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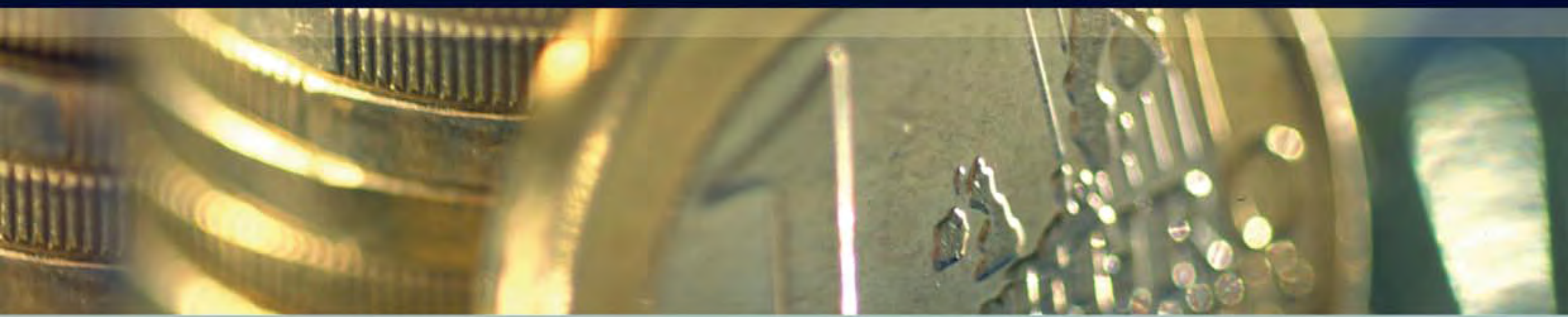

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A quantitative assessment using a semi-endogenous growth model

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How to close the productivity gap between the US and Europe

A quantitative assessment using a semi-endogenous growth model*

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Abstract

This paper uses a semi-endogenous growth model to identify possible sources for three interrelated stylised differences between the EU and the US, namely a higher level of productivity and knowledge investment and larger skill premia in the US compared to the EU. The model allows us to explain these differences in terms of differences in subsidies to R&D, mark ups, administrative entry barriers and financial frictions. The paper provides a ranking about the relative importance of these factors. Goods market competition and both administrative and financial entry barriers are the most important explanatory factors for lower productivity in the EU, while entry barriers explain the bulk of the knowledge investment gap and high skilled wage premia.

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

JEL classification: E10, O20, O30, O41

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1 Introduction

Western Europe has caught up with the US in terms of productivity in the post war period, but this process came to an end in the mid 1990s. Since then the productivity gap with the US has slightly widened again to more than 10%. This can be seen as evidence of conditional convergence, i.e. European institutions, technologies and endowments prevent full convergence of productivity levels. There are other important stylised differences between the two regions. The US invests more in knowledge and this is reflected in an R&D share of about 3% compared to 2% for the former EU15. This difference in knowledge investment has persisted since a long time, despite efforts of European policymakers to close this gap. Another important stylised fact is the size of the skill premium, where the US shows a wider dispersion of wages across skill groups. For instance, for high skilled wages in the education sector, a proxy for the wage level of R&D workers, there exists a skill premium relative to medium skilled workers of 39% in the US vs. 34.6% in the former EU15.

There has been a long debate on how these persistent differences could possibly be explained. Interest has focused on the productivity gap. There is a sizeable literature which blames product market regulations as a major reason for the income gap. In a 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%. Deeper and more efficient financial markets, especially venture capital markets in the US (see Bottazzi et al. (2001)) are also regarded as an important explanatory factor. In a recent empirical study, Aghion and Scarpetta (2007) conclude that financial constraints related to entry could be as important as labour market rigidities in terms of obstacles to growth. The consequences of differences in goods and financial markets for knowledge investment have so far been less explored. Though there exists some literature on the effects of financing constraints, the emphasis has been on fiscal factors for explaining differences in R&D spending. The factors which are regarded as important for explaining the productivity and knowledge investment gap are even less prominent when it comes to assessing determinants of skill premia and permanent differences in these across the Atlantic.

This paper tries to fill this gap by mapping differences in product markets, financial markets and R&D policies onto these three stylised differences using an endogenous growth model. This allows us to look at the relative importance of important structural features distinguishing the two economies for explaining the differences in productivity, knowledge investment and skill premia. Endogenous growth models do obviously suggest that links exist between productivity, R&D investment and skill premia and therefore serve as an appropriate tool to look at all three aspects simultaneously.

In this exercise we make use of 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. We focus our comparison on the former EU15, i.e. we only look at the old member states that were part of the European Union pre 2004 enlargement, and exclude the new member states which generally have a much larger gap vis-a-vis the US. Concerning goods markets we use various indicators such as mark up estimates as well as indicators of administrative entry barriers as well as financial frictions to characterise the state of product market competition. Concerning knowledge production we make use of recent empirical estimates as presented by Bottazzi and Peri (2007). We control for differences in endowments in both economies by using information on the skill composition of the labour force. Concerning fiscal measures we concentrate on R&D tax credits as measured by the OECD B-index.

