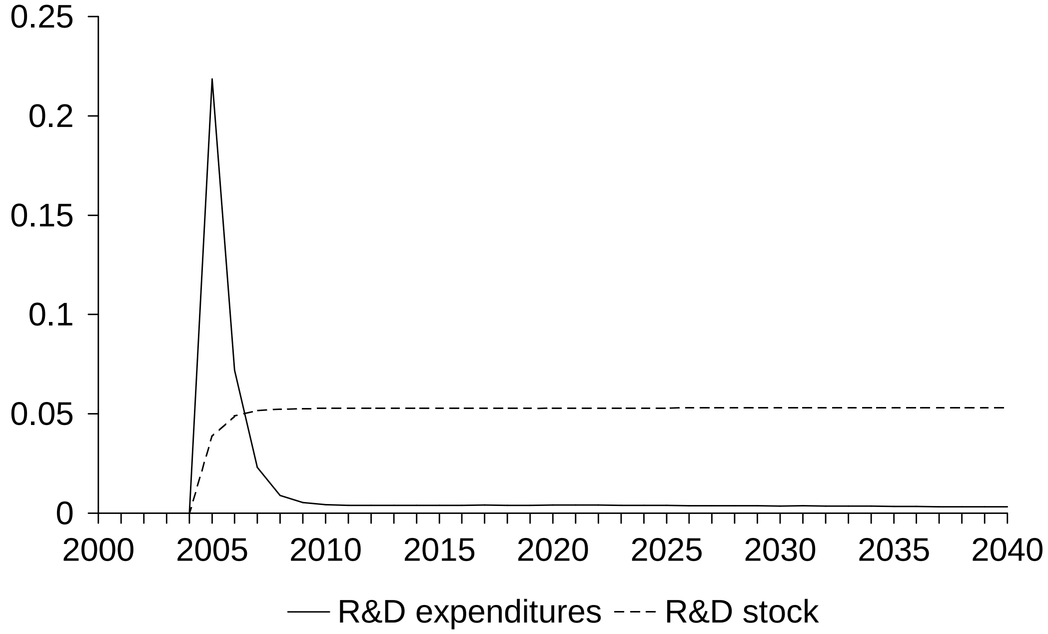
[33] Guellec and Van Pottelsberghe (2000) contrast this with R&D subsidies which are directed to specific projects (preferably those with the highest social return) and hence influence the sectors' relative performance, distorting the relative R&D intensity brought about by market forces.

[34] International spillovers are not included as they play no role in a scenario with a country-specific shock.

distinguish between R&D performed by the public and private sector. We do however make a distinction between the source of financing for R&D. In the presence of the tax credit, each R&D effort is partly financed from public funds (the tax credit) and partly from private funds. We refer to the latter as private R&D expenditures.

Figure 4.2 shows that the R&D tax credit is successful at raising the R&D content of the economy. The R&D stock increases by about 5% compared to the baseline. In terms of expenditures, the tax credit has a positive leverage effect on private R&D expenditures in the short run, as these markedly increase in the years following the introduction of the tax credit. The leverage effect disappears relatively quickly and in the long run private R&D expenditures are nearly identical to those that would arise without the tax credit. Thus, there is also no crowding out of private R&D expenditures by publicly funded R&D expenditures. Total R&D expenditures (formed by both public and private R&D expenditures) rise by the amount of the tax credit - no more, no less.[35] It conforms to the findings in the empirical literature of a dollar-for-dollar correspondence between the tax credit and the additional total R&D expenditures (see box 5).

Figure 4.2 Relative change of the R&D stock and R&D expenditures in response to a 5% R&D tax credit



[35] This conclusion is also reached in Gelauff and Lejour (2006) using a more sophisticated policy experiment.

Box 5: The effectIveness of a tax credit in empirics

The empirical evidence on the effectiveness of R&D tax credits is remarkably scarce considering the increasing emphasis on R&D and innovation in policy circles. R&D tax credits are motivated by the existence of market failures: the discrepancy between the private and social returns to R&D. The real test of the effectiveness of an R&D tax credit should therefore be based on the ability of the tax credit to bring social and private returns more into alignment (Guellec and Van Pottelsberghe de la Potterie, 1997). The concept of social returns to R&D however remains rather elusive in a quantitative sense. As a result, most studies content with testing whether the R&D tax credit provokes an increase in R&D expenditures. Hall and van Reenen (2000) give an excellent overview of the methodological issues involved in capturing the effect of an R&D tax credit.

