How to close the productivity gap between the US and Europe

A quantitative assessment using a semi-endogenous growth model*

PRELIMINARY VERSION

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Abstract

This paper uses a semi-endogenous growth model to identify possible sources for the productivity and knowledge investment gap between the EU and the US. The framework allows us to explain differences in productivity and R&D spending levels in terms of differences in taxation, subsidies to R&D, mark ups, entry barriers, the skill composition and efficiency of the labour force. The paper tries to provide a ranking of the relative importance of these factors for explaining the productivity gap. The analysis shows that goods market competition and entry barriers for innovative firms are likely to be important explanatory factors for both a lower productivity and a lower R&D share in the EU compared to the US. The paper also shows that in the light of endogenous growth models mark up estimates must be interpreted carefully as measures of competition. In particular one should control for possible fixed costs arising from R&D investment of firms.

Keywords: productivity differences, endogenous growth, R&D, market structure, skill composition, dynamic general equilibrium modelling

JEL classification: E10, O20, O30, O41

1 Introduction

In the post war period Western Europe has caught up with the US in terms of productivity. This process came to an end in the mid 90s. Since then the productivity gap to the US remained fairly stable at around 10%. This can be seen as evidence of conditional convergence, i. e. European institutions, technologies and endowments prevent full convergence of productivity levels. There has been a long debate how this gap in productivity and employment could possibly be explained.

*This paper has benefited from comments received at the ECARES seminar at the ULB in Brussels and at the OECD seminar on Productivity Comparisons in Paris. The views presented in this paper are those of the authors and not necessarily those of the European Commission.

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Roughly speaking, there are two alternative explanations. There is a sizeable literature which blames product market regulations - leading to higher mark ups of prices over marginal cost - as a major reason for the income gap. In a recent simulation exercise Bayoumi et al. (2004) estimates that increasing competition in the goods market to US levels could increase GDP per capita by about 7% and employment by about 3%. Another literature blames differences in knowledge investment as a source of the productivity gap. The US is spending a larger share of its GDP on R&D and employs more skilled labour. If one applies standard estimates on the social return to R&D, increasing R&D spending to US levels could considerably narrow the productivity gap. For example, recent estimates by Bayar (2007) suggest this could actually close the productivity gap. Unfortunately these two explanations are somewhat separated. So far there is little attempt to look at market imperfections and knowledge investment simultaneously in the literature using general equilibrium models, even though current endogenous growth models suggest various links. That such a link exists is also confirmed by various regression studies analysing the link between productivity and regulation using panel data for industrial countries as presented recently, for example, by Nicoletti and Scarpetta (2005), Aghion et al. (2007) or European Commission (2007). It is suggested in this paper that these studies could be complemented by a model based analysis which could provide a more detailed view on the transmission mechanisms. This paper therefore makes an attempt to disentangle the impact of market structure, technology, endowments and policies for an explanation of the gap in productivity and knowledge investment between Europe and the US by using an endogenous growth model.

In this exercise we make use on a wealth of empirical evidence which has been gathered in recent years on differences in institutions, technologies, endowments and policies between Europe and the US. Concerning goods markets we concentrate on mark up differences which we take as indicators for the degree of product market competition as well as evidence on entry barriers. Concerning technological differences we make use of empirical estimates of knowledge production parameters as presented by Coe and Helpman (1995) and Bottazzi and Peri (2007). Differences in endowments in both economies are measured by using information on the skill composition of the labour force. When it comes to policies we look at labour taxation and R&D subsidies.

A choice has to be made on the type of endogenous growth model we want to use for this exercise. Aghion and Howitt (2006) distinguish three main endogenous growth paradigms. The first version is the AK-theory, which is a neoclassical growth model without imposing diminishing returns on capital. The second version of endogenous growth models followed the product-variety paradigm (see Romer (1990)) in which innovation generates endogenous productivity growth by creating new varieties of products. The third paradigm arises from industrial organization theory (see Aghion and Howitt (1992, 1998)), and it is commonly referred to as "Schumpeterian" growth theory. This paradigm involves the Schumpeterian notion of creative destruction via focusing on quality improving innovations which forces obsolete products out of the market. Recent models of directed technological change developed in Acemoglu (1998, 2002 and 2007) can be considered as new paradigm in which the direction of technological change is also endogenized.

The product-variety paradigm along with some earlier R&D based models in the literature shares the prediction of empirically unjustified scale-effects: if the level of resources devoted to R&D - for instance measured by the number of scientists engaged in R&D - is doubled, then the per capita growth rate of output should also double in the steady state. Jones (1995, 2005) offers an alternative setting for the product-variety paradigm, a semi-endogenous growth model which is free from the inconsistent scale-effects. In this paper we extend the Jones model to capture the endogenous development of R&D. The preference for semi-endogenous growth models to fully endogenous structures is also supported by Bottazzi and Peri (2007) which favours semi-endogenous models of growth which imply weak scale effects. In addition to the R&D framework, our model also includes the disaggregation of labour into three skill-groups (low-, medium,- and high-skilled) in order to capture differences in human capital endowments.

The paper is structured as follows. In section one we describe the model, section two provides details on the calibration. Section three presents the simulation results to identify the possible sources for the productivity gap between the EU and the US and the final section concludes.

2 Model

The model economy is populated by households, final and intermediate goods producing firms, a research industry, a monetary and a fiscal authority. In the final goods sector firms produce differentiated goods which are imperfect substitutes for goods produced abroad. Final good producers use a composite of intermediate goods and three types of labour - (low-, medium-, and high-skilled). Households buy the patents of designs produced by the R&D sector and license them to the intermediate goods producing firms. The intermediate sector is composed of monopolistically competitive firms which produce intermediate products from rented capital input using the designs licensed from the household sector. The production of new designs takes place in research labs, employing high skilled labour and making use of the existing stock of ideas. Technological change is modelled as increasing product variety in the tradition of Dixit and Stiglitz (1977).

2.1 Households

The household sector consists of a continuum of households $h \in [0, 1]$. A share $(1 - \epsilon)$ of these households are not liquidity constrained and indexed by $i \in [0, 1 - \epsilon]$. They have access to financial markets where they can buy and sell domestic and foreign assets (government bonds), accumulate physical capital which they rent out to the intermediate sector, and they also buy the patents of designs produced by the R&D sector and license them to the intermediate goods producing firms. Non-liquidity constrained households offer medium and high skilled labour services indexed by $s \in \{M, H\}$. The remaining share ϵ of households is liquidity constrained and indexed by $k \in [1 - \epsilon, 1]$. These households can not trade in financial and physical assets and consume their disposable income each period. Members of liquidity constrained households offer low-skilled labour services only. For each skill group we assume that households supply differentiated labour services to unions which act as wage setters in monopolistically competitive labour markets. The unions pool wage income and distribute it in equal proportions among their members. Nominal rigidity in wage setting is introduced by assuming that the households face adjustment costs for changing wages.

2.1.1 Non liquidity constrained households (medium-, and high-skilled)

Each non liquidity constrained household maximise an intertemporal utility function in consumption and leisure subject to a budget constraint. These households makes decisions about consumption (C_t^i), and labour supply (L_t^i), investments into domestic and foreign financial assets (B_t^i and $B_t^{F,i}$), the purchases of investment good (J_t^i), the renting of physical capital stock (K_t^i), the purchases of new patents from the R&D sector $(J_t^{A,i})$, and the licensing of existing patents (A_t^i), and receives wage income (W_t^i), unemployment benefits ($b_t^s W_t^{i,s}$)[1], transfer income from the government (TR_t^i),and interest income (i_t, i_t^K and i_t^A). Hence, non-liquidity constrained households face with the following Lagrangian

$$\max_{\left\{\begin{array}{l} C_t^i, L_t^i, B_t^i \\ B_t^{F,i}, J_t^i, K_t^i \\ J_t^{A,i}, A_t^i \end{array}\right\}_{t=0}^{\infty}} V_0^i = E_0 \sum_{t=0}^{\infty} \beta^t \left(U(C_t^i) + \sum_s V(1 - L_t^{i,s}) \right) \tag{1}$$

$$-E_0 \sum_{t=0}^{\infty} \lambda_t^i \beta^t \left(\begin{array}{l} (1+t_t^c) P_t^C C_t^i + B_t^i + E_t B_t^{F,i} + P_t^I \left(J_t^i + \Gamma_J(J_t^i) \right) + P_t^A J_t^{A,i} \\ -(1+r_{t-1}) B_{t-1}^i - \left(1 + r_{t-1}^F - \Gamma_{B^F}\left(E_t B_{t-1}^F / Y_{t-1} \right) \right) E_t B_{t-1}^{F,i} \\ -\sum_s (1 - t_t^{w,s}) W_t^{i,s} L_t^{i,s} - b_t^s W_t^{i,s} (1 - NPART_t^{i,s} - L_t^{i,s}) + \Gamma_W(W_t^{i,s}) \\ -(1 - t_{t-1}^K)(i_{t-1}^K - rp_{t-1}^K) P_t^J K_{t-1}^i - t_{t-1}^K \delta^K P_t^I K_{t-1}^i - \tau^K P_t^I J_t^i \\ -(1 - t_{t-1}^K)(i_{t-1}^A - rp_{t-1}^A) P_t^A A_{t-1}^i - t_{t-1}^K \delta^A P_t^A A_{t-1}^i - \tau^A P_t^A J_t^{A,i} \\ -TR_t^i - \sum_{j=1}^n PR_{j,t}^{f,i} - \sum_{j=1}^{A_t} PR_{j,t}^{x,i} \end{array} \right)$$

$$-E_0 \sum_{t=0}^{\infty} \lambda_t^i \xi_t^i \beta^t \left(K_t^i - J_t^i - (1-\delta^K) K_{t-1}^i \right) - E_0 \sum_{t=0}^{\infty} \lambda_t^i \psi_t^i \beta^t \left(A_t^i - J_t^{A,i} - (1-\delta^A) A_{t-1}^i \right)$$

The budget constraints are written in real terms with all prices and wages normalized with P_t, the price of domestic final goods. All firms of the economy are owned by non liquidity constrained households who share the total profit of the final and intermediate sector firms, $\sum_{j=1}^n PR_{j,t}^{f,i}$ and $\sum_{j=1}^{A_t} PR_{j,t}^{x,i}$, where n and A_t denote the number of firms in the final and intermediate sector respectively. As shown by the budget constraints, all households pay t_t^w wage income taxes and t_t^Kcapital income taxes less tax credits (τ^K and τ^A) and depreciation allowances ($t_t^K \delta^K$and $t_t^K \delta^A$) after their earnings on physical capital and patents. There is no perfect arbitrage between different types of assets. When taking a position in the international bond market, the household faces an financial intermediation premium $\Gamma_{B^F}(.)$ which depends on the economy-wide net holdings of internationally traded bonds. Also, when investing into tangible and intangible capital the household requires premia rp_t^K and rp_t^A in order to cover the increased risk on the return related to these assets. The real interest rate r_t is equal to the nominal interest rate minus expected inflation: $r_t = i_t - E_t(\pi_{t+1})$.