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 finds evidence of weak scale effects as implied by semi-endogenous models of growth. 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. We begin with a description of the model, followed by a section that provides details on the calibration. The next section 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 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), 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

[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

income (i_t, i_t^K and i_t^A). Hence, non-liquidity constrained households face the following Lagrangian

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

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

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

The budget constraints are written in real terms with the price for patents P_t^A and wages W normalized with 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. 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. We define the real interest rate r_t as equal to the nominal interest rate minus

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.

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.

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

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 are given by

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

with $\kappa > 0$.

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

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

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:

$$\frac{\partial V_0}{\partial C_t^i} => U_{C,t}^i - \lambda_t^i(1 + t_t^c) = 0 \tag{4a}$$

$$\frac{\partial V_0}{\partial B_t^i} => -\lambda_t^i + E_t\left(\lambda_{t+1}^i\beta\left(1 + r_t\right)\right) = 0 \tag{4b}$$

$$\frac{\partial V_0}{\partial K_t^i} => -\lambda_t^i\xi_t^i + E_t\left(\lambda_{t+1}^i\xi_{t+1}^i\beta(1-\delta) + \lambda_{t+1}^i\beta\left((1 - t_t^K)(i_t^K - rp_t^K) + t_t^K\delta^K\right)\right) = 0 \tag{4c}$$

$$\frac{\partial V_0}{\partial J_t^i} => -\lambda_t^i\left(1 + \gamma_K\left(\frac{J_t^i}{K_{t-1}^i}\right) + \gamma_I\Delta J_t^i - \tau^K\right) + E_t\left(\lambda_{t+1}^i\beta\gamma_I\Delta J_{t+1}^i\right) + \lambda_t^i\xi_t^i = 0. \tag{4d}$$

Using the arbitrage conditions and neglecting the second order terms, investment is given as a function of the variable ξ_t^i

$$\xi_t^i - 1 = \gamma_K \left(\frac{J_t^i}{K_{t-1}^i} \right) + \gamma_I \Delta J_t^i - \tau^K - E_t \left(\frac{\gamma_I \Delta J_{t+1}^i}{1 + r_t} \right) \tag{5a}$$

where ξ_t^i is the present discounted value of the rental rate of return from investing in real assets

$$\xi_t^i = E_t \left(\frac{1-\delta}{1+r_t} \xi_{t+1}^i + \frac{(1-t_t^K)(i_t^K - rp_t^K) + t_t^K \delta^K}{1+r_t} \right). \tag{5b}$$

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

$$\frac{\partial V_0}{\partial A_t^i} => -\lambda_t^i \psi_t^i + E_t \left(\lambda_{t+1}^i \psi_{t+1}^i \beta (1-\delta^A) + \lambda_{t+1}^i \beta \left((1-t_t^K)(i_t^A - rp_t^A) + t_t^K \delta^A \right) P_{t+1}^A \right) = 0 \tag{5c}$$

$$\frac{\partial V_0}{\partial J_t^{A,i}} => -\lambda_t^i P_t^A \left(1 - \tau^A\right) + \lambda_t^i \psi_t^i = 0 \tag{5d}$$

Therefore the rental rate can be obtained from (4b), (5c) and (5d) after neglecting the second order terms:

$$i_t^A \approx \frac{(1-\tau^A)\left(i_t - \pi_{t+1}^A + \delta^A\right) - t_t^K \delta^A}{(1-t_t^K)} + rp_t^A \tag{6}$$

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

Equation (6) 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

$$(1+t_t^c)C_t^k = \sum_s \left(\left(1 - t_t^{w,L}\right) W_t^{k,L} L_t^{k,L} + b_t^L W_t^{k,L} (1 - NPART_t^{k,L} - L_t^{k,L}) \right) + TR_t^k. \quad (7)$$

2.1.3 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].

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

$$\frac{U_{1-L,t}^{h,s}}{U_{C,t}^{h,s}} \frac{1}{\eta_t^W} = \frac{W_t^s (1 - t_t^{w,s} - b_t^s)}{(1 + t_t^C)} \text{ for } h \in \{i, k\} \text{ and } s \in \{L, M, H\}. \quad (8)$$

2.1.4 Aggregation

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

$$X_t = \int_0^1 X_t^h dh = (1 - \epsilon) X_t^i + \epsilon X_t^k, \quad (9)$$

Hence aggregate consumption and employment is given by

$$C_t = (1 - \epsilon) C_t^i + \epsilon C_t^k \quad (10)$$

[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 $\eta_t^w = 1 - 1/\sigma_s - \gamma_W/\sigma_s \left[\beta(sfw\pi_{t+1}^w - (1 - sfw)\pi_{t-1}^w) - \pi_t^w\right]$.