Micro studies

Hall and van Reenen (2000) offer the most comprehensive and recent review of the empirical evidence on the effectiveness of tax credits using micro-data. Unlike other reviews they also include the (scarcely) available evidence based on non-US data. They find that while some of the older studies of the 1980s were sceptical about the effectiveness of R&D tax credits in stimulating R&D expenditures, newer studies that employ more sophisticated empirical techniques generally find evidence in favour of these credits. They formulate their conclusion rather decidedly: "...[T]here is little doubt about the story that the firm-level publicly reported R&D data tell: the R&D tax credit produces roughly a dollar-for-dollar increase in reported R&D spending on the margin."[36] The available evidence is however not entirely in unison as point estimates differ widely between studies. The estimates cited in Hall and van Reenen (2000) fall within the range [0.35, 1.6] for US based studies and [0.04, 1.1] for studies based on data from Canada, Sweden, Japan, France and Australia. A similar conclusion is reached in Guellec and Pottelsberghe de la Potterie (1997) who report a range of [0.07, 2.7] and conclude that: "In general, it appears that tax incentives do not generate much R&D beyond the tax expenditures incurred by the government."[37]

Macro studies

Considering the aim of the R&D tax credit (reconciling the private and social returns to R&D), one would seemingly prefer using data at high levels of aggregation to integrate the effect of R&D spillovers (Guellec and Van Pottelsberghe de la Potterie, 1997).[38] Most available studies are however based on firm-level data. The few studies exploiting data on the country level include Guellec and Van Pottelsberghe de la Potterie (1997, 2001) and Bloom *et al*. (2000). The former study estimates both short-run and long-run elasticities of private R&D with respect to tax incentives. The authors use a so-called "B-index", introduced by Warda (1996) to evaluate a country's generosity in terms of R&D tax credits. They consider 17 OECD countries in the years 1981-1996. The index offers (what the authors admit to be) a synthetic view of countries' tax generosity and is subject to the usual criticisms attached to such an aggregate index. It does however allow the authors to exploit cross-country differences in the fiscal treatment of R&D. They find that fiscal incentives are effective in stimulating R&D expenditures. The exact size of the estimated effect is difficult to quantify given their use of an index. The other macro-level study known to us is Bloom *et al*. (2000). They estimate both short-run and long-run elasticities of the level of R&D with respect to its user cost using a panel of 9 OECD countries over the period 1979-1996. They construct a measure of the user cost of R&D, which they find to differ considerably across countries and across time. They find that the long-run elasticity substantially exceeds the short-run elasticity and equals approximately -1 (meaning that a 1% decrease in the user cost of R&D leads to a 1% increase in the R&D level). One of their more interesting findings is that the location of R&D is influenced by the presence of fiscal amenities to R&D, giving scope for strategic behaviour of governments in the form of R&D tax competition. A result that is confirmed in a recent study by Wilson (2007).

[36] Hall and van Reenen (2000), p.462.

[37] Guellec and Pottelsberghe de la Potterie (1997), p.101.

What appears to be instrumental in explaining the absence of a crowding out-effect in WorldScan is the substitution elasticity that is assumed between R&D and the capital-labour composite, i.e. the substitution elasticity in the TVR nest. Table 4.1 shows the effect of the tax credit in 2020 for different values of this substitution elasticity. It is clear from table 4.1 that when we lower the substitution elasticity to 0.1, a significant crowding out effect on private R&D expenditures occurs. As this set-up approaches a Leontieff production function, the possibility/rationale for increasing the amount of R&D in production disappears. On the contrary, when we increase the substitution elasticity to 2, a clear leverage effect appears. With a higher elasticity of substitution, it is possible to substitute R&D for the capital-labour composite in response to the fall in the investment price of R&D. Given that our current calibration produces a close fit to the current state of the empirical literature, the model requires no further adjustments on this point.

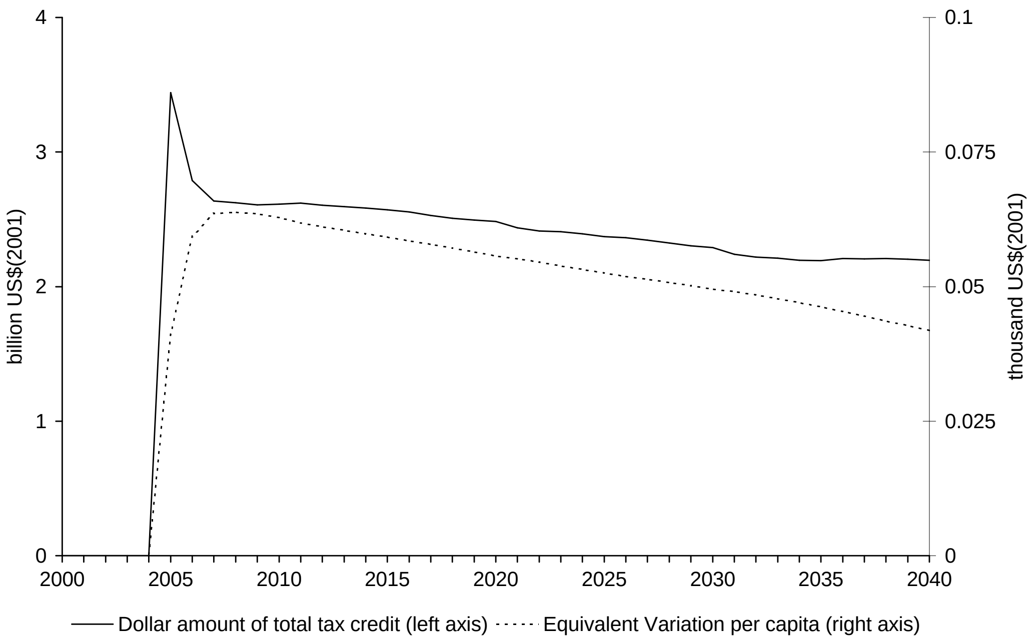
Table 4.1 The degree of crowding out of private R&D expenditures by the introduction of an R&D tax credit (5%) in Germany (2040)