The utility function is additively separable in consumption (C_t^i) and leisure ($1 - L_t^{i,s}$). We assume log-utility for consumption and allow for habit persistence.

$$U(C_t^i) = (1 - habc) \log \left(C_t^i - habc C_{t-1} \right). \tag{2a}$$

For leisure we assume CES preferences with common labour supply elasticity but a skill specific weight (ω_s) on leisure. This is necessary in order to capture differences in employment levels across skill groups. Thus preferences for leisure is given by

$$V(1 - L_t^{i,s}) = \frac{\omega_s}{1-\kappa} (1 - L_t^{i,s})^{1-\kappa}, \tag{2b}$$

[1]Notice, the households only make a decision about the level of employment but there is no distinction on the part of households between unemployment and non participation. It is assumed that the government makes a decision how to classify the non working part of the population into unemployed and non participants. The non participation rate $NPART$ must therefore be seen as a policy variable characterising the generosity of the benefit system.

with $\kappa > 0$.

The investment decisions w.r.t. real capital are subject to convex adjustment costs , which are given by

$$\Gamma_J(J_t^i) = \frac{\gamma_K}{2}\frac{\left(J_t^i\right)^2}{K_{t-1}^i} + \frac{\gamma_I}{2}(\Delta J_t^i)^2. \tag{3}$$

Wages are also subject to convex adjustment costs given by

$$\Gamma_W(W_t^{i,s}) = \sum_s \frac{\gamma_W L_t^{i,s}}{2}\frac{\left(\Delta W_t^{i,s}\right)^2}{W_{t-1}^{i,s}}. \tag{4}$$

Consumption (C^i) and investment (I^i) is itself an aggregate of domestic and foreign varieties of final goods, with preferences expressed by the following CES utility function

$$Z^i = \left[(1-s^M)^{\frac{1}{\sigma}} Z^{d^i \frac{\sigma-1}{\sigma}} + s^{M\frac{1}{\sigma}} Z^{f^i \frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{5a}$$

with $Z^i \in \left\{C^i, I^i\right\}$ and Z^{d^i} and Z^{f^i} are indexes of demand across the continuum of differentiated goods produced respectively in the domestic economy and abroad, given by

$$Z^{d^i} = \left[\sum_{h=1}^{n}\left(\frac{1}{n}\right)^{\frac{1}{\sigma^d}} Z_h^{d^i \frac{\sigma^d-1}{\sigma^d}}\right]^{\frac{\sigma^d}{\sigma^d-1}}, \quad Z^{f^i} = \left[\sum_{h=1}^{m}\left(\frac{1}{m}\right)^{\frac{1}{\sigma^m}} Z_h^{f^i \frac{\sigma^m-1}{\sigma^m}}\right]^{\frac{\sigma^m}{\sigma^m-1}}. \tag{5b}$$

We denote with P^C the corresponding utility based deflator for the C and J aggregate. The first order conditions of the household with respect to consumption, financial and real assets are given by the following equations:

$$\frac{\partial V_0}{\partial C_t^i} => U_{C,t}^i - \lambda_t^i(1+t_t^c)P_t^C = 0 \tag{6a}$$

$$\frac{\partial V_0}{\partial B_t^i} => -\lambda_t^i + E_t\left(\lambda_{t+1}^i \beta\left(1+r_t\right)\right) = 0 \tag{6b}$$

$$\frac{\partial V_0}{\partial B_t^{F,i}} => -\lambda_t^i + E_t\left(\lambda_{t+1}^i \beta\left(1+r_t^F - \Gamma_{B^F}\left(E_t B_t^F/Y_t\right)\right) E_{t+1}/E_t\right) = 0 \tag{6c}$$

$$\frac{\partial V_0}{\partial K_t^i} => -\lambda_t^i\xi_t^i + E_t\left(\lambda_{t+1}^i\xi_{t+1}^i\beta(1-\delta) + \lambda_{t+1}^i\beta\left((1-t_t^K)(i_t^K - rp_t^K) + t_t^K\delta^K\right)P_{t+1}^C\right) = 0 \tag{6d}$$

$$\frac{\partial V_0}{\partial J_t^i} => -\lambda_t^i P_t^C\left(1+\gamma_K\left(\frac{J_t^i}{K_{t-1}^i}\right) + \gamma_I\Delta J_t^i - \tau^K\right) + E_t\left(\lambda_{t+1}^i\beta P_{t+1}^C\gamma_I\Delta J_{t+1}^i\right) + \lambda_t^i\xi_t^i = 0. \tag{6e}$$

All arbitrage conditions are standard, except for a trading friction ($\Gamma_{B^F}(.)$) on foreign bonds, which is modelled as a function of the ratio of assets to GDP. Using the arbitrage conditions and neglecting the second order terms, investment is given as a function of the variable Q_t

$$Q_t - 1 = \gamma_K\left(\frac{J_t^i}{K_{t-1}^i}\right) + \gamma_I\Delta J_t^i - \tau^K - E_t\left(\frac{\gamma_I\Delta J_{t+1}^i}{1+i_t-\pi_{t+1}^C}\right) \tag{7a}$$

with $Q_t = \frac{\xi_t}{P_t^C}$, where Q_t is the present discounted value of the rental rate of return from investing in real assets

$$Q_t = E_t \left(\frac{1-\delta}{1+i_t-\pi_{t+1}^C} Q_{t+1} + \frac{(1-t_t^K)(i_t^K - rp_t^K) + t_t^K \delta^K}{1+i_t-\pi_{t+1}^C} \right). \tag{7b}$$

Notice, the relevant discount factor for the investor is the nominal interest rate adjusted by the trading friction minus the expected inflation of investment goods (π_{t+1}^C).

Non-liquidity constrained households buy new patents of designs produced by the R&D sector (I_t^A) and rent their total stock of design (A_t) at rental rate i_t^A to intermediate goods producers in period t. Households pay income tax at rate t_t^Kon the period return of intangibles and they receive tax subsidies at rate τ^A. Hence, the first order conditions with respect to R&D investments are given by

$$\frac{\partial V_0}{\partial A_t^i} => -\lambda_t^i \psi_t^i + E_t \left(\lambda_{t+1}^i \psi_{t+1}^i \beta (1-\delta^A) + \lambda_{t+1}^i \beta \left((1-t_t^K)(i_t^A - rp_t^A) + t_t^K \delta^A \right) P_{t+1}^A \right) = 0 \tag{7c}$$

$$\frac{\partial V_0}{\partial J_t^{A,i}} => -\lambda_t^i P_t^A \left(1-\tau^A\right) + \lambda_t^i \psi_t^i = 0 \tag{7d}$$

Therefore the rental rate can be obtained from (6b), (7c) and (7d) after neglecting the second order terms:

$$i_t^A \approx \frac{(1-\tau^A)\left(i_t - \pi_{t+1}^A + \delta^A\right) - t_t^K \delta^A}{(1-t_t^K)} + rp_t^A \tag{7c'}$$

where $1+\pi_{t+1}^A = \frac{P_{t+1}^A}{P_t^A}$.

Equation (7c') states that household require a rate of return on intangible capital which is equal to the nominal interest rate minus the rate of change of the value of intangible assets and also covers the cost of economic depreciation plus a risk premium. Governments can affect investment decisions in intangible capital by giving tax incentives in the form of tax credits and depreciation allowances or by lowering the tax on the return from patents.

2.1.2 Liquidity constrained households

Liquidity constrained households do not optimize but simply consume their current income at each date. Real consumption of household k is thus determined by the net wage income plus net transfers

$$(1+t_t^c) P_t^C C_t^k + \sum_s \frac{\gamma_W L_t^{k,L}}{2} \frac{\left(\Delta W_t^{k,L}\right)^2}{W_{t-1}^{k,L}} = \sum_s \left(\left(1-t_t^{w,L}\right) W_t^{k,L} L_t^{k,L} + b_t^L W_t^{k,L} (1 - NPART_t^{k,L} - L_t^{k,L}) \right) + TR_t^k. \tag{8}$$

Wage setting Within each skill group a variety of labour services are supplied which are imperfect substitutes to each other. Thus trade unions can charge a wage mark-up ($1/\eta_t^W$) over the reservation wage[2].

[2] The mark-up depends on the intratemporal elasticity of substitution between different types of labour σ_s and fluctuations in the mark-up arise because of wage adjustment costs and the fact that a fraction $(1-sfw)$ of workers is indexing the growth rate of wages π^w to wage inflation in the previous period $\eta_t^w = 1 - 1/\sigma_s - \gamma_W/\sigma_s \left[\beta(sfw\pi_{t+1}^w - (1-sfw)\pi_{t-1}^w) - \pi_t^w\right]$.

The reservation wage is given as the marginal utility of leisure divided by the corresponding marginal utility of consumption. The relevant net real wage to which the mark up adjusted reservation wage is equated is the gross wage adjusted for labour taxes, consumption taxes and unemployment benefits which act as a subsidy to leisure. Thus the wage equation is given as

$$\frac{U_{1-L,t}^{h,s}}{U_{C,t}^{h,s}}\frac{1}{\eta_t^W} = \frac{W_t^s(1-t_t^{w,s}-b_t^s)}{(1+t_t^C)P_t^C} \text{ for } h \in \{i,k\} \text{ and } s \in \{L,M,H\}. \tag{9}$$

Aggregation The aggregate of any household specific variable X_t^h in per capita terms is given by

$$X_t = \int_0^1 X_t^h dh = (1-\epsilon)\, X_t^i + \epsilon X_t^k, \tag{10}$$

Hence aggregate consumption and employment is given by

$$C_t = (1-\epsilon)\, C_t^i + \epsilon C_t^k \tag{11}$$

and

$$L_t = (1-\epsilon)\, L_t^i + \epsilon L_t^k. \tag{12}$$

Firms

2.1.3 Final output producers

Since each firm j ($j = 1, ..., n$) produces a variety of the domestic good which is an imperfect substitute for the varieties produced by other firms, it acts as a monopolistic competitor facing a demand function with a price elasticity given by σ^d. Final output (Y^j) is produced using A varieties of intermediate inputs (x) with an elasticity of substitution $1/(1-\theta)$. The final good sector uses a labour aggregate and intermediate goods in a Cobb-Douglas technology, subject to a fixed cost FC

$$Y^j = \left(L_{Y,t}^j\right)^\alpha \left(\sum_{i=1}^{A_t}\left(x_{i,t}^j\right)^\theta\right)^{\frac{1-\alpha}{\theta}} - FC, \quad 0<\theta<1 \tag{13}$$

with

$$L_{Y,t} = \left(s_L^{\frac{1}{\sigma_L}}\left(ef_L L_t^L\right)^{\frac{\sigma_L-1}{\sigma_L}} + s_M^{\frac{1}{\sigma_L}}\left(ef_M L_t^M\right)^{\frac{\sigma_L-1}{\sigma_L}} + s_{H,Y}^{\frac{1}{\sigma_L}}\left(ef_H L_t^{HY}\right)^{\frac{\sigma_L-1}{\sigma_L}}\right)^{\frac{\sigma_L}{\sigma_L-1}}. \tag{14}$$

Parameter s_s is the population share of labour-force in subgroup s (low-, medium- and high-skilled), L^s denotes the employment rate of population s, ef_s is the corresponding efficiency unit, and σ_L is the elasticity of substitution between different labour types. Note that high-skilled labour in the final goods sector, L_t^{HY}, is the total high-skill employment minus the high-skilled labour working for the R&D sector ($L_{A,t}$). The employment aggregates L_t^s combine varieties of differentiated labour services supplied by individual household

$$L_t^s = \left[\int_0^1 \left(L_t^{s,h}\right)^{\frac{\sigma_s-1}{\sigma_s}} dh\right]^{\frac{\sigma_s}{\sigma_s-1}}. \tag{15}$$

The parameter $\sigma_s > 1$ determines the degree of substitutability among different types of labour. The above production function employs the idea of product variety framework proposed by Dixit and Stiglitz (1977) and applied in the literature of international trade and R&D diffusion[3], and we will explicitly model the underlying development of R&D by the semi-endogenous framework of Jones (1995 and 2005Jones (2005))[4].