and

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

2.2 Firms

2.2.1 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

$$Y^j = \left(L_{Y,t}^j\right)^{\alpha} \left(\sum_{i=1}^{A_t} \left(x_{i,t}^j\right)^{\theta}\right)^{\frac{1-\alpha}{\theta}} - FC, \quad 0 < \theta < 1 \tag{12}$$

with

$$L_{Y,t} = \left(s_L^{\frac{1}{\sigma_L}} \left(ef_L L_t^L\right)^{\frac{\sigma_L - 1}{\sigma_L}} + s_M^{\frac{1}{\sigma_L}} \left(ef_M L_t^M\right)^{\frac{\sigma_L - 1}{\sigma_L}} + s_{H,Y}^{\frac{1}{\sigma_L}} \left(ef_H L_t^{HY}\right)^{\frac{\sigma_L - 1}{\sigma_L}}\right)^{\frac{\sigma_L}{\sigma_L - 1}}. \tag{13}$$

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_t^{HA}). The employment aggregates L_t^s combine varieties of differentiated labour services supplied by individual household

$$L_t^s = \left[\int_0^1 \left(L_t^{s,h}\right)^{\frac{\sigma_s - 1}{\sigma_s}} dh\right]^{\frac{\sigma_s}{\sigma_s - 1}}. \tag{14}$$

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 2005)[4].

The objective of the firm is to maximise profits

$$PR_t^{f,j} = P_t^j Y_t^j - \left(W_t^L L_t^{j,L} + W_t^M L_t^{j,M} + W_t^H L_t^{j,HY} \right) - \sum_{i=1}^{A_t} \left(px_{i,t} x_{i,t}^j \right), \qquad (15)$$

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

$$\alpha \frac{Y_t}{L_{Y,t}} \left(\frac{L_{Y,t}}{L_t^s} \right)^{\frac{1}{\sigma_L}} s_s^{\frac{1}{\sigma_L}} ef_s^{\frac{\sigma_L - 1}{\sigma_L}} \eta_t = W_t^s, \quad s \in \{L, M, H\} \qquad (16a)$$

$$px_{i,t} = \eta_t (1-\alpha) Y \left(\sum_{i=1}^{A_t} \left(x_{i,t}^j \right)^\theta \right)^{-1} \left(x_{i,t} \right)^{\theta - 1} \qquad (16b)$$

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

2.2.2 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 (16b).

[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.

Each intermediate firm solves the following profit-maximisation problem

$$PR^{x}_{i,t} = \max_{x_{i,t}} \left\{ px_{i,t}x_{i,t} - i^{K}_{t}k_{i,t} - i^{A}P^{A}_{t} - FC_{A} \right\}. \tag{17}$$

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

$$x_i = k_i. \tag{18}$$

In a symmetric equilibrium the first order condition is

$$\theta\eta_t(1-\alpha)Y\left(\sum_{i=1}^{A_t}\left(x^{j}_{i,t}\right)^{\theta}\right)^{-1}(x_t)^{\theta-1} = i^{K}_{t} \tag{19}$$

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

$$PX_t = px_{i,t} = \frac{i^{K}_{t}}{\theta} \tag{20}$$

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

$$PR^{x}_{i,t} = PR^{x}_{t} = i^{A}_{t}P^{A}_{t} + \left(i^{A}_{t} + \pi^{A}_{t+1}\right)FC_{A}, \quad \forall i \tag{21}$$

For an intermediate producer, entry costs consist of the licensing fee $i^{A}_{t}P^{A}_{t}$ 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^{HA}_{t}) and generates new designs according to the following knowledge production function:

$$\Delta A_t = \nu {A_{t-1}^{w}}^{\xi} A_{t-1}^{\phi} \left(L_t^{HA}\right)^{\lambda}. \tag{22}$$

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^w 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_t^{HA}). 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:

$$\max_{L_t^{HA}} \sum_{t=0}^{\infty} d_t \left(P_t^A \Delta A_t - W_t^H L_t^{HA} - \frac{\gamma_A}{2} W_t^H \left(\Delta L_t^{HA}\right)^2 \right) \tag{23}$$

therefore the first order condition implies:

$$\lambda P_t^A \frac{\Delta A_t}{L_t^{HA}} = W_t^H + \gamma_A \left(W_t^H \Delta L_t^{HA} - d_t W_{t+1}^H \Delta L_{t+1}^{HA} \right) \tag{24}$$

where d_t is the discount factor.

2.4 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

$$BEN_t = \sum_s b_t^s W_t^s (1 - NPART_t^s - L_t^s), \tag{25}$$

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

$$b_t^s = \hat{b}_t^s \left[(1 + t_t^C)\right]^{\chi^c} (1 - t_t^{W\chi^w}), \quad 0 \leq \chi^c, \chi^w \leq 1. \tag{26}$$

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

$$S_t = t_{t-1}^K \left(\delta^K K_{t-1}^{i,H} + \delta^A P_t^A A_{t-1}^{i,H}\right) + \tau^K J_t^{i,H} + \tau^A P_t^A J_t^{A,i,H}. \tag{27}$$

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

$$B_t = (1 + r_t)B_{t-1} + G_t + TR_t + BEN_t + S_t - R_t^G - T_t^{LS}. \tag{28}$$

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

$$\Delta T_t^{LS} = \tau^B \left(\frac{B_{t-1}}{Y_{t-1}} - b^T\right) + \tau^{DEF} \Delta \left(\frac{B_t}{Y_t}\right), \tag{29}$$

where b^T is the government debt target.