Substitution elasticity	Change in Investment price of R&D	Total R&D activity (in volume)	Private R&D expenditures (in value)
0.1	– 4.8%	2.0%	– 2.8%
0.9	– 5.0%	5.3%	0.3%
2.0	– 5.1%	10.4%	5.3%

The effect of the tax credit on welfare is calculated in terms of equivalent variation (EV) and shown in figure 4.3. Equivalent variation measures the amount of money that a person in the baseline situation (here: the situation without the tax credit) would have to receive in order to attain the welfare level of an alternative situation (here: the situation with the tax credit). Figure 4.3 shows that the tax credit raises instantaneous welfare in all periods. The effect on welfare is slightly larger in the short term, but even in the long term the tax credit continues to raise welfare.

[38] As pointed out by Bloom *et al*. (2000), other drawbacks of using firm-level data are that 1) changes in the tax treatment of R&D are macroeconomic which causes identification problems in the presence of other macroeconomic shocks; 2) there may be an endogeneity problem as the effectiveness of the tax credit depends on characteristic of the firm (such as their tax position); and 3) country-specific results are hard to generalize.

Figure 4.3 The effect of a 5% R&D tax credit on welfare



Diminishing returns?

Now that we have established that the R&D tax credit raises both R&D expenditures and welfare, one might wonder whether the effects are linear in the size of the tax credit or whether instead diminishing returns might arise. Over the period 2005-2040, we calculate the discounted sum of the additional private R&D expenditures and instantaneous EV's respectively.[39] In turn, we divide these by the discounted sum of the dollar amounts of tax credits that are spent. This way, we obtain a measure for the overall effectiveness of one dollar of tax credit in raising R&D expenditures and welfare.

Table 4.2 The effects of a tax credit on private R&D expenditures and welfare in Germany for different values of the tax credit

Tax credit	0%	5%	10%	15%	20%
Discounted sum of additional private R&D expenditures[1] / Discounted sum of dollar amount of tax credit[1]	0	0.35	0.33	0.31	0.29
Discounted sum of equivalent variation[2] / Discounted sum of dollar amount of tax credit[1]	0	0.031	0.030	0.028	0.027

[1] In billion US$ (2001), using the real interest rate as the discount factor

[2] In billion US$ (2001), using a discount factor of 4%

As shown in table 4.2, the return to one dollar of tax credit in terms of additional private R&D expenditures and welfare are decreasing. For example, at a tax credit of 5% each discounted dollar of tax credit generates € 0.35 worth of additional private R&D expenditures over the

[39] We use the real interest rate as the discount factor for the additional R&D private expenditures and for the discounted sum of EV's we use a discount factor of 4%.

entire timespan.[40] At a tax credit of 20%, the increase is only € 0.29. The extent of the decreasing returns seems fairly limited. One might question the validity of this aspect of the model in particular for very high rates of the tax credit. An explanation for this might be found in the fact that we use a (non-distortionary) lump-sum transfer to finance the tax-credit. If we were to use a more distortionary tax instrument, which we are more likely to encounter in reality, the extent to which we find diminishing returns should increase. In view of this finding, we suggest that analyses be restricted to low or intermediate values of the tax credit.

4.2 Conclusion

Two mechanisms are available in WorldScan that allow for an increase in the R&D content of an economy. One comes at no cost; an increase of the productivity with which R&D is produced. The second mechanism is government policy in the form of a tax credit on R&D. As this second mechanism does come at a cost (in the form of a lump-sum transfer from households) it is in closer agreement to what we would expect to find in real life and is therefore our preferred mechanism. The current palette of policy instruments may, at first glance, seem slightly limited, as the only mode for government intervention in WorldScan is a universal tax credit. However, this palette can be easily extended to include a tax credit targeted at specific sectors. Another interesting extension would be to include a public R&D sector in WorldScan.