The objective of the firm is to maximise profits

$$PR_t^{f,j} = P_t^j Y_t^j - \left(W_t^L L_t^{j,L} + W_t^M L_t^{j,M} + W_t^H L_t^{j,HY} \right) - \sum_{i=1}^{A_t} \left(px_{i,t} x_{i,t}^j \right), \tag{16}$$

where $px_{i,t}$ and $x_{i,t}^j$ are the price and volume of intermediate inputs and W_t^s is a wage index corresponding to the CES aggregate $L_t^{j,s}$. All prices and wages are normalized with P_t, the price of domestic final goods. In a symmetric equilibrium, the demand for labour and intermediate inputs is given by

$$\alpha \frac{Y_t}{L_{Y,t}} \left(\frac{L_{Y,t}}{L_t^s} \right)^{\frac{1}{\sigma_L}} s_s^{\frac{1}{\sigma_L}} ef_s^{\frac{\sigma_L - 1}{\sigma_L}} \eta_t = W_t^s, \quad s \in \{L, M, H\} \tag{17a}$$

$$px_{i,t} = \eta_t (1-\alpha) Y \left(\sum_{i=1}^{A_t} \left(x_{i,t}^j \right)^{\theta} \right)^{-1} \left(x_{i,t} \right)^{\theta - 1} \tag{17b}$$

where $\eta_t = 1 - 1/\sigma^d$.

2.2 Intermediate goods producers

The intermediate sector consists of monopolistically competitive firms which have entered the market by licensing a design from domestic households and by making an initial payment FC_A to overcome administrative entry barriers. Capital inputs are also rented from the household sector for a rental rate of i_t^K. Firms which have acquired a design can transform each unit of capital into a single unit of an intermediate input. In a symmetric equilibrium, the respective inverse demand functions of intermediate goods producing firms are given as (17b).

Each intermediate firm solves the following profit-maximisation problem

$$PR_{i,t}^x = \max_{x_{i,t}} \left\{ px_{i,t} x_{i,t} - i_t^K P_t^C k_{i,t} - i^A P_t^A - FC_A \right\}. \tag{18}$$

Subject to a linear technology which allows to transform one unit of capital (k_i) into one unit of an intermediate good

$$x_i = k_i. \tag{19}$$

In a symmetric equilibrium the first order condition is

$$\theta \eta_t (1-\alpha) Y \left(\sum_{i=1}^{A_t} \left(x_{i,t}^j \right)^{\theta} \right)^{-1} \left(x_t \right)^{\theta - 1} = i_t^K P_t^C \tag{20a}$$

[3] See Grossman and Helpman (1991) and Aghion and Howitt (1998).

[4] Butler and Pakko (1998) also applied Jones (1995) semi-endogenous growth framework to examine the effect of endogenous technological change on the properties of a real business cycle model without skill disaggregation.

Intermediate goods producers set prices as a mark up over marginal cost. Therefore prices for the domestic market are given by:

$$PX_t = px_{i,t} = \frac{i_t^K P_t^C}{\theta} \tag{20b}$$

The no-arbitrage condition requires that entry into the intermediate goods producing sector takes place until

$$PR_{i,t}^x = PR_t^x = i_t^A P_t^A + r_t FC_A, \quad \forall i \tag{20c}$$

or equivalently, the present discounted value of profits is equated to the fixed entry costs plus the net value of patents

$$P_t^A \frac{1}{1 - t_t^K \left(1 - \delta^A\right) + \tau^A} + FC_A = \sum_{\tau=0}^{\infty} \prod_{j=0}^{\tau} \left(\frac{1}{1 + r_{t+j}}\right) PR_{t+\tau}^x. \tag{20d}$$

For an intermediate producer, entry costs consist of the licensing fee $i_t^A P_t^A$ for the design or patent which is a prerequisite of production of innovative intermediate goods and a fixed entry cost FC_A.

2.3 R&D sector

Innovation corresponds to the discovery of a new variety of producer durables that provides an alternative way of producing the final good. The R&D sector hires high-skilled labour (L_A) and generates new designs according to the following knowledge production function:

$$\Delta A_t = \nu A_{t-1}^{*\varpi} A_{t-1}^{\phi} L_{A,t}^{\lambda}. \tag{21}$$

In this framework we allow for international R&D spillovers following Bottazzi and Peri (2007). Parameters ϖ and ϕ measure the foreign and domestic spillover effects from the aggregate international and domestic stock of knowledge (A^* and A) respectively. Negative value for these parameters can be interpreted as the "fishing out" effect, i.e. when innovation decreases with the level of knowledge, while positive values refer to the "standing on shoulders" effect and imply positive research spillovers. Note that $\phi = 1$ would give back the strong scale effect feature of fully endogenous growth models with respect to the domestic level of knowledge. Parameter ν can be interpreted as total factor efficiency of R&D production, while λ measures the elasticity of R&D production on the number of researchers (L_A). The international stock of knowledge grows exogenously at rate g_{A^w}. We assume that the R&D sector is operated by a research institute which employs high skilled labour at their market wage W^H. We also assume that the research institute faces an adjustment cost of hiring new employees and maximizes the following discounted profit-stream:

$$\max_{L_{A,t}} \sum_{t=0}^{\infty} d_t \left(P_t^A \Delta A_t - W_t^H L_{A,t} - \frac{\gamma_A}{2} W_t^H \Delta L_{A,t}^2\right) \tag{22}$$

therefore the first order condition implies:

$$\lambda P_t^A \frac{\Delta A_t}{L_{A,t}} = W_t^H + \gamma_A \left(W_t^H \Delta L_{A,t} - d_t W_{t+1}^H \Delta L_{A,t+1}\right) \tag{23}$$

where d_t is the discount factor.

2.4 Trade and the current account

The economies trade their final goods. The elasticity of substitution between bundles of domestic and foreign goods Z^{d^i} and Z^{f^i} is σ. Thus aggregate imports are given by

$$IM_t = s^M \left(\frac{P_t^C}{P_t^{IM}}\right)^{\sigma} (C_t + I_t + G_t) \tag{24}$$

and there is producer pricing of imports and exports.

$$P_t^{EX} = P_t \tag{25}$$

and

$$P_t^{IM} = E_t P_t^*. \tag{26}$$

Thus net foreign assets evolve according to

$$E_t B_t^F = (1 + r_t^F) E_t B_{t-1}^F + P_t^{EX} EX_t - P_t^{IM} IM_t \tag{27}$$

2.5 Policy

On the expenditure side we assume that government consumption, government transfers and government investment are proportional to GDP and unemployment benefits are indexed to wages as follows

$$BEN_t = \sum_s b_t^s W_t^s (1 - NPART_t^s - L_t^s), \tag{28}$$

where the benefit replacement rate b_t^s can be indexed to consumer prices and net wages in different degrees according to the following rule

$$b_t^s = \hat{b}_t^s \left[(1 + t_t^C) P_t^C\right]^{\chi^c} (1 - t_t^{W^{\chi^w}}), \quad 0 \leq \chi^c, \chi^w \leq 1. \tag{29}$$

The government provides subsidies (S_t) on physical capital and R&D investments in the form of a tax-credit and depreciation allowances

$$S_t = t_{t-1}^K \left(\delta^K P_t^I K_{t-1}^{i,H} + \delta^A P_t^A A_{t-1}^{i,H}\right) + \tau^K P_t^I J_t^{i,H} + \tau^A P_t^A J_t^{A,i,H}. \tag{30}$$

Government revenues R_t^G are made up of taxes on consumption as well as capital and labour income. Government debt (B_t) evolves according to

$$B_t = (1 + r_t) B_{t-1} + P_t^C G_t + TR_t + BEN_t + S_t - R_t^G - T_t^{LS}. \tag{31}$$

There is a lump-sum tax (T_t^{LS}) used for controlling the debt to GDP ratio according to the following rule

$$\Delta T_t^{LS} = \tau^B \left(\frac{B_{t-1}}{Y_{t-1} P_{t-1}} - b^T\right) + \tau^{DEF} \Delta \left(\frac{B_t}{Y_t P_t}\right), \tag{32}$$

where b^T is the government debt target.

2.6 Determinants of the long run level of labour productivity

Unfortunately this model is too complicated to allow for an analytical solution of the steady state level of productivity. However some insights can be gained from a simplified version which abstracts from elastic labour supply and skill disaggregation (see the Appendix 1 for a detailed derivation).

The most important determinant of labour productivity in this model is total factor productivity, represented by the variable A. In the steady state, A is a positive function of the amount of labour devoted to research. As shown in the appendix the share of labour devoted to R&D is given by

$$s_{L,A/Y}(\underset{(0)}{mp_f}\underset{(+)}{mp_i}, \underset{(-)}{\alpha}, \underset{(-)}{fc_a}, \underset{(+)}{g_A}, \underset{(+)}{n}, \underset{(-)}{\tau}) = \frac{\lambda\left(1-\frac{1}{1+mp_i}\right)(1-\alpha)(1-\tau)g_A}{\alpha r - (mp_i(1-\alpha)-\alpha)g_A - \alpha n}\frac{1}{1+fc_a}. \tag{33}$$

Concerning goods market conditions eq. (33) shows that the TFP effects depend very much on the goods market condition in the intermediate production sector, while mark ups in the final goods sector do not have an impact on the allocation of resources into R&D.

Eq. (33) suggests that a shift of resource towards R&D requires an increase of the mark up in intermediate production. In the intermediate sector positive mark ups are required to cover the fixed costs associated with the acquisition of a patent which is a prerequisite for market entry. What is relevant for entry of new firms is the size of profits, which is a positive function of the mark up and the scale of production (i. e. it is inversely related to the number of intermediate producers). Why does a reduction in the mark up in final goods production not lead to an increase in A? The reason is that there are various opposing forces at work. First increased competition in the final goods sector increases demand for intermediates and for labour. This increases profits in the intermediate sector but it also increases the price of patents because of an increase in wages. The net result is that each incumbent firm is increasing production of the intermediate good but there is no additional entry. Thus increasing competition in the final goods sector also increases productivity, however this occurs via an increase in capital intensity and not via an increase in TFP (see Appendix 1, eqs. A23 and A24).[5] As can also be seen from eq. (33), a reduction in entry barriers (fc_a) and an increase in R&D subsidies (τ) shifts labour from production into research.