2.5 Determinants of the long run level of labour productivity, R&D share and skill premia

We use a slightly simplified version of the model with unit elasticity of substitution between skills, only two skill groups and inelastic supply of labour to derive the steady state solutions for productivity, the R&D share and the skill premium (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 (see eq 22). As shown in the appendix the share of high-skilled labour devoted to R&D is given by

$$s_{L,A/Y}(\underset{(0)}{mp_f}, \underset{(+)}{mp_i}, \underset{(-)}{\alpha}, \underset{(-)}{fc_a}, \underset{(+)}{g_A}, \underset{(+)}{n}, \underset{(-)}{\tau}) = \frac{\lambda\left(1-\frac{1}{1+mp_i}\right)(1-\alpha)(1-\tau)g_A}{\alpha r-\left(mp_i\left(1-\alpha\right)-\alpha\right)g_A-\alpha n}\frac{1}{1+fc_a}. \quad (30)$$

Eq. (30) shows that the share of R&D workers is highly dependent 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. (30) 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. A26 and A27).[5] As can also be seen from eq. (30), a reduction in entry barriers (fc_a) and an increase in R&D subsidies (τ) shifts labour from production into research. In order to calculate productivity we first note that we can express A as a positive function of the share of high skilled workers (L_t^H) and the share of high skilled workers devoted to R&D ($s_{L,A/Y}$)

[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.

$$A_t = \left(\frac{\nu}{g_A} A_t^{w\xi} \left(\frac{s_{L,A/Y} L_t^H}{1 + s_{L,A/Y}} \right)^{\lambda} \right)^{\frac{1}{1-\phi}} \tag{31}$$

However for total economy labour productivity there is a trade off between high skilled workers devoted to research and production, i. e. shifting labour to research reduces the efficiency of the labour aggregate in final production. As shown in the appendix we arrive at the following expression for labour productivity

$$y_t = \left(\frac{\nu \left(1 - \phi - \zeta\right)}{\lambda n} A_t^{w\xi} \right)^{\frac{\sigma}{\alpha} \frac{1}{1-\phi}} \left(\frac{\theta\eta(1-\alpha)}{r+\delta} \right)^{\frac{1-\alpha}{\alpha}} (1 - s_H)^{\frac{\alpha_L}{\alpha}} \left(\frac{s_H L_t}{1 + s_{L,A/Y}} \right)^{\frac{\alpha_H}{\alpha}} \left(\frac{s_H L_t}{1 + \frac{1}{s_{L,A/Y}}} \right)^{\frac{\sigma}{\alpha} \frac{\lambda}{1-\phi}}$$

Similarly the skill premium depends crucially on the share of workers in R&D production. A high demand of R&D workers reduces the supply of high skilled workers in the final goods production sector where relative wages are determined. As shown in the appendix, relative wages between high and low skilled workers can be expressed as follows

$$\frac{W^H}{W^L} = \frac{\alpha_H}{\alpha_L} \frac{L_t^{LY}}{L_t^{HY}} = \frac{\alpha_H}{\alpha_L} \left(\frac{L_t^{LY}(1 + s_{L,A/Y})}{L_t^H} \right)$$

3 Identifying structural differences between the EU and the US

3.1 Goods Market

The productivity gap between the US and the former EU15, as measured by GDP per hour worked, amounted to 13% on average between 1998 and 2007[6]. We identify the intermediate sector as the manufacturing sector and the final goods sector as the aggregate of all sectors without manufacturing. The manufacturing sector resembles the intermediate sector along various dimensions. First, this sector is more R&D and patent

[6] We focus here on the differences between the two regions. There are sizeable differences across the member states of the former EU15 and across states in the US but the variation in GDP per capita across EU15 member states is actually slightly lower than the variation across US states, when Luxembourg and the District of Columbia are excluded.

intensive, second, a large fraction of manufacturing supplies innovative goods (in the form of investment goods but also innovative consumer goods). Final goods sectors, including services, on the other hand are typically not subject to large (patented) innovations but rely on 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 degree of competition, with manufacturing showing smaller mark ups compared to final goods sectors. 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 final goods in the EU15 (24% vs. 20%) while mark ups in manufacturing are slightly lower in the EU15 (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 belongs to 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.