In WorldScan, the tax credit has neither a leverage effect nor a crowding out effect on privately financed R&D expenditures. Each dollar of tax credit broadly generates an equal amount of additional total R&D expenditures – no more, no less. A brief literature review reveals that this conforms to the findings in the empirical literature. We find some evidence of diminishing returns to the R&D tax credit. However, the degree of diminishing returns seems very slim, such that it seems advisable to limit analyses to low- or medium values of the tax credit.

[40] Note that this does not contradict our earlier conclusion: In the short run, the model shows a leverage effect in private R&D expenditures. This effect disappears in the long run.

5 Conclusion

This study analysed the R&D version of WorldScan, the CGE model for the world economy developed by the Netherlands Bureau of Economic Policy Analysis. It discussed some of the more striking features in the model that should be taken into account in the interpretation of model outcomes, such as the homogeneity of the production function, the generic nature of R&D and the dual role of R&D as a factor of production and a determinant of productivity. In addition, we contrast the main model outcomes with the empirical estimates that inspired the specification of the model and the results in the empirical literature on R&D. We focussed on two model outcomes in particular: the effect of R&D on TFP and the effectiveness of a tax credit in stimulating R&D expenditures in WorldScan. Our main findings are:

- The effect of R&D on TFP in WorldScan differs considerably over countries and sectors. On this point, the model differs from the empirical estimates on which it is calibrated. A review of the empirical evidence, however, presented some validation for this sectoral pattern.
- Unlike the empirical estimates, WorldScan distinguishes two separate roles of R&D (as a production factor and as spillovers). This approach introduces the risk of double-counting the effect of private R&D. In response, the second role of R&D (as spillovers) was nullified in previous applications of WorldScan. Our results show that the risk of double-counting the effects of private R&D are not fully realized. The practice of nullifying the second role of private R&D does not seem to be the optimal approach. Rather, we suggest taking the role of intrasectoral spillovers into account, but restricting their magnitude to be smaller than the empirical estimates.
- The policy instrument used by WorldScan, an R&D tax credit, is effective in raising both R&D expenditures and welfare. The effectiveness of the tax credit in stimulating private R&D expenditures is primarily determined by elasticity of substitution between R&D and capital and labour. In the current calibration, the level of effectiveness conforms to the findings in the empirical literature: €1 extra R&D tax credit raises total R&D expenditures by an equal amount; there is neither a leverage nor a crowding out effect.

A number of possible future extensions of the model can be identified in conclusion. First, the introduction of more heterogeneity of R&D should provide the model both with more realism and possibilities for policy design. The most promising route, given the availability of data and empirical evidence, appears to be the introduction of publicly performed R&D. A second possible extension would be to allow for international trade of R&D. Again, this would expand the scope of possible policy experiments as it would facilitate the analysis of issues such as outsourcing of R&D and international cooperation or tax competition in R&D. On the other hand, the available data and empirical evidence on trade in R&D services is scarce which would certainly impede the calibration of such an extension. A final extension would be to introduce a more explicit link between R&D and human capital, being representative of a country's absorption capacity, see Benhabib and Spiegel (1994).[41] Again, one would first have to investigate whether enough empirical evidence exists to make such an extension feasible. Overall, the extension of introducing a public R&D sector appears the most promising.

In its current form, the R&D version of WorldScan is a valuable instrument in the arsenal of the applied economic researcher. However, the potency of this instrument is governed by the necessary abstractions that are made in the modelling process. The choice for WorldScan has been to focus on the long-run productivity effects of innovation. For an appropriate use of the model as a policy instrument, it is important to be aware of its limitations and to evaluate the suitability of the model for the given application.

[41] Moreover, in the current set-up, an increase in the R&D content of an economy has very limited consequences for the market for high-skilled labour as there are no restrictions on employing high-skilled labour from other sectors as R&D researchers, which seems slightly unrealistic. For example, Reinthaler and Wolff (2004) have found that public R&D spending has a significant and positive effect on scientists' wages.