3 Identifying structural differences between the EU and the US

3.1 Goods Market

We identify the final goods sector as the service sector and the intermediate sector as the manufacturing sector. The manufacturing sector resembles the intermediate sector along various dimensions. First, this sector is more R&D and patent intensive, second, a large fraction of manufacturing supplies innovative goods (in the form of investment goods but also innovative consumer goods). Services on the other hand are typically not subject to large (patented) innovations but are subject to organisational changes possibly in relation to new technologies supplied by the manufacturing sector. A good example in this respect is the ICT investment driven productivity increase in retail, wholesale trade and banking in some countries, notably the US. Also the two sectors differ in the

[5] As shown in the appendix, decreasing the final goods mark-up will always lead to higher output per capita, however the effect of intermediate mark-ups is not straightforward.

degree of competition, with manufacturing showing smaller mark ups compared to services. For calculating mark ups we use a method suggested by Roeger (1995). There are marked differences between the US and the EU. We find substantially higher mark ups in services in the EU (24% vs. 20%) while mark ups in manufacturing are slightly lower in the EU (11% vs. 12%). Similar results but with even stronger differences in manufacturing industries have been obtained by Christopoulou and Vermeulen (2008). The results on cross country differences in the level of mark ups are interesting since they suggest a positive link between the level of mark ups and R&D investment as suggested by our model. This comes out even clearer in earlier work by Oliveira Martins and Price (2004) which shows that sectors with high R&D intensities tend to have higher mark ups. Again the US shows up in the group of countries with the highest mark ups.

It is a stylised fact that product markets are more regulated in the EU compared to the US. Recent evidence can be found in Hoj et al. (2007). Section 1 of this paper stresses especially entry barriers in the intermediate goods (manufacturing) sector as being detrimental for innovative activities. To our knowledge estimates on entry barriers for specific sectors do not exist. Therefore we rely on the aggregate estimates provided by Djankov et al. (2002). These estimates are particularly useful since they provide directly quantifiable evidence on costs of procedures and time that a start-up must bear before the firm can operate legally. This information can be directly used for the calibration of the entry cost parameter in the model. The average entry cost per firm is estimated to be around 66 percent of GDP per capita in the whole sample. Their calculations show that the European countries impose 2 to 60 times higher entry costs than the US. Based on the Djankov et al. (2002) methodology Kox (2005) re-estimated the start-up costs for the EU. He estimates the EU average entry cost of setting up a standard firm at 57.3 percent of per capita GDP and only to 1.6% for the US. Cross country variation is large and ranges from 4.5 percent of per capita GDP for the UK to 1.83 times per capita GDP in Hungary.

3.2 Financial markets

It is a well known fact that the US has a more developed market for risk capital. In fact venture capital financing of innovative start ups was invented in the US (see Bottazzi and Rin (2002)). Even though venture capital financing has also become popular in the US it still only amounts to .12% of GDP compared to.19% in the US[6]. There are various studies indicating that access to finance for innovating firms are easier in the US. A recent study by Aghion et al. (2007) even concludes that financial constraints related to entry could be as important as labour market rigidities in terms of obstacles to growth. Unfortunately, the available indicators on financial market developments cannot easily be translated into quantitative measures of differences in risk premia[7]. However we can use the model together with all the other observable information to calculate a risk premium. Using the free entry condition (eq 20c) and eliminating P_t^A by using the definition of the R&D share allows us to express the risk premium as

$$rp_t^A = \left(\eta\,(1-\theta)\,(1-\alpha)\frac{Y_t}{A_t} - r_t FC_A\right)\frac{g_A A_{t-1}}{rdi_t P_Y Y_t} - \frac{(1-\tau^A)(i_t - \pi_{t+1}^A + \delta^A) - t^K\delta^A}{(1-t^K)},$$

[6] These figures are calculated as an average over the period 2004-2006 (source: Meyer (2008)). Notice however, some countries in the EU, notably those with a high tech specialisation such as the UK, Sweden and Denmark have a share of venture capital investment that exceeds that of the US. However high tech states in the US such as California have VC investment shares far larger than EU regions.

[7] Alternatively the risk premium can also be interpreted as the shadow price of the collateral constraint for the firm investing in intangible capital.

where rdi_t is the R&D-intensity: total R&D expenditure of the intermediate sector in percentage of GDP. Our calibrated risk-premia for the EU is significantly higher then the one obtained for the US (4.7% vs. 2.6%)

3.3 Knowledge production technology

Empirical evidence on output elasticities has recently been provided by Bottazzi and Peri (2007). According to these estimates (see Table 1) the US exhibits a more efficient knowledge production technology as measured by the output elasticity of production workers and the stock of domestic knowledge capital. Nevertheless, the EU can achieve similar TFP growth rates because of higher technology spillover parameters (see the Appendix for a more detailed discussion of the calibration).

3.4 Labour market and the skill composition of the labour force

We use information from DG ECFINs macroeconomic model QUEST III (see Ratto et al. (2006)) to calibrate the labour market in the two regions. The estimates show a higher labour supply elasticity in the case of the US. This together with higher labour taxes and a higher value for leisure in the EU explains a higher employment rate in the US. Labour force is disaggregated into three skill-groups: low-, medium- and high-skilled labour[8]. Data on skill-specific population shares, participation rates and wage-premia are obtained from OECD (2006), the Labour Force Survey and Science and Technology databases of EUROSTAT (EUROSTAT). The elasticity of substitution between different labour types (σ) is one of the major issue addressed in the labour-economics literature. We follow Caselli and Coleman (2006) which analysed the cross-country differences of the aggregate production function when skilled and unskilled labour are imperfect substitutes. The authors argue in favour of using the Katz and Murphy (1992) estimate of 1.4. We set the efficiency of low-skilled at 1 for EU27, the other efficiency units are restricted by the labour demand equations which imply the following relationship between wages, labour-types and efficiency units:

$$ef_m = \left(\frac{w_m}{w_l}\right)^{\frac{\sigma}{\sigma-1}} \left(\frac{s_m L_m}{s_l L_l}\right)^{\frac{1}{\sigma-1}} ef_l$$

$$ef_h = \left(\frac{w_h}{w_m}\right)^{\frac{\sigma}{\sigma-1}} \left(\frac{s_h L_h - L_A}{s_m L_m}\right)^{\frac{1}{\sigma-1}} ef_m$$

We information on the skill composition and wage differentials by skill to determine skill specific efficiencies in the two regions. Note that these efficiencies are proportional to the relative population shares. In order to get comparable efficiency units we must normalize with the population share using the following correction:

$$ef_i^* = ef_i \left(s_i l_i\right)^{\frac{1}{1-\sigma}} .$$

3.5 R&D subsidies and taxes

The empirical evidence provided by Warda (1996 and 2006) indicates an average of 5.7 percentage point higher rate of R&D subsidies for the US based on the B-index.[9] Larger differences can be

[8] We define high skilled workers as that segment of in the labour force that can potentially be employed in the R&D sector, i. e. engineers and natural scientists.

[9] See Appendix 3 for more details on the B-index and how it relates to tax parameters in the model.

found in the case of labour taxation, with substantially higher tax rates in the EU compared to the US.

Table 1: EU - US Parameter Comparison

	EU	US	Source
R&D sector			
L_A	0.010	0.016	EUROSTAT/OECD
R&D intensity (%)	1.840	2.670	EUROSTAT/OECD
λ	0.729	0.860	calibration (constrained by equations)
ϕ	0.531	0.642	Bottazzi-Peri (2007)/Coe-Helpman (1995)
ω	0.447	0.323	Bottazzi-Peri (2007)/Coe-Helpman (1995)
(R&D efficiency)	0.351	0.440	calibration (constrained by equations)
Intermediate sector			
markup	0.11	0.12	ECFIN
risk-premia on intangibles			
(on annual basis)	0.05	0.03	calibration (constrained by equations)
fixed entry costs	0.38	0.02	Djankov et al. (2002)
Final goods sector			
Final good mark up	0.242	0.205	own estimates
Skill distribution			
s_L	0.350	0.121	EUROSTAT/OECD
s_M	0.588	0.803	EUROSTAT/OECD
s_H	0.062	0.076	EUROSTAT/OECD
Employment rates			
L_L	0.572	0.600	EUROSTAT/OECD
L_M	0.744	0.774	EUROSTAT/OECD
L_H	0.837	0.871	EUROSTAT/OECD
σ_L	1.400	1.400	Katz and Murphy (1992)
(elasticity of. substitution)			
L	0.689	0.716	EUROSTAT/OECD
Skill premium %	50.11	72.00	EUROSTAT/OECD
(high vs. medium)			
Skill premium %	23.66	53.84	EUROSTAT/OECD
(medium vs. low)			
Efficiency levels			
ef_L^*	1.000	1.000	calibration (constrained by equations)
ef_M^*	2.103	4.517	calibration (constrained by equations)
ef_H^*	8.175	30.141	calibration (constrained by equations)
Taxes and subsidies			
B-index	0.96	0.89	OECD/Warda (2006)
Labour taxes	0.386	0.306	own estimates
Labour Market			
Labour adjustment cost	18	10	own estimates
(% of total add. wage costs)			
Labour supply elasticity ($1/\kappa$)	1/4	1/.8	own estimates

Table 1 shows that the US has higher employment rates in all three skill categories. In terms of skill composition, the US skill distribution is more tilted towards high skilled workers. The large difference of the corrected efficiencies of high skilled labour between US and EU27 are explained by the almost three times higher skill premiums in the US.

4 Simulation results

This section tries to account for three of the four major stylized differences between the US and the EU, namely the productivity gap, the higher share of R&D spending and the higher skill premium. We put less emphasis on the employment gap. This would require a more careful analysis of the labour market.

4.1 Changing mark ups

Our estimates suggest that the US mark up in manufacturing exceeds the mark up in the EU by 1% point. As shown in Table 2, this difference explains .03% of the productivity gap and .12% of the difference in R&D intensity. Notice, in our framework, mark ups are required to cover fixed costs from innovative activities. Higher mark ups thus stimulate entry of new innovative firms and therefore the demand for R&D. However, higher mark ups and therefore higher prices also exert a negative effect on the demand for incumbents, the demand for physical capital declines. Because of these offsetting effects a change in markup in manufacturing does hardly have any productivity effect. Higher mark ups in US manufacturing do however explain about 10% of the R&D spending gap and a small fraction of the high skilled skill premium (see Table 3). Product market competition in the final goods sector explains a larger fraction of the productivity gap, namely 2.49%. This is mainly due to the larger mark up difference that can be found in services. As discussed in section 2.6, the higher factor demand generated by higher competition in final output production leads primarily to a higher level of physical capital while the long run level of TFP only changes slightly[10] (see Table 4). It is interesting to note that the (nominal) R&D share also increases slightly in this case. This is to a large extent the results from an increase in wages which leads to an increase in the relative price of R&D.

4.2 Reducing administrative start up costs

In this simulation we account for a 95% reduction in EU entry costs. According to our simulations, entry barriers explain a productivity gap of around 1% and about 20% of the lower EU R&D share. Decreasing entry costs lowers the profit requirement for intermediate producers and thus increases entry of new firms. As shown in Table 5, increased demand for patents increases the demand for high skilled worker and leads to some relocation of high skilled workers from production to the R&D sector and an increase in the wage of high skilled workers and thus explains a small fraction of the difference in the skill premium of high skilled workers. Despite the wage increase, the price for patents falls because of a productivity improving effect emanating from higher knowledge capital. Reducing entry barriers is a more efficient way of incrasing productivity and knowledge investment compared to an increase in mark ups because the former does not lead to an nincrease in the price of intermediate goods.