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 0.12% of GDP compared to 0.19% in the US[7]. 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[8]. However we can use the model together with all the other observable information to calculate a country specific risk premium. Using the free entry condition (eq 21) and eliminating P_t^A by using the definition of the R&D share allows us to express the risk premium as

$$rp_t^A = \frac{\eta\,(1-\theta)\,(1-\alpha)}{rdi_t\,(1+fc_A)} - \frac{\pi_{A,t} fc_A}{(1+fc_A)} - \frac{(1-\tau^A)(i_t - \pi_{t+1}^A + \delta^A) - t^K \delta^A}{(1-t^K)},$$

where rdi_t is the R&D-intensity: total R&D expenditure of the intermediate sector in percentage of GDP[9]. Our calibrated risk-premia for the EU15 is significantly higher then the one obtained for the US (2.5% vs. 1.6%). Is a 100 basis point difference in the risk premium a plausible number? Some recent research on the effects of capital market integration in the EU have used the US as a benchmark. Hardouvelis et al. (2004) reports remaining differences of 100BP, while Baele et al. (2004) estimates that equity

[7] 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.

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

[9] See Appendix 2.

and corporate bond risk premia differ by about 50BP after coming down by about 100BP.

3.3 Knowledge production technology

Empirical evidence on output elasticities has recently been provided by Bottazzi and Peri (2007) and Pessoa (2005). The growth rate of ideas were obtained from Pessoa (2005) with the assumption of a 5% obsolescence rate. Pessoa (2005) also estimated the semi-endogenous idea-production function for 21 OECD countries. In our model the R&D elasticity of research labour (λ) is determined by the wage cost share in the total R&D spending. Our calibrated values for the elasticity of research labour (λ), 0.40 and 0.44 respectively, and the stock of domestic intangible capital (ϕ), 0.62 and 0.70 resp., are very close to the ones reported in Pessoa (2005) (0.447 and 0.642 respectively). According to the empirically given and calibrated parameters (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 (A). 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). We set the level of domestic stock of knowledge for the EU at 1 and the US domestic stock of knowledge 30% higher, at 1.3 which roughly corresponds to the US vs. EU ratio of the number of patents in force registered by the WIPO in 2005[10].

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. (2009)) 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[11]. Data on skill-specific population shares, participation rates and wage-premia

[10] 2005 is the latest available year for most of the EU member states in the World Intellectual Property Organization (WIPO) database.

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

are obtained from OECD (2006), the Labour Force Survey and Science and Technology databases of EUROSTAT. The elasticity of substitution between different labour types (σ_L) 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 to fit the US and the EU production functions with the data. The other efficiency units are restricted by the labour demand equations which imply the following relationship between wages, skill-specific population and employment ratios, and efficiency units:

$$ef_M = \left(\frac{W_M}{W_L}\right)^{\frac{\sigma_L}{\sigma_L - 1}} \left(\frac{s_M}{s_L}\right)^{\frac{1}{1-\sigma_L}} \left(\frac{L^M}{L^L}\right)^{\frac{1}{\sigma_L - 1}} ef_L$$

$$ef_H = \left(\frac{W_H}{W_M}\right)^{\frac{\sigma_L}{\sigma_L - 1}} \left(\frac{s_{HY}}{s_M}\right)^{\frac{1}{1-\sigma}} \left(\frac{L^{HY}}{L^M}\right)^{\frac{1}{\sigma_L - 1}} ef_M. \tag{32}$$

3.5 R&D subsidies and taxes

The empirical evidence provided by Warda (1996 and 2006) indicates an average of 5 percentage point higher rate of R&D subsidies for the US based on the B-index.[12] Larger differences can be found in the case of labour taxation, with substantially higher tax rates in the EU compared to the US (see EUROSTAT and Coenen et al. (2007)).

sector as proxy for the wage level of the R&D labour.

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

Table 1: EU15 - US Parameter Comparison

	EU15	US	Source
R&D sector			
L^{HA}	0.007	0.011	EUROSTAT/OECD
R&D intensity (%)	1.908	2.670	EUROSTAT/OECD
Stock of "ideas" (A)	1.000	1.300	WIPO (US-EU ratio of patents in force)
λ	0.398	0.441	calibration (constrained by equations)
ϕ	0.619	0.704	Bottazzi-Peri (2007)
ξ	0.363	0.279	Bottazzi-Peri (2007)
(R&D efficiency)	0.082	0.090	calibration (constrained by equations)
Intermediate sector			
markup	0.11	0.12	ECFIN
risk-premia on intangibles			
(on annual basis)	0.025	0.016	calibration (constrained by equations)
fixed entry costs	0.31	0.02	Djankov et al. (2002)
Final goods sector			
mark up	0.242	0.205	own estimates
Skill distribution			
s_L	0.339	0.121	EUROSTAT/OECD
s_M	0.592	0.803	EUROSTAT/OECD
s_H	0.069	0.076	EUROSTAT/OECD
Employment rates			
L^L	0.575	0.654	EUROSTAT/OECD
L^M	0.757	0.841	EUROSTAT/OECD
L^H	0.842	0.944	EUROSTAT/OECD
σ_L	1.400	1.400	Katz and Murphy (1992)
(elasticity of. substitution)			
L	0.699	0.827	EUROSTAT/OECD
Skill premium %	34.60	39.00	EUROSTAT/OECD
(high vs. medium)			
Skill premium %	23.27	49.25	EUROSTAT/OECD
(medium vs. low)			
Efficiency levels			
ef_L	0.183	0.126	calibration (constrained by equations)
ef_M	0.381	0.511	calibration (constrained by equations)
ef_H	1.08	1.618	calibration (constrained by equations)
Taxes and subsidies			
B-index	0.98	0.93	Warda (2006)
Labour taxes	0.44	0.29	EUROSTAT/Coenen et al. (2007)
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 premia in the US.