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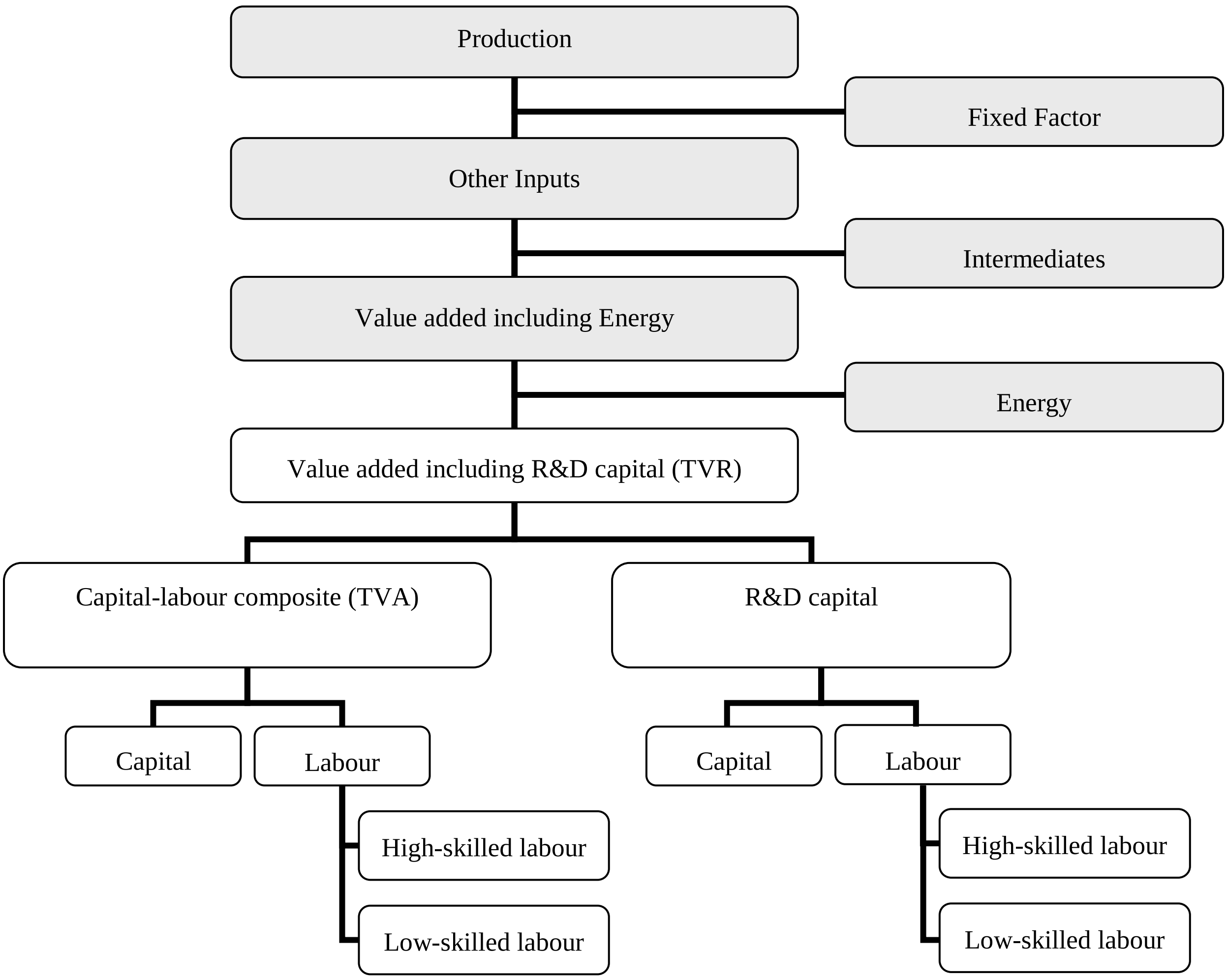
Appendix 1


Production
Fixed Factor
Other Inputs
Intermediates
Value added including Energy
Energy
Value added including R&D capital (TVR)
Capital-labour composite (TVA)
R&D capital
Capital
Labour
High-skilled labour
Low-skilled labour
Capital
Labour
High-skilled labour
Low-skilled labour

Appendix 2: A microfoundation of the sectoral production function in WorldScan[42]

WorldScan relies on sectoral production functions that include both spillovers between firms within a sector and spillovers from other sectors. It has not previously been demonstrated what these spillovers should look like for individual firms. Below the properties of the production function for individual firms are derived from the sectoral production function.

Sectoral production in WorldScan is a function of labour, capital, R&D, intrasectoral spillovers, intersectoral and international spillovers. For the present purpose, international spillovers are conceptually equivalent to intersectoral spillovers so that we may leave them out of the present discussion. R&D actually affects production in three ways. First, it is considered a production factor similar to capital and labour. Second, a firm's R&D is assumed to affect the productivity of other firms in the sector (intrasectoral spillovers). Third, a firm's R&D also raises the productivity of firms in other sectors (intersectoral spillovers). The difficulty of deriving the properties of a firm level production function lies in the treatment of these three roles of R&D.

In WorldScan, the production of sector *s* is modelled with the production function that is stated below.

$$y_s = F\left(l_s, k_s, r_s, S_s, S_s^*\right) \tag{A2.1}$$

The function F is linearly homogeneous in labour l_s, capital k_s, and the sectoral R&D stock r_s and the function is homogeneous of degree η in all variables jointly. The other two variables are intrasectoral spillovers S_s and spillovers from outside of the sector S_s^*.