[10] In contrast to the theoretical discussion in section 2.6 and the appendix, there is a slight increase in TFP because increased competition also increases labour supply of high skilled workers.

4.3 Reducing risk premium on intangible capital

The simulation is designed as a 46% reduction in the risk premium of intangible capital. Similar to start up costs, the financial friction constitutes an entry barrier by requiring a higher discount rate for intermediate goods producers. The effects of reducing the risk premium on intangible capital are similar to a reductionn of start up costs. Our calibration suggests that financial frictions are about twixce as important for explaining productivity and knowledge investment differences than administrative start up costs and turn out to be the most important factor for explaining differences in knowledge investment shares between the EU and the US.

4.4 Reducing labour taxes

Reducing labour taxes has important employment effects across all skill groups (see Table 7). Total employment increases by 3.32% The elasticity of employment w. r. t. labour taxation is similar to the estimates obtained by Daveri and Tabellini (2000) The skill premium increases slightly because the labour supply of low skilled increases more strongly than that of high skilled workers (non linearity in the labour supply curve). In contrast to conventional models reducing labour taxes has beneficial long run productivity effects, because the increase in labour supply allows some relocation of high skilled workers in knowledge production. The productivity gap with the US falls by about 1.07% in the long run.

4.5 Skill composition

Table 8 shows the productivity effects of changing the EU skill composition to the US level. The simulation is designed to shift labour from low-skilled to medium-skilled and then from medium to high-skilled while keeping the efficiencies (ef_i^*) unchanged. Changes in the skill composition help in explaining a substantial fraction of the difference in the employment rate between the two countries, while they do not add towards an explanation of the other dimensions. Because an increased supply of skilled workers lowers the skill premium, the skill composition cannot explain the skill premium in this model. A perhps more surprising result is a slight long run deterioration of labour productivity, despite an increase in the efficiency level of the labour force. Notice however, changing the skill composition not only increases the level of efficiency but also labour supply. In the long run there is a terms of trade loss, which increases capital costs and lowers the capital labour ratio. the latter effect sligtly dominates the effect from skill upgrading.

Table 2: US-EU gaps explained by differences in exogenous variables

	Y/L	L	Skill premium high vs. medium	Skill premium medium vs. low	R&D intensity
Lower mark up (final goods)	2.99	0.18	0.30	-0.57	0.06
Increase mark up (intermediates)	0.03	-0.01	1.40	0.00	0.12
Reducing entry barrier	1.07	-0.02	2.38	-0.07	0.20
Reducing risk premia	2.16	-0.02	5.21	0.02	0.45
Reducing labour tax	1.07	3.32	1.45	3.08	-0.01
Skill composition	-0.30	5.05	-3.26	-1.36	-0.01
Efficiencies	2.35	0.80	15.07	25.84	-0.01
R&D subsidies	0.32	0.00	0.67	0.04	0.06
Total*	9.71	9.31	24.10	32.97	0.86
Initial gap	10.00	18.61	22.06	30.01	0.81

4.6 Efficiency upgrading

This simulation is designed to shift the efficiency of EU low, medium- and high-skilled labour (ef_L^*, ef_M^*, ef_H^*) to the corresponding US levels. This explains the bulk of the differences in skill premia between the US and the EU in this model and it also helps to explain about one quarter of the productivity differential between the EU and the US.

4.7 R&D subsidies

Differences between Europe and the US concerning R&D subsidies are small. OECD estimates (see Warda (1996, 2006)) suggest that the subsidy rate for R&D is about 5% points higher in the US. Because of positive externalities associated with R&D investment (in particular due to the positive effect of the knowledge capital stock for R&D output), increasing subsidies in the EU to US levels would further close the productivity gap between Europe and the US and raise the R&D expenditure share (see Table 10).

5 Conclusions

Reaching approximately US levels of productivity and R&D spending are among the most prominent Lisbon targets. This paper uses a semi-endogenous growth model to identify possible sources for the productivity and R&D spending gap between the EU and the US. Identifying the main causes for these differences is a prerequisite for defining possible reform areas which would contribute mostly towards closing the gap. The analysis in this paper suggests that differences in the functioning of product market are the main causes of productivity differentials between the EU and the US. An important obstacle to higher productivity levels are entry barriers in innovating sectors. Reducing them would both increase the R&D share and labour productivity in the long run. Another interesting result is the partial ambiguity between estimated mark ups and innovation. While mark up estimates in the final goods production sector (services) can be seen as indicators of a lack of competition and a reduction of mark ups would consequently increase productivity, the interpretation of mark ups in innovating sectors is more complicated. In these sectors mark ups must be seen as capturing innovation rents and they must therefore be partially seen as the outcome of innovative activities of firms. The factors which explain productivity and knowledge investment differentials between the US and the EU only explain a relatively minor fraction of the difference in the skill premium. Other factors, especially differences in efficiency levels of different types of workers turn out to be crucial in this case. Another interesting feature of our results is a certain orthogonality between factors explaining productivity and knowledge investment on the one hand and labour market performance on the other. Except for a reduction in the final goods mark up, the employment rate is not significantly affected by important determinants of productivity and knowledge investment. Important determinats for explaining differences in employment rates are (ranked according to their importance) the skill composition of the lbour force, the level of labour taxes and efficiency differentials. However, these factors only explain about 50% of the difference in the employment rate. Other factors such as differences in benefit and transfer generosity as well as differences in the labour supply elasticity and the weight attached to leisure in the two regions must explain the remaining 50% of the employment gap. Since employment is not the focus of this paper it will be explored in future research.

Table 3: Increasing the mark-up in the intermediate good sector to US-level (11% to 12%)

Years	1	5	10	15	20	30	50	100	200
GDP	-0.04	-0.25	-0.26	-0.25	-0.24	-0.20	-0.12	-0.01	0.02
"Ideas/Patents"	0.07	1.20	2.65	3.84	4.80	6.20	7.72	8.70	8.83
Capital	-0.01	-0.19	-0.41	-0.57	-0.69	-0.81	-0.87	-0.81	-0.76
Employment	0.10	0.05	0.03	0.01	0.00	-0.01	-0.01	-0.01	-0.01
-low	0.08	0.08	0.05	0.02	0.01	-0.01	-0.02	-0.02	-0.02
-medium	0.08	0.03	0.02	0.00	0.00	-0.01	-0.02	-0.01	-0.02
-high	-0.46	-2.12	-2.05	-1.91	-1.80	-1.63	-1.44	-1.32	-1.31
-R&D	3.83	9.36	8.91	8.27	7.74	6.98	6.17	5.66	5.59
Consumption	0.05	0.05	0.06	0.06	0.07	0.08	0.11	0.17	0.22
Investment	-0.23	-0.72	-0.82	-0.86	-0.88	-0.90	-0.87	-0.79	-0.76
Wages	-0.01	0.04	0.02	0.02	0.02	0.04	0.09	0.17	0.19
-low	-0.10	-0.17	-0.17	-0.16	-0.14	-0.10	-0.03	0.05	0.08
-medium	-0.08	-0.14	-0.15	-0.14	-0.13	-0.10	-0.04	0.05	0.08
-high	0.47	1.48	1.35	1.24	1.16	1.06	0.99	1.00	1.01
R&D price	4.67	3.48	2.32	1.42	0.71	-0.30	-1.32	-1.93	-1.99
Int. price	0.46	0.22	0.36	0.47	0.56	0.68	0.77	0.80	0.79
R&D intensity	0.14	0.21	0.20	0.18	0.17	0.15	0.14	0.12	0.12

Table 4: Decreasing the mark-up in the final good sector to US-level (24.2% to 20.5%)

Years	1	5	10	15	20	30	50	100	200
GDP	0.32	1.03	1.39	1.74	2.02	2.44	2.88	3.15	3.18
"Ideas/Patents"	0.03	0.31	0.48	0.60	0.69	0.83	0.97	1.05	1.05
Capital	0.05	0.85	1.82	2.59	3.19	4.06	4.96	5.52	5.61
Employment	0.22	0.23	0.13	0.14	0.16	0.19	0.20	0.20	0.18
-low	0.19	-0.06	-0.40	-0.41	-0.39	-0.34	-0.29	-0.29	-0.29
-medium	0.23	0.35	0.32	0.34	0.36	0.37	0.38	0.37	0.36
-high	-0.01	-0.17	-0.04	0.00	0.02	0.05	0.08	0.08	0.07
-R&D	1.64	1.45	1.07	0.97	0.91	0.83	0.74	0.68	0.67
Consumption	-0.08	0.42	0.67	0.81	0.90	1.02	1.16	1.32	1.48
Investment	1.06	3.16	3.65	4.03	4.34	4.79	5.26	5.55	5.61
Wages	1.37	3.87	4.28	4.58	4.83	5.18	5.56	5.80	5.84
-low	1.32	4.09	4.66	4.98	5.21	5.55	5.92	6.15	6.19
-medium	1.33	3.75	4.11	4.41	4.66	5.02	5.41	5.66	5.70
-high	1.62	4.10	4.38	4.67	4.91	5.26	5.64	5.87	5.91
R&D price	4.17	4.25	4.41	4.62	4.78	5.04	5.31	5.48	5.52
Int. price	0.92	2.26	1.84	1.53	1.30	0.98	0.66	0.45	0.40
R&D intensity	0.09	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06

Table 5: Decreasing the entry costs of the intermediate sector to the US-level

Years	1	5	10	15	20	30	50	100	200
GDP	-0.02	-0.12	0.00	0.12	0.23	0.43	0.70	0.98	1.05
"Ideas/Patents"	0.11	1.85	4.11	6.02	7.60	9.99	12.73	14.73	15.04
Capital	0.00	-0.01	-0.02	0.00	0.03	0.13	0.34	0.64	0.74
Employment	0.06	0.04	0.02	0.00	0.00	-0.01	-0.01	-0.02	-0.02
-low	0.02	0.03	-0.02	-0.05	-0.06	-0.08	-0.08	-0.08	-0.09
-medium	0.02	0.03	0.02	0.01	0.01	0.00	0.00	0.00	-0.01
-high	-0.84	-3.30	-3.24	-3.06	-2.91	-2.68	-2.41	-2.22	-2.19
-R&D	5.89	14.52	14.07	13.25	12.57	11.56	10.41	9.57	9.44
Consumption	0.07	0.13	0.19	0.23	0.27	0.34	0.45	0.61	0.75
Investment	0.00	-0.05	-0.01	0.05	0.12	0.24	0.44	0.67	0.75
Wages	0.10	0.30	0.39	0.48	0.56	0.71	0.92	1.14	1.20
-low	-0.02	0.00	0.13	0.25	0.35	0.52	0.76	0.99	1.05
-medium	-0.02	0.00	0.10	0.20	0.30	0.46	0.70	0.93	1.00
-high	0.81	2.53	2.50	2.46	2.44	2.43	2.47	2.56	2.60
R&D price	7.23	5.61	4.02	2.77	1.77	0.32	-1.23	-2.27	-2.40
Int. price	0.04	-0.06	0.01	0.08	0.12	0.18	0.22	0.19	0.16
R&D intensity	0.22	0.33	0.31	0.29	0.28	0.25	0.23	0.21	0.20