4 Simulation results

This section tries to account for three stylized differences between the US and the EU15, namely the productivity gap, the higher share of R&D spending and the higher skill premium. Productivity per hour worked in purchasing power parities in the US exceeded the EU15 level by 13% between 1998-2007. R&D intensity was 0.76%p higher in the US and the gap in skill premia for high- versus medium-skilled workers was 4.4% .

4.1 Changing mark ups

Our estimates suggest that the US mark up in manufacturing exceeds the mark up in the EU15 by 1% point. As shown in Table 8, this difference has a negligible effect on productivity but explains some 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 0.12% points of the difference in R&D intensity which is more than 15% of the gap with the US, and also explain a small fraction of the high skilled skill premium (see Table 2).

Product market competition in the final goods sector explains a larger fraction of the productivity gap, namely 2.9%. As discussed in section 2.5, 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[13] (see Table 3). It is interesting to note that the (nominal) R&D share also increases slightly in this

[13] In contrast to the theoretical discussion in section 2.5 and the appendix, there is a slight increase in TFP because increased competition also increases labour supply of high skilled workers.

case. This is to a large extent the result from an increase in wages, or the skill premium which leads to an increase in the relative price of R&D.

Table 2: 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	-0.09	-0.25	-0.30	-0.34	-0.36	-0.38	-0.34	-0.17	-0.02
"Ideas/Patents"	0.03	0.52	1.17	1.76	2.31	3.26	4.72	6.72	7.86
Capital	-0.01	-0.21	-0.44	-0.63	-0.76	-0.94	-1.07	-0.99	-0.80
Employment	0.04	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02
-low	0.02	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-medium	0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.03
-high	-0.20	-1.01	-1.03	-1.00	-0.98	-0.94	-0.88	-0.80	-0.75
-R&D	3.70	8.49	8.38	8.16	7.96	7.62	7.11	6.45	6.09
Consumption	0.00	-0.01	-0.05	-0.08	-0.10	-0.11	-0.07	0.11	0.26
Investment	-0.26	-0.76	-0.88	-0.96	-1.01	-1.08	-1.09	-0.95	-0.79
Wages	-0.03	-0.08	-0.14	-0.18	-0.20	-0.22	-0.19	-0.05	0.09
-low	-0.06	-0.17	-0.23	-0.26	-0.28	-0.30	-0.27	-0.12	0.02
-medium	-0.06	-0.16	-0.21	-0.25	-0.27	-0.28	-0.25	-0.11	0.03
-high	0.16	0.58	0.51	0.46	0.42	0.37	0.36	0.45	0.56
R&D price	6.16	5.58	4.87	4.23	3.66	2.72	1.36	-0.31	-1.17
Int. price	0.29	0.20	0.34	0.45	0.53	0.66	0.78	0.82	0.78
R&D intensity	0.14	0.17	0.17	0.17	0.16	0.16	0.14	0.13	0.12

Table 3: 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	0.55	1.19	1.36	1.62	1.84	2.19	2.61	2.99	3.09
"Ideas/Patents"	0.02	0.15	0.23	0.30	0.37	0.50	0.72	1.08	1.32
Capital	0.06	0.94	1.80	2.46	2.99	3.79	4.74	5.54	5.74
Employment	0.43	0.52	0.27	0.25	0.24	0.24	0.23	0.23	0.23
-low	0.41	0.39	-0.13	-0.20	-0.20	-0.20	-0.18	-0.16	-0.16
-medium	0.43	0.60	0.43	0.42	0.42	0.40	0.39	0.37	0.37
-high	0.30	0.14	0.12	0.12	0.11	0.10	0.09	0.08	0.09
-R&D	1.80	1.39	1.03	1.04	1.07	1.10	1.13	1.10	1.04
Consumption	0.16	0.30	0.51	0.77	0.97	1.29	1.68	2.03	2.13
Investment	1.33	3.13	3.34	3.69	4.00	4.49	5.09	5.60	5.74
Wages	1.11	3.47	3.88	4.14	4.34	4.67	5.06	5.41	5.50
-low	1.06	3.56	4.18	4.46	4.66	4.97	5.35	5.68	5.78
-medium	1.10	3.40	3.75	3.99	4.20	4.53	4.93	5.28	5.38
-high	1.30	3.74	3.97	4.22	4.43	4.75	5.15	5.50	5.59
R&D price	5.12	4.39	4.47	4.67	4.85	5.10	5.35	5.40	5.28
Int. price	1.35	2.17	1.68	1.38	1.14	0.79	0.39	0.08	0.00
R&D intensity	0.10	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06

4.2 Reducing administrative start up costs

In this simulation we account for a 95% reduction in EU entry costs. According to our simulations (see Table 4), entry barriers explain a productivity gap of around 1.4% and about 40% of the lower EU R&D share. Decreasing entry costs lowers the profit requirement for intermediate producers and thus increases entry of new firms. 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 increasing productivity and knowledge investment compared to an increase in mark ups because the former does not lead to an increase in the price of intermediate goods.