The implicit assumptions of the sectoral production function can be made explicit in the firm level production function f.

$$y_i = f\left(l_i, k_i, r_i, R_i, S_i^*\right) \tag{A2.2}$$

The subscript i indexes the firms of a sector; the set of all firms is denoted by σ. Like F, the function f_i is linearly homogenous in labour l_i, capital k_i and the firm-specific R&D stock r_i. The function is homogeneous of degree η in all variables jointly. The firm employs profit maximizing levels of l_i, k_i, and r_i. The other two variables are the R&D stock of the other firms in the sector $R_i \equiv r_s - r_i$, and spillovers from outside the sector $S_i^* = S_s^*$. Both types of spillovers are beyond the control of the firm. The sectoral quantities of output, labour, capital and R&D are the sums of firm-level quantities.

$$y_s = \sum_{i \in \sigma} y_i \qquad l_s = \sum_{i \in \sigma} l_i$$

[42] This appendix was written by Bas Straathof.

$$k_s = \sum_{i \in \sigma} k_i \qquad r_s = \sum_{i \in \sigma} r_i$$

The profits π of the firm are given by

$$\pi_i = p_y y_i - w l_i - p_c k_i - p_R r_i \tag{A2.3}$$

where, p_y is the price of the good produced by i, w is the wage rate, and p_c and p_R are the cost of using one unit of capital and one unit of R&D respectively.[43] All prices are taken as given by the firm. The fist order conditions for profit maximization imply that

$$\frac{\partial f_i}{\partial l_i} = \frac{w}{p_y} \qquad \frac{\partial f_i}{\partial k_i} = \frac{p_c}{p_y} \qquad \frac{\partial f_i}{\partial r_i} = \frac{p_R}{p_y}$$

Applying Euler's theorem on f regarding the three production factors yields:

$$y_i = \frac{\partial f_i}{\partial l_i} l_i + \frac{\partial f_i}{\partial k_i} k_i + \frac{\partial f_i}{\partial r_i} r_i \tag{A2.4}$$

After substitution of the marginal productivities, output and the production factors can be aggregated straightforwardly.

$$\sum_{i \in \sigma} y_i = \frac{w}{p_y} \sum_{i \in \sigma} l_i + \frac{p_c}{p_y} \sum_{i \in \sigma} k_i + \frac{p_R}{p_y} \sum_{i \in \sigma} r_i \tag{A2.5}$$

$$y_s = \frac{w}{p_y} l_s + \frac{p_c}{p_y} k_s + \frac{p_R}{p_y} r_s \tag{A2.6}$$

As F is homogeneous of degree one in l_s, k_s, and r_s, we can conclude that

$$\frac{\partial F}{\partial l_s} = \frac{\partial f_i}{\partial l_i} = \frac{w}{p_y} \tag{A2.7}$$

$$\frac{\partial F}{\partial k_s} = \frac{\partial f_i}{\partial k_i} = \frac{p_c}{p_y} \tag{A2.8}$$

[43] We assume that both capital goods and the R&D stock are tradable. The cost of using k units of capital goods can be expressed as the value at the beginning of the period minus the expected value at the end of the period plus interest payments on the loan used to finance the purchase of the goods (including a risk premium o_k).

$$p_c k = (1 + r + o_k) p_k k - p_k^e k^e$$

The superscript e means expectation. Assuming adaptive expectations, the expected price equals the current price. The expected stock of capital goods equals the sock at the beginning of the period depreciated at rate δ_k, such that we obtain the following relation between the user cost of capital and the price of capital goods.

$$p_c = (r + o_k + \delta_k) p_k$$

For R&D a similar expression can be found.

$$p_R = (r + o_{RD} + \delta_{RD}) p_{RD}$$

$$\frac{\partial F}{\partial r_s} = \frac{\partial f_i}{\partial r_i} = \frac{p_R}{p_y} \tag{A2.9}$$

What remains to be done now, is to find the relations between $\frac{\partial F}{\partial S_s}$ and $\frac{\partial f_i}{\partial R_i}$, and between $\frac{\partial F}{\partial S_s^*}$ and $\frac{\partial f}{\partial S_i^*}$. Applying Euler's theorem to *F* and *f* regarding all variables gives

$$q_s = \frac{1}{\eta}\left(\frac{\partial F}{\partial l_s} l_s + \frac{\partial F}{\partial k_s} k_s + \frac{\partial F}{\partial r_s} r_s + \frac{\partial F}{\partial S_s}\frac{\partial S_s}{\partial r_s} r_s + \frac{\partial F}{\partial S_s^*} S_s^*\right) \tag{A2.10}$$

And, after aggregation,

$$q_s = \frac{1}{\eta}\sum_{i\in\sigma}\left(\frac{\partial f_i}{\partial l_i} l_i + \frac{\partial f_i}{\partial k_i} k_i + \frac{\partial f_i}{\partial r_i} r_i + \frac{\partial f_i}{\partial R_i} R_i + \frac{\partial f_i}{\partial S_i^*} S_i^*\right) \tag{A2.11}$$