Table 6: Decreasing the risk premia on intangibles by 46%

Years	1	5	10	15	20	30	50	100	200
GDP	-0.05	-0.28	-0.02	0.24	0.48	0.89	1.46	2.01	2.14
"Ideas/Patents"	0.25	4.04	9.04	13.27	16.79	22.11	28.16	32.47	33.13
Capital	0.00	-0.03	-0.05	-0.02	0.06	0.26	0.71	1.31	1.52
Employment	0.14	0.11	0.07	0.04	0.02	0.01	0.00	-0.01	-0.02
-low	0.08	0.17	0.13	0.08	0.05	0.02	0.00	-0.01	-0.01
-medium	0.06	0.06	0.03	0.01	-0.01	-0.01	-0.02	-0.02	-0.04
-high	-1.89	-7.31	-7.17	-6.73	-6.35	-5.80	-5.18	-4.75	-4.70
-R&D	13.08	32.20	31.04	29.06	27.41	24.99	22.32	20.48	20.21
Consumption	0.21	0.29	0.37	0.46	0.54	0.69	0.92	1.24	1.53
Investment	-0.02	-0.13	-0.03	0.10	0.24	0.51	0.92	1.37	1.52
Wages	0.22	0.67	0.85	1.03	1.20	1.49	1.92	2.35	2.47
-low	-0.07	-0.08	0.16	0.39	0.60	0.96	1.45	1.92	2.04
-medium	-0.03	0.01	0.22	0.44	0.64	0.98	1.46	1.93	2.06
-high	1.86	5.81	5.71	5.56	5.46	5.37	5.37	5.52	5.60
R&D price	16.30	12.38	8.74	5.94	3.76	0.70	-2.44	-4.41	-4.65
Int. price	0.11	-0.13	0.03	0.17	0.27	0.39	0.45	0.38	0.32
R&D intensity	0.50	0.75	0.71	0.66	0.62	0.56	0.50	0.45	0.45

Table 7: Decreasing labour taxes to US-level (38.6% to 30.5%)

Years	1	5	10	15	20	30	50	100	200
GDP	0.26	2.30	2.78	3.13	3.38	3.75	4.13	4.39	4.43
"Ideas/Patents"	0.02	0.40	0.94	1.39	1.75	2.26	2.80	3.12	3.16
Capital	0.01	0.23	0.67	1.10	1.48	2.06	2.72	3.17	3.26
Employment	0.59	2.93	3.20	3.29	3.33	3.35	3.34	3.33	3.32
-low	0.99	5.32	6.09	6.25	6.27	6.23	6.17	6.14	6.12
-medium	0.48	2.27	2.37	2.45	2.49	2.53	2.55	2.55	2.54
-high	0.09	0.69	0.76	0.86	0.94	1.04	1.13	1.17	1.17
-R&D	0.91	3.36	3.33	3.10	2.88	2.56	2.24	2.04	2.02
Consumption	2.53	2.95	2.74	2.84	2.99	3.21	3.45	3.67	3.84
Investment	0.13	1.08	1.62	1.97	2.22	2.57	2.94	3.20	3.26
Wages	-0.82	-1.49	-1.13	-0.86	-0.64	-0.33	0.00	0.22	0.26
-low	-1.15	-3.26	-3.06	-2.82	-2.58	-2.23	-1.87	-1.63	-1.59
-medium	-0.75	-0.99	-0.53	-0.25	-0.03	0.27	0.59	0.81	0.86
-high	-0.43	0.18	0.60	0.87	1.06	1.32	1.60	1.79	1.83
R&D price	-0.14	0.94	1.01	0.97	0.92	0.82	0.73	0.69	0.71
Int. price	-0.83	1.07	1.19	1.17	1.09	0.94	0.73	0.58	0.54
R&D intensity	0.00	0.02	0.02	0.02	0.01	0.00	0.00	-0.01	-0.01

Table 8: Upgrading to US skill-distribution

Years	1	5	10	15	20	30	50	100	200
GDP	-0.05	-0.11	-0.08	0.10	0.42	1.41	4.71	4.88	4.74
"Ideas/Patents"	-0.02	0.15	1.70	4.43	7.97	16.20	15.68	6.89	5.85
Capital	0.00	0.02	0.09	0.20	0.36	0.87	2.70	3.88	3.72
Employment	-0.02	0.26	0.61	0.99	1.41	2.45	4.90	5.03	5.05
-low	-0.93	-6.69	-13.80	-21.02	-28.38	-43.44	-60.29	-60.16	-60.14
-medium	0.30	2.54	5.35	8.25	11.24	17.63	26.62	26.75	26.78
-high	0.35	1.75	2.71	4.08	5.86	10.88	26.74	25.72	25.61
-R&D	-0.91	4.32	13.08	20.24	25.88	32.00	-1.60	3.13	3.71
Consumption	-1.73	-2.51	-1.81	-0.97	0.02	2.39	6.42	5.99	5.37
Investment	-0.02	0.12	0.26	0.48	0.78	1.51	3.53	3.89	3.71
Wages	-0.68	-4.48	-8.09	-10.72	-12.41	-12.40	5.79	5.99	5.85
-low	0.02	-0.13	-0.39	-0.49	-0.42	0.26	3.79	3.73	3.58
-medium	-0.90	-6.02	-10.80	-14.20	-16.38	-16.71	2.45	2.58	2.44
-high	-1.01	-5.53	-9.33	-12.17	-14.09	-14.63	-0.50	0.27	0.21
R&D price	-3.16	-4.42	-6.94	-9.61	-12.06	-14.79	-8.36	-2.41	-1.81
Int. price	0.04	-0.03	-0.07	-0.05	0.01	0.27	1.00	0.34	0.38
Low-skilled share	-0.28	-2.07	-4.32	-6.56	-8.80	-13.29	-17.94	-17.94	-17.94
Medium-skilled share	0.26	1.92	4.00	6.08	8.15	12.31	16.62	16.62	16.62
High-skilled share	0.02	0.15	0.32	0.49	0.65	0.98	1.33	1.33	1.33
R&D intensity	-0.07	-0.02	0.05	0.10	0.14	0.21	-0.12	-0.03	-0.01

Table 9: Changing skill-efficiencies to US-levels

Years	1	5	10	15	20	30	50	100	200
GDP	0.01	0.34	0.63	0.90	1.17	1.71	2.54	3.07	3.17
"Ideas/Patents"	0.01	-0.05	-0.48	-1.05	-1.53	-1.81	0.69	2.99	3.26
Capital	0.00	0.06	0.18	0.34	0.51	0.86	1.54	2.19	2.34
Employment	0.02	0.23	0.34	0.43	0.51	0.66	0.76	0.80	0.80
-low	-0.06	-0.24	-0.60	-0.96	-1.29	-1.84	-2.37	-2.21	-2.19
-medium	0.04	0.39	0.65	0.89	1.12	1.51	1.83	1.82	1.81
-high	0.20	1.72	3.31	4.47	5.35	6.60	7.50	7.73	7.75
-R&D	-0.25	-5.25	-10.88	-14.80	-17.64	-21.48	-24.18	-25.17	-25.29
Consumption	-0.20	-0.10	0.33	0.76	1.17	1.89	2.71	2.71	2.79
Investment	0.04	0.27	0.49	0.68	0.87	1.25	1.81	2.25	2.34
Wages	0.43	3.18	6.34	9.24	11.94	16.87	21.81	22.27	22.36
-low	0.05	0.29	0.67	1.04	1.38	2.02	2.92	3.23	3.30
-medium	0.45	3.46	6.96	10.19	13.20	18.73	24.24	24.78	24.88
-high	0.89	6.22	11.81	16.78	21.30	29.33	36.96	37.33	37.42
R&D price	0.98	1.60	2.26	2.78	3.06	2.82	0.83	-0.46	-0.58
Int. price	-0.09	0.18	0.27	0.33	0.38	0.47	0.53	0.42	0.38
R&D intensity	0.02	0.00	-0.02	-0.03	-0.02	0.00	0.02	-0.01	-0.01

Table 10: Increasing the subsidies (intermediate sector) to the US-level

Years	1	5	10	15	20	30	50	100	200
GDP	-0.01	-0.03	0.01	0.05	0.08	0.15	0.23	0.30	0.32
"Ideas/Patents"	0.04	0.59	1.30	1.88	2.34	3.01	3.73	4.18	4.23
Capital	0.00	0.00	-0.01	0.00	0.01	0.05	0.11	0.20	0.23
Employment	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00
-low	0.01	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03
-medium	0.01	0.00	0.00	0.00	-0.01	-0.01	-0.01	-0.01	-0.01
-high	-0.27	-1.05	-1.01	-0.94	-0.88	-0.79	-0.70	-0.64	-0.63
-R&D	1.89	4.58	4.35	4.03	3.76	3.39	2.98	2.73	2.70
Consumption	0.05	0.06	0.06	0.07	0.09	0.11	0.15	0.19	0.23
Investment	0.00	-0.02	0.00	0.02	0.04	0.08	0.15	0.21	0.23
Wages	0.03	0.09	0.12	0.14	0.17	0.21	0.28	0.34	0.35
-low	-0.01	-0.03	0.00	0.04	0.07	0.12	0.20	0.26	0.28
-medium	0.00	0.01	0.04	0.07	0.10	0.16	0.23	0.29	0.31
-high	0.26	0.79	0.77	0.75	0.73	0.72	0.72	0.74	0.75
R&D price	2.33	1.78	1.25	0.84	0.51	0.05	-0.43	-0.70	-0.73
Int. price	0.01	-0.02	0.01	0.03	0.04	0.06	0.07	0.06	0.05
R&D intensity	0.07	0.10	0.09	0.09	0.08	0.07	0.06	0.06	0.06

Table 11: Full structural change of the EU economy

Years	1	5	10	15	20	30	50	100	200
GDP	0.42	2.54	3.81	5.12	6.37	8.85	14.00	15.70	15.89
"Ideas/Patents"	0.50	8.54	20.21	31.42	41.93	60.61	71.79	71.14	71.28
Capital	0.04	0.86	2.09	3.29	4.45	6.62	10.67	13.92	14.31
Employment	1.14	3.64	4.07	4.50	4.93	5.98	8.43	8.53	8.51
-low	0.39	-1.11	-7.90	-15.08	-22.47	-37.58	-54.49	-54.39	-54.39
-medium	1.22	5.29	8.11	11.06	14.08	20.50	29.51	29.62	29.60
-high	-2.83	-11.50	-10.05	-7.70	-5.11	1.08	18.22	18.05	18.02
-R&D	26.09	69.80	75.85	78.92	81.16	82.30	43.26	44.30	44.34
Consumption	0.90	1.40	2.27	3.51	4.88	7.85	12.67	13.18	13.40
Investment	0.95	3.44	4.68	5.80	6.85	8.80	12.37	14.11	14.32
Wages	0.63	-1.00	-3.56	-5.32	-6.27	-5.10	14.55	16.00	16.17
-low	0.05	0.41	1.33	2.18	3.09	5.08	10.20	11.48	11.62
-medium	0.00	-3.38	-7.00	-9.46	-10.84	-9.92	10.80	12.25	12.43
-high	4.47	9.38	5.99	3.39	1.68	1.53	16.29	17.75	17.92
R&D price	32.38	24.02	14.84	6.94	0.38	-8.16	-7.75	-5.55	-5.36
Int. price	0.66	3.32	3.37	3.40	3.41	3.50	3.90	2.79	2.63
R&D intensity	0.98	1.48	1.44	1.39	1.35	1.32	0.89	0.86	0.86