Table 4: Decreasing the entry costs of the intermediate sector to the US-level

Years	1	5	10	15	20	30	50	100	200
GDP	-0.04	-0.11	-0.06	0.00	0.06	0.20	0.47	1.00	1.43
"Ideas/Patents"	0.06	1.03	2.34	3.57	4.72	6.80	10.17	15.36	18.98
Capital	0.00	-0.04	-0.09	-0.11	-0.11	-0.06	0.15	0.70	1.23
Employment	0.02	0.02	0.02	0.01	0.01	0.01	0.00	-0.01	-0.01
-low	-0.01	-0.01	0.00	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01
-medium	-0.01	0.01	0.02	0.01	0.01	0.01	0.00	-0.01	-0.01
-high	-0.49	-2.03	-2.12	-2.09	-2.07	-2.03	-1.96	-1.86	-1.80
-R&D	7.50	17.45	17.51	17.30	17.09	16.73	16.16	15.32	14.77
Consumption	-0.05	-0.08	-0.02	0.05	0.11	0.26	0.54	1.07	1.49
Investment	-0.04	-0.16	-0.16	-0.13	-0.09	0.02	0.27	0.80	1.25
Wages	0.05	0.13	0.18	0.23	0.29	0.41	0.65	1.12	1.49
-low	0.00	-0.02	0.02	0.08	0.13	0.26	0.51	0.98	1.35
-medium	-0.01	-0.04	0.00	0.06	0.12	0.24	0.49	0.97	1.35
-high	0.43	1.52	1.56	1.60	1.64	1.73	1.93	2.34	2.67
R&D price	12.77	11.69	10.52	9.46	8.51	6.87	4.40	1.00	-1.13
Int. price	-0.03	-0.04	0.03	0.08	0.12	0.17	0.20	0.14	0.03
R&D intensity	0.29	0.36	0.36	0.35	0.35	0.34	0.33	0.31	0.30

4.3 Reducing risk premium on intangible capital

The simulation in Table 5 is designed as a 36% 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 reduction of start up costs. Our calibration suggests that financial frictions are nearly as important for explaining productivity and knowledge investment differences than administrative start up costs.

Table 5: Decreasing the risk premia on intangibles to US-level

Years	1	5	10	15	20	30	50	100	200
GDP	-0.04	-0.11	-0.06	0.00	0.07	0.21	0.48	0.98	1.34
"Ideas/Patents"	0.07	1.06	2.39	3.63	4.77	6.79	9.96	14.45	17.15
Capital	0.00	-0.04	-0.09	-0.11	-0.11	-0.05	0.16	0.70	1.16
Employment	0.03	0.02	0.02	0.01	0.01	0.00	0.00	-0.01	-0.01
-low	-0.01	-0.01	0.00	-0.01	-0.01	-0.02	-0.02	-0.02	-0.01
-medium	-0.01	0.01	0.02	0.01	0.01	0.01	0.00	-0.01	-0.01
-high	-0.50	-2.07	-2.13	-2.08	-2.04	-1.97	-1.85	-1.70	-1.61
-R&D	7.72	17.76	17.61	17.21	16.85	16.22	15.26	13.96	13.21
Consumption	-0.04	-0.08	-0.02	0.05	0.12	0.27	0.54	1.04	1.39
Investment	-0.05	-0.17	-0.16	-0.13	-0.08	0.03	0.28	0.79	1.18
Wages	0.05	0.14	0.18	0.23	0.29	0.41	0.64	1.08	1.39
-low	0.00	-0.02	0.02	0.08	0.14	0.27	0.51	0.95	1.26
-medium	-0.01	-0.04	0.01	0.06	0.12	0.25	0.49	0.94	1.26
-high	0.44	1.54	1.57	1.59	1.61	1.68	1.85	2.18	2.43
R&D price	13.14	11.92	10.61	9.43	8.39	6.61	4.01	0.65	-1.19
Int. price	-0.03	-0.03	0.03	0.08	0.13	0.18	0.20	0.13	0.03
R&D intensity	0.30	0.37	0.36	0.35	0.34	0.33	0.31	0.28	0.27

4.4 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 in terms of the B-index. 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 6). Subsidising R&D also increases wages/skill premium of high skilled workers, suggesting the presence of crowding out effects. This is consistent with empirical evidence reported by Goolsbee (1998).