Equating both expressions and using (A2.7), (A2.8) and (A2.9) yields the following relation.

$$\frac{\partial F}{\partial S_s}\frac{\partial S_s}{\partial r_s} r_s + \frac{\partial F}{\partial S_s^*} S_s^* = \sum_{i\in\sigma}\frac{\partial f_i}{\partial R_i}\left(r_s - r_i\right) + \sum_{i\in\sigma}\frac{\partial f_i}{\partial S_i^*} S_i^* \tag{A2.12}$$

All firms are exposed to the same intersectoral spillovers, such that $S_j^* = S_i^* = S_s^* \forall i, j \in \sigma$. Combining these observations reveals the relation between the partial derivatives for intersectoral spillovers.

$$\frac{\partial F}{\partial S_s^*} = \sum_{i\in\sigma}\frac{\partial f_i}{\partial S_i^*} = n\frac{\partial f}{\partial S^*} \tag{A2.13}$$

The right-most part of the expression assumes that all firms are identical; *n* is the number of firms. As opposed to the partial derivatives of labour, capital and R&D, the partial derivative of sectoral production to intersectoral spillovers depends on the number of firms in the sector.

Maintaining the assumption of identical firms and defining , $\frac{\partial S_s}{\partial a_s} \equiv 1$ we can also solve for the derivative with respect to spillovers within the sector.

$$\frac{\partial F}{\partial S_s} = \frac{\partial f}{\partial A_i}\left(n-1\right) \tag{A2.14}$$

Hence, also spillovers within the sector are a function of the number of firms.

Concluding, the sectoral production function used in WorldScan can be seen as a consistent aggregate of the production of the firms in a sector. However, a qualification of this result is warranted as the magnitude of the spillover effects depends on the number of firms in the sector. This is not problematic as long as the number of firms in the sector is kept exogenous. When the number of firms would become endogenous, the homogeneity of the sectoral production function would no longer be guaranteed.

Appendix 3

In section 3.1, we calculate the partial equilibrium elasticity of sectoral value added with respect to the R&D stock as the cost share of R&D in that sector's value added. Why this is possible is shown in the following calculation. Starting from the CES production function in the value-added nest:

$$Y = \left(\alpha_{CL}^{1-\rho} (CL)^{\rho} + \alpha_{R}^{1-\rho} R^{\rho} \right)^{\frac{1}{\rho}} \tag{A3.1}$$

where Y is value added, CL is the capital-labour composite and R is the R&D stock. Furthermore α_{CL} and α_R denote the value share of the capital-labour composite (CL) and R&D respectively, while ρ is the substitution parameter. The substitution elasticity, $\sigma = 1/(1-\rho)$, in the value added nest is set at 0.9, see section 2.2. The elasticity can be calculated as:

$$\gamma = \frac{\partial Y}{\partial R} \cdot \frac{R}{Y} = \alpha_{R}^{1-\rho} \left(\frac{R}{Y} \right)^{\rho} = \alpha_{R}^{1/\sigma} \left(\frac{R}{Y} \right)^{(\sigma-1)/\sigma} \tag{A3.2}$$

Substituting the factor demand equation for given prices and production volume[44] :

$$R = \alpha_{R} Y \left(\frac{p_Y}{p_R} \right)^{\sigma} \tag{A3.3}$$

gives for the base year (*t=0*):

$$\gamma = \left(\frac{p_R R}{p_Y Y} \right)_0 \tag{A3.4}$$

[44] See equation 2.5 in Lejour *et al*. (2006)

Appendix 4

In the partial equilibrium analysis of section 3.1, we calculate the elasticity of value added instead of the elasticity of TFP. We can see that these elasticities are closely related when we consider the following production function:

$$Y = g(C, L)\, h(R) \tag{A4.1}$$

Note that the production function is separable in R, i.e. R&D is factor neutral. TFP can be defined as:

$$TFP = \frac{Y}{g(C, L)} = h(R) \tag{A4.2}$$

It follows that under the assumption that R&D is separable in the production function, the R&D elasticity of TFP is equal to that of value added:

$$\frac{d \ln Y}{d \ln R} = \frac{d \ln TFP}{d \ln R} = \frac{\partial h}{\partial R} \frac{R}{h} \tag{A4.3}$$