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Appendix 1. Deriving the steady-state R&D share and the determinants of labour productivity

The Economic Environment

Suppose we have the following simplified economic structure:

$$Y_t = \left(\int_0^{A_t} x_t(\nu)^\theta d\nu \right)^{(1-a)/\theta} L_{Y,t}^{\alpha} \tag{A1}$$

$$L_{Y,t} + L_{A,t} = L_t = L_0 e^{nt} \tag{A2}$$

$$\begin{aligned} K_t &= \int_0^{A_t} x_t(\nu) d\nu, \\ \dot{K}_t &= Y_t - C_t - \delta K_t \end{aligned} \tag{A3}$$

$$\dot{A}_t = \mu A_t^{w\xi} A_t^{\phi} L_{A,t}^{\lambda}, \tag{A4}$$

$$U_t = \int_t^{\infty} L_t \frac{(C_t/L_t)^{1-\epsilon} - 1}{1-\epsilon} e^{-\rho(s-t)} ds, \quad \rho > n \tag{A5}$$

$$w_t = \alpha\eta \frac{Y_t}{L_{Y,t}} \tag{A6}$$

$$(1 + fc_a) P_{A,t} = \frac{(1-\tau)\pi_t}{r - g_{P_A}}, \quad fc_a > 0 \tag{A7}$$

where $g_{P_A} = \frac{\dot{P}_{A,t}}{P_{A,t}}$, fc$_a$ is the (constant) proportion of entry cost in terms of the price of R&D products and $\tau < 1$ is the effective (possibly negative) tax- (subsidy) rate on profit financed from lump-sum taxes.

Assume also that along the balanced growth path the domestic and foreign stock of knowledge grows at the same rate: $g_A = g_{A^w}$

BGP growth rates

To solve for the balanced growth path growth rate of the economy, rewrite (A4) and use the time-derivatives

$$\frac{\dot{A}_t}{A_t} = \mu A_t^{w\xi} A_t^{\phi-1} L_{A,t}^{\lambda} \rightarrow g_A = \frac{\lambda}{1-\phi-\zeta} n. \tag{A8}$$

From the symmetric structure of the model follows that

$$x_t(\nu) = \frac{K_t}{A_t} \tag{A9}$$

for all varieties.

Therefore the aggregate production function can be rewritten as

$$Y_t = A_t^{\sigma} L_{Y,t}^{\alpha} K_t^{1-\alpha}, \quad \sigma = \left(\frac{1}{\theta} - 1\right)(1-\alpha). \tag{A1'}$$

The constancy of the capital-output ratio then implies that the growth rate of output is given by

$$g_Y = \frac{\sigma}{\alpha} g_A + n. \tag{A10}$$

Given the price of R&D designs, which is determined by equation (A7), the Research Institute maximizes its profit when the marginal productivity equals to the real wage paid by the institute:

$$\begin{aligned} \lambda \frac{P_{A,t}\dot{A}_t}{L_{A,t}} &= w_t, \text{ or} \\ \lambda P_{A,t} g_A A_t &= w_t L_{A,t} \end{aligned} \tag{A11}$$

Notice that along the balanced growth path the share of R&D in output, s_A, is constant, therefore:

$$s_A = \frac{P_{A,t}\dot{A}_t}{Y_t} \tag{A12}$$

or equivalently

$$s_A = \frac{1}{\lambda} \cdot \frac{w_t L_{A,t}}{Y_t}.$$

Dividing (A11) by A_t and differentiating we can solve for $\frac{\dot{P}_{A,t}}{P_{A,t}} = g_{P_A}$:

$$\frac{\dot{P}_{A,t}}{P_{A,t}} = g_Y - g_A. \tag{A13}$$

The arbitrage equation can be rewritten as

$$(1 + fc_a)P_{A,t} = \frac{(1-\tau)\pi_t}{r - (g_Y - g_A)}. \tag{A7'}$$

Intermediate sector's profit

The profit-maximization of the intermediate sector requires the following first order condition:

$$i^K = \theta\eta(1-a)\left(\int_0^{A_t} x_t(\nu)^{\theta} d\nu\right)^{(1-a)/\theta - 1} L_{Y,t}^{\alpha} x_t(\nu)^{\theta-1}, \tag{A14}$$

where from the symmetric structure of the model it follows that

$$i^K = \theta\eta(1-\alpha)\frac{Y_t}{K_t} \tag{A14'}$$

and the intermediate sector's profit is given by

$$\pi_t = \eta(1-\theta)(1-\alpha)\frac{Y_t}{A_t}. \tag{A15}$$

Steady state R&D intensity

Substituting (A15) into (A7') reveals:

$$(1+fc_a)P_{A,t}=\frac{\eta\,(1-\theta)\,(1-\alpha)(1-\tau)\frac{Y_t}{A_t}}{r-(g_Y-g_A)}. \tag{A16}$$

Notice that $P_{A,t}$ can be expressed from (A12) as $P_{A,t}=\frac{s_AY_t}{\dot{A}_t}=\frac{s_AY_t}{g_AA_t}$and substitute it back to (A16):

$$(1+fc_a)\frac{s_AY_t}{g_AA_t}=\frac{\eta\,(1-\theta)\,(1-\alpha)(1-\tau)\frac{Y_t}{A_t}}{r-(g_Y-g_A)}. \tag{A17}$$

Therefore the steady-state R&D share, s_A:

$$s_A=\frac{\eta\,(1-\theta)\,(1-\alpha)(1-\tau)g_A}{r-(g_Y-g_A)}\frac{1}{1+fc_a}. \tag{A18}$$

Let us denote the first part of the expression which is the R&D share without fixed costs in the intermediate sector by s_{nfx} and denote the final and intermediate sector's mark-ups by mp_f and mp_i respectively, where $1+mp_f=\frac{1}{\eta}$ and $1+mp_i=\frac{1}{\theta}$. Therefore we get from (A18):

$$s\left(\underset{(+)}{s_{nfx}},\underset{(-)}{fc_a}\right)=\frac{s_{nfx}}{1+fc_a} \tag{A19}$$

, where

$$s_{nfx}(\underset{(-)}{mp_f}\underset{(+)}{mp_i},\underset{(-)}{\alpha},\underset{(-)}{r},\underset{(+)}{g_A},\underset{(+)}{n},\underset{(-)}{\tau})=\frac{\frac{1}{1+mp_f}\left(1-\frac{1}{1+mp_i}\right)(1-\alpha)(1-\tau)g_A}{r-\left(mp_i\left(\frac{1}{\alpha}-1\right)-1\right)g_A-n}.$$

Equation (A18) and (A19) reveal that the steady state R&D share is determined by
- the mark-ups in the final and intermediate sector (mp_f, mp_i) ,
- the effective tax/subsidy of the intermediate sector (τ) ,
- long-run growth-rate of population and ideas (g_A, n) ,
- the equilibrium interest rate (r).
- the entry costs share (fc_a).

Notice that Table 2 corresponds to the signs of the effects on the parameters above: decreasing the mark up in the final, and increasing it in the intermediate sector indeed increased the R&D share, higher subsidies resulted in higher R&D intensity and decreasing the entry barriers had the strongest positive effect on R&D.

Steady state L_A/L_Y ratio

To calculate the ratio of labour devoted R&D relative to the final good sector's employment we can use the assumption that wages are equal across sectors. Then from (A6) and (A12):

$$s_{L,A/Y}=\frac{L_{A,t}}{L_{Y,t}}=\frac{w_tL_{A,t}}{w_tL_{Y,t}}=\frac{\lambda s_AY_t}{\alpha\eta Y_t}=\frac{\lambda}{\alpha\eta}s_A=\frac{\lambda\,(1+mp_f)\,s_A}{\alpha}$$

We can rewrite this ratio as

$$s_{L,A/Y} = \frac{\lambda\left(1-\frac{1}{1+mp_i}\right)(1-\alpha)(1-\tau)g_A}{\alpha r-(mp_i(1-\alpha)-\alpha)\,g_A-\alpha n}\frac{1}{1+fc_a}. \tag{A20}$$

Comparing (A19) and (A20) we can see a major difference between the "nominal" and "real" ratio of resources devoted to R&D: the "real" ratio measured in terms of labour does not depend on the final good sector's mark-up (mp_f) while the "nominal" R&D intensity is decreasing in it.

Determinants of labour productivity

Denote $s_K = 1 - C_t/Y_t$, therefore along the balance growth path, output per capita $y_t = Y_t/L_t$ can be written as

$$y_t = A_t^{\frac{\sigma}{\alpha}}\left(\frac{s_K}{n+g_k+\delta}\right)^{\frac{1-\alpha}{\alpha}}(1-s_{LA})^{\frac{1}{\alpha}} \tag{A21}$$

using (A1') and (A3), where $s_{LA} = L_A/(L_A+L_Y) = 1/\left(1+1/s_{L,A/Y}\right)$. Along the balanced growth path, the stock of knowledge can be obtained from (A9)

$$A_t = \left(\frac{\mu}{g_A}A_t^{w\xi}(s_{LA}L_t)^{\lambda}\right)^{\frac{1}{1-\phi}} \tag{A9'}$$

Combining these results we get

$$y_t = \left(\frac{\mu}{g_A}A_t^{w\xi}\right)^{\frac{\sigma}{\alpha}\frac{1}{1-\phi}}\left(\frac{s_K}{n+g_k+\delta}\right)^{\frac{1-\alpha}{\alpha}}(1-s_{LA})\,s_{LA}^{\lambda\frac{\sigma}{\alpha}\frac{1}{1-\phi}}L_t^{\lambda\frac{\sigma}{\alpha}\frac{1}{1-\phi}} \tag{A21'}$$

The balanced growth path saving rate s_K can be obtained from (A3) and (A14') using that $i^K = r+\delta$.

$$s_K = \frac{\theta\eta(1-\alpha)(n+g_k+\delta)}{r+\delta} \tag{A22}$$

Therefore from (A21'), (A22) and (A9), we obtain that output per capita along the balanced growth path is a function of the structural parameters and proportional to the exogenously growing labour force and the international stock of knowledge

$$y_t = \left(\frac{\mu(1-\phi-\zeta)}{\lambda n}A_t^{w\xi}\right)^{\frac{\sigma}{\alpha}\frac{1}{1-\phi}}\left(\frac{\theta\eta(1-\alpha)}{r+\delta}\right)^{\frac{1-\alpha}{\alpha}}(1-s_{LA})\,s_{LA}^{\lambda\frac{\sigma}{\alpha}\frac{1}{1-\phi}}L_t^{\lambda\frac{\sigma}{\alpha}\frac{1}{1-\phi}}. \tag{A23}$$

Note that decreasing the final good mark-up (increasing η) will always lead to higher output per capita. However the effect of intermediate mark-ups is not straightforward because both σ and s_{LA} depends on the inverse of gross intermediate goods mark-up, θ. One can show that the first order derivative of y_t in terms of R&D labour share (s_{LA}) is also not necessarily positive. However, under our calibration to the data both derivatives are positive. Note that our simulation results also confirm these observations.