Appendix 5

In appendix 3 we elaborated on the static (partial equilibrium) approach to the elasticity of value added with respect to changes in the R&D stock. Similarly, this appendix will discuss the static approach to the returns to R&D. Recall the definition of the elasticity of value added with respect to growth in the R&D stock of appendix 3:

$$\gamma = \frac{\partial Y}{\partial R} \cdot \frac{R}{Y} \tag{A3.2}$$

When we define the rate of return to R&D as

$$r = \frac{\partial Y}{\partial R} \tag{A5.1}$$

we immediately see the relation between these two concepts:

$$r = \gamma \cdot \frac{Y}{R} \tag{A5.2}$$

In the current set-up of WorldScan, the rate of return on R&D is approximately 90%. This figure is a ballpark estimate, as the different components of the calculation differ across sectors and over time. Nevertheless, to obtain some intuition for this figure, some of the relevant parameters from the model are listed in table A4.1. The figures correspond to only rough estimates of the average or representative values of these parameters.[45]

Table A4.1 Components of the rate of return to R&D in WorldScan

Total R&D elasticity of TFP growth	γ	0.18
Value share of R&D in total value added (TVR)	$p_R R/p_Y Y$	0.023
Reward for R&D services	p_{RS}	0.12
Deflator of value added	p_Y	1
Investment price of R&D	p_R	1

The rate of return can then be calculated as:

$$r = \gamma \frac{Y}{R} = \gamma \frac{p_Y Y}{p_R R} \frac{p_{RS}}{p_Y} = 0.18 \frac{1}{0.023} 0.12 \approx 0.94$$

Equation A4.2 gives the gross rate of return, i.e. it does not correct for depreciation.

[45] For example, for the value share of R&D, we list the average macro value share in the calibration year. As shown in the main text, this share differs across countries and in addition, also varies over time.

This rate of return may be interpreted as an internal rate of return.[46] To see this, consider the following situation: In period $t=0$, R&D expenditures rise by $\Delta(p_R R)$. We assume that the prices of both value added and R&D remain constant and equal to one. In the absence of depreciation, the R&D stock rises by ΔR in response to this increase R&D expenditures. Suppose this raises value added in all future periods $t=1...\infty$ by an equal amount ΔY. Finally, assume that social preferences can be captured by a constant discount factor $0 < \rho < 1$. The present value of the additional value added generated by the increase in R&D expenditures in period $t=0$ equals:

$$PV = \sum_{t=1}^{\infty} \rho^t \Delta Y = \frac{\rho}{1-\rho} \Delta Y \tag{A5.3}$$

If we interpret r as a social rate of time preference, which relates to the social discount factor as $\rho = 1 / (1+r)$, we find:

$$PV = \frac{1}{r} \Delta R \tag{A5.4}$$

r thus equals the internal rate of return for the additional R&D expenditures. If r is the social rate of time preference that equates the present value of the costs of the expenditures to the present value of the benefits, we can find its value by the following equation:

$$\frac{1}{r} \Delta Y = \Delta R \tag{A5.5}$$

where the present value of the cost simply equals to the increase in the R&D stock ΔR. Rearranging terms and letting the time interval become infinitely small gives the familiar equation:

$$r = \frac{\partial Y}{\partial R} \tag{A5.1}$$

The social rate of return produced by WorldScan falls in the high end of the spectrum found in the empirical literature (see box A4.1). Compared to internal rates of return on more conventional investments which would lie at around 5%, the social return on an R&D investment is an eighteenth fold. However, there is some flexibility on this point in the application of WorldScan. For example, previous exercises with the R&D version of WorldScan (e.g. Gelauff and Lejour (2006)) have calculated both an upper bound scenario

[46] This paragraph draws heavily from Shanks and Zheng (2006).

using the current specification of the model and a lower bound scenario in which the parameters concerning the spillovers in equation (2.6) were adjusted downward resulting in a lower overall R&D elasticity of TFP, such that the social return to R&D correspondingly decreased.

Box A4.1 Empirical evidence

The table presents the main conclusions from two reviews on the empirical evidence of the rate of return to R&D. The first review is by Nadiri (1993) citing studies from the 1980s and early 1990s, while the second review by Dowrick (2003) incorporates mainly studies from the 1990s and the early years of the 21th century. As can be seen in table below, there is a remarkable extent of agreement in the main conclusions of the two reviews. Both authors cite point estimates that show a considerable extent of variation. The overall range for both the private and social returns to R&D is very similar for both reviews. The returns on R&D are generally higher as the aggregation level of the data rises, reflecting the presence of spillovers. Thus estimates based on macro-level data are commonly considered to measure social returns to R&D, while the studies using micro-level data only measure the private (excess) returns to R&D. The private return to R&D is generally found to be about 20-40%. The social return is much higher and reaches up to 100%. The rate of return in WorldScan of 90% on the macro-level falls at the high end of the spectrum cited in both reviews.

Reviews of the empirical literature

	Macro-level data	Micro-level data	
Nadiri (1993)	20-100%	20-40%	
Dowrick (2003)	50-100%	20-30%	(excluding spillovers)
		30-40%	(including spillovers)