Appendix 2. Calibrating Knowledge production parameters

The driving equation system of the semi-endogenous technological change can be summarized as

$$\Delta A_t = \nu A_{t-1}^{*\varpi} A_{t-1}^{\phi} L_{A,t}^{\lambda} \tag{a}$$

$$1 + g_A = (1 + g_n)^{\frac{\lambda}{1-\phi-\xi}} \tag{b}$$

$$\lambda \cdot P_{A,t} \Delta A_t = w_H \cdot L_{A,t} \tag{c}$$

$$rdi_t = \frac{P_{A,t} g_A A_{t-1}}{P_Y Y_t} \tag{d}$$

$$i_{A,t} P_{A,t} + r_t FC_A = \pi_t, \quad where \quad \pi_t = \eta (1-\theta)(1-\alpha) \frac{Y_t}{A_t} \tag{e}$$

$$i_A = \frac{(1-\tau^A)(i_t - \pi_{t+1}^A + \delta^A) - t^K \delta^A}{(1-t^K)} + rp_t^A \tag{f}$$

$$K_t = A_t x_t \tag{g}$$

The first equation is the spillover-augmented version of Jones (1995) R&D production. This form of R&D equation accounts for international spillovers almost identically to the specification of Bottazzi and Peri (2007). Equation (b) states the balanced-growth relationship between the growth of ideas $g_A (= g_{A^w})$ and population g_n, equation (c) shows the first order condition of R&D production, equation (d) is the definition of R&D-intensity: total R&D expenditure of the intermediate sector in percentage of GDP. Equation (e) states the free-entry condition between the profit of the intermediate sector (π_t), and the per unit price of R&D inventions (P_A) and the fixed (entry) cost FC_A. Equation (f) defines the rental rate of intangible capital which takes into account that households pay income tax at rate t_t^K on the period return of intangibles and they receive tax subsidies at rate τ^A. Since one unit of capital is used to produce one unit of intermediate good (x_t), equation (g) states the identity between the total intermediate goods production and physical capital under symmetric equilibrium.

Although we do not have direct estimates of ν, ϖ, ϕ and λ, we can use the existing literature and the model restrictions to get calibrated values for them. Data on the R&D share of labour ($L_{A,t}$) and on the R&D intensity $\left(\frac{P_{A,t}\Delta A_t^D}{P_Y Y_t}\right)$ is obtained from EUROSTAT, the values of g_A and g_n are given in our baseline model[11]. These values together with the restrictions of the balanced growth dynamics and the other variables of the baseline pin down λ and P_A. In order to set ϕ and ϖ in the first step we express the sum of these two parameters from equation (b). In the

[11] Pessoa (2005) provides estimates for the growth of patents or ideas in various OECD countries at an average of $g_A = 0.057$. The population growth g_n is obtained from EUKLEMS potential output calculations.

second step we use the estimated long-term relationship between λ and ξ from Bottazzi and Peri (2007) to approximate ϖ separately. The authors do not estimate directly ϕ and ϖ, however their estimated cointegration vector contains two coefficients μ and γ, satisfying the following theoretical restrictions between the long-term coefficients of λ, ϕ and ϖ:

$$\mu = \frac{\lambda_{long-term}}{1-\phi_{long-term}}$$

and

$$\gamma = \frac{\varpi_{long-term}}{1-\phi_{long-term}}.$$

The estimated values for these two coefficients show fairly big variations under the different regressions, and it might be inadequate to apply these long-term coefficients on our "contemporary" specification. However the ratios of these two coefficients $\frac{\gamma}{\mu} = \frac{\varpi_{long-term}}{\lambda_{long-term}}$ vary less, furthermore, imposing the ratio of the long-term parameters instead of their exact values is also less restrictive. To approximate our ϖ for the EU27, we use the ratio of these parameters from the specification in which the authors omitted the US from their regressions[12]. In the last step we subtract this value from the sum of ϕ and ϖ as we calculated from equation (b) earlier. Since the authors do not provide estimations for the US separately we must rely on another source. Coe and Helpman (1995) estimates that the elasticity of total factor productivity is 0.033 and 0.234 with respect to foreign R&D and domestic R&D respectively. We impose this implied ratio between ϕ and ϖ for the US. Finally, we normalize the stock of domestic and foreign ideas to one and therefore the values for ν and θ can be obtained from expressions (a) and (e).

The calibration of the parameters in intermediate goods production relies on the entry costs estimations of Djankov et al. (2002), and the estimations for R&D related subsidies (τ^A) of Warda (2006). Given that we normalized the stock of domestic ideas to one (A_t), equation (g) pins down the per firm quantity of intermediate goods production. The profit of a representative intermediate firm is determined by its production and the net mark-up of the sector[13]. All other variables given, the arbitrage equation (e) gives the rental rate of intangible capital, i_t^A. The B-indices published in Warda (2006) can be applied to calibrate τ^A and t^K. Finally, we use the definition of equation (f) to obtain as residual the calibrated approximation of the risk-premium on intangibles, rp_t^A:

$$rp_t^A = \left(\eta\,(1-\theta)\,(1-\alpha)\frac{Y_t}{A_t} - r_t FC_A\right)P_{A,t} - \frac{(1-\tau^A)(i_t - \pi_{t+1}^A + \delta^A) - t^K\delta^A}{(1-t^K)}$$

Appendix 3. The tax treatment of intangible capital

The model is formulated in such a way that statutory corporate tax rates, depreciation allowances and tax credits can be incorporated in the analysis. This section explains how the tax measures in the model relate to Warda's (1996) B-index which serves as a comprehensive measure of the tax treatment of R&D as, for example, advocated by the OECD. Algebraically the B index is equal to the after tax cost of a Euro expenditure on R&D, divided by one minus the corporate income tax

[12] The full sample consists of fifteen OECD countries including the US and ten member states of the European Union.

[13] We use the net mark-up of the manufacturing sector calculated in EUKLEMS to obtain θ, the inverse of the gross mark-up in the intermediate sector.

rate (t^K). Apart from the corporate income tax rate, the relevant tax parameters for an investor in R&D are the investment tax credit (τ) and the present discounted value of depreciation allowances (Al_t). Depreciation allowances depend on the corporate tax rate and the depreciation scheme for a specific investment good as defined in the national tax laws. Standard depreciation schemes are declining balance and straight line depreciation as well as combinations of both. In the model we implicitly assume a declining balance scheme since it yields a simple representation for the user cost of capital. With a declining balance scheme, the present discounted value at period t of depreciation allowances of an investment good with unit value in t and rate of depreciation δ is given by

$$\begin{aligned} Al_t &= t^K\delta + \left(\frac{1}{1+r}\right) t^K\delta(1-\delta) + \left(\frac{1}{1+r}\right)^2 t^K\delta(1-\delta)^2 + ... \\ &= \sum_{j=0}^{\infty} \left(\frac{1}{1+r+\delta}\right)^j t^K\delta = \frac{t^K\delta}{r+\delta}. \end{aligned}$$

The B-index is defined as

$$B - index = \frac{(1-\tau-Al_t)}{(1-t^K)}$$

and one obtains the standard neoclassical user cost of capital (cc) when multiplying the B-index with the sum of the real interest rate and the rate of depreciation. Using the definition of Al_t it can be seen immediately that Warda's user cost approach can be linked directly to the user cost formula (7c') used in the model

$$cc = \frac{(1-\tau-Al_t)}{(1-t^K)}(r+\delta) = \frac{(1-\tau-\frac{t\delta}{r+\delta})}{(1-t^K)}(r+\delta) = \frac{(1-\tau)(r+\delta)-t^K\delta}{(1-t^K)}.$$

Appendix 4. Robustness of US-EU gaps explained by differences in exogenous variables

We checked the robustness of the US-EU gaps explained by the model with respect to the elasticity of substitution between skills (σ_L), the labour-supply elasticity ($1/\kappa$) and the openness (elasticity of substitution between bundles of domestic and foreign goods). The following tables compare the baseline simulations with three alternative scenarios a.) by setting σ_L to 2, close to the upper bound of the estimated elasticity of substitution between skill groups according to the empirical literature (Katz and Murphy (1992)), b.) by imposing more elastic labour supply (setting κ to 2 instead of 4) and c.) higher elasticity of substitution between domestic and foreign goods (increasing σ to 5 from 2.5). The simulations suggest that under the empirically plausible range of the elasticity of substitution between skill-groups the results does not change significantly. The less elastic labour supply slightly decreases the gap explained by the model and productivity difference is sensitive to the measure of openness (σ), with more open economy the structural changes of the EU can fully close the the US-EU productivity gap.

Table 12: Productivity gap under higher EOF between skill groups

	Y/L	L	Skill premium high vs. medium	medium vs. low	R&D intensity
Lower mark up (final)	2.99	0.18	0.22	-0.40	0.06
Increase mark up (intermediates)	0.06	-0.01	1.02	0.00	0.12
Reducing entry barrier	1.11	-0.02	1.76	-0.05	0.20
Reducing risk premia	2.24	-0.01	3.82	0.01	0.44
Reducing labour tax	1.11	3.33	1.08	2.16	-0.01
Skill composition	-0.40	5.03	-2.35	-0.94	-0.01
Efficiencies	2.25	0.78	16.91	27.08	-0.01
R&D subsidies	0.33	0.00	0.49	0.02	0.06
Total*	9.70	9.27	23.67	34.04	0.86
Initial gap	10.00	18.61	22.06	30.01	0.81

Table 13: Productivity gap under with more inelastic labour supply

	Y/L	L	Skill premium high vs. medium	medium vs. low	R&D intensity
Lower mark up (final)	3.09	0.32	0.44	-1.09	0.06
Increase mark up (intermediates)	0.04	-0.02	1.34	0.00	0.12
Reducing entry barrier	1.08	-0.04	2.30	-0.12	0.20
Reducing risk premia	2.18	-0.03	5.02	0.05	0.45
Reducing labour tax	1.82	5.75	2.42	5.09	-0.02
Skill composition	-0.15	5.37	-2.94	-2.60	-0.02
Efficiencies	3.21	1.33	15.44	22.01	-0.01
R&D subsidies	0.32	0.00	0.64	0.07	0.06
Total*	11.58	12.67	25.76	28.52	0.85
Initial gap	10.00	18.61	22.06	30.01	0.81

Table 14: Productivity gap under higher EOF between domestic and foreign goods

	Y/L	L	Skill premium high vs. medium	Skill premium medium vs. low	R&D intensity
Lower mark up (final)	3.24	0.23	0.33	-0.54	0.06
Increase mark up (intermediates)	0.04	-0.01	1.40	0.00	0.12
Reducing entry barrier	1.16	0.00	2.39	-0.06	0.20
Reducing risk premia	2.35	0.02	5.23	0.04	0.45
Reducing labour tax	1.40	3.36	1.47	3.10	-0.01
Skill composition	-0.02	5.11	-3.24	-1.33	-0.01
Efficiencies	2.60	0.84	15.10	25.87	-0.01
R&D subsidies	0.35	0.01	0.67	0.04	0.06
Total*	11.12	9.56	24.26	33.18	0.86
Initial gap	10.00	18.61	22.06	30.01	0.81