Table 6: Increasing the R&D subsidies to the US-level

Years	1	5	10	15	20	30	50	100	200
GDP	0.00	-0.02	-0.01	0.01	0.03	0.06	0.13	0.26	0.34
"Ideas/Patents"	0.02	0.27	0.60	0.90	1.18	1.67	2.41	3.43	4.00
Capital	0.00	-0.02	-0.03	-0.03	-0.03	-0.01	0.05	0.19	0.30
Employment	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
-low	0.01	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.04
-medium	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.01
-high	-0.11	-0.50	-0.52	-0.51	-0.49	-0.47	-0.44	-0.41	-0.38
-R&D	1.90	4.30	4.25	4.15	4.05	3.89	3.63	3.30	3.12
Consumption	0.00	-0.01	0.00	0.02	0.04	0.08	0.15	0.27	0.36
Investment	-0.02	-0.05	-0.04	-0.03	-0.01	0.02	0.08	0.21	0.30
Wages	0.01	0.03	0.04	0.05	0.07	0.10	0.16	0.27	0.34
-low	-0.01	-0.03	-0.03	-0.01	0.00	0.04	0.10	0.21	0.29
-medium	0.00	0.00	0.01	0.02	0.04	0.07	0.14	0.25	0.32
-high	0.11	0.37	0.38	0.38	0.39	0.41	0.45	0.53	0.59
R&D price	3.20	2.92	2.61	2.32	2.07	1.63	0.98	0.14	-0.31
Int. price	0.01	0.00	0.01	0.03	0.04	0.05	0.05	0.03	0.01
R&D intensity	0.07	0.09	0.09	0.08	0.08	0.08	0.07	0.07	0.06

4.5 Discussion of results (sensitivity analysis)

Our results show a clear ranking of those factors which can partially explain the three stylised differences between the EU15 and the US.

Along the productivity dimension, the most important factor appears to be mark up differences in final goods production. Entry barriers and risk premia in the financing of start ups are significant as well and about equally important. Less important are differences in R&D subsidies. The four factors explain about half of the labour productivity gap between the EU and the US. There are other important differences between the EU and the US, which we have identified in our calibration, such as differences in the skill composition of the labour force and differences in the efficiency of individual skill groups. The US has a larger share of high skilled workers and high skilled workers in the US have higher efficiency levels. Both factors are likely to contribute significantly in explaining the remaining productivity gap. These differences are likely to be related to differences in the education system and migration policies which have not been the focus of our analysis.

Knowledge investment (R&D intensity) is to a large extent explained by entry conditions in intermediate goods production, i.e. both by differences in administrative entry costs and financing conditions. Lowering entry barriers unambiguously increases the demand for patents. Market structure in both final and intermediate goods production has ambiguous effects on knowledge investment. Increased competition in final goods production increases both the demand for labour in production and for R&D labour via an increase in the demand for intermediate goods, i.e. it does not lead to a relocation of resources from production to research but only has an effect on research via an increase in the supply of labour. An increase in the mark up of intermediate goods increases the demand for patents because it increases the present discounted value of profits in intermediate goods production, but since it is associated with an increase in intermediate goods prices there is a reduction of demand for intermediates, which partly offsets the positive effect from increased profits.

The factors explaining knowledge investment also explain the skill premium between high skilled and medium skilled workers. In particular the increase in the intermediate mark up and the reduction in risk premia explain this skill premium. [14]

Since there are large differences concerning labour supply elasticities and relatively little information about elasticity of substitution between skills, the appendix contains a sensitivity analysis w.r.t. these two parameters. It is shown that our results are not affected by changing the parameter values within plausible bands.

[14] The model is less successful in explaining the wage differentials between medium and low skilled workers. But it must be kept in mind that the model has not been designed to analyse the skill premium between these two types, which is determined to a large part by exogenous differences in their efficiency levels.

Table 7: Full structural change of the EU economy

Years	1	5	10	15	20	30	50	100	200
GDP	0.38	0.71	0.93	1.29	1.64	2.28	3.35	5.04	6.17
"Ideas/Patents"	0.20	3.02	6.72	10.16	13.34	19.00	27.96	40.99	49.25
Capital	0.05	0.63	1.15	1.58	1.99	2.73	4.02	6.14	7.61
Employment	0.53	0.56	0.30	0.27	0.26	0.24	0.22	0.20	0.20
-low	0.41	0.41	-0.09	-0.17	-0.19	-0.19	-0.18	-0.16	-0.14
-medium	0.44	0.61	0.44	0.43	0.41	0.39	0.36	0.33	0.31
-high	-1.00	-5.47	-5.67	-5.56	-5.47	-5.30	-5.04	-4.68	-4.46
-R&D	22.59	49.33	48.74	47.81	46.97	45.50	43.23	40.08	38.19
Consumption	0.07	0.12	0.43	0.80	1.15	1.78	2.84	4.50	5.62
Investment	0.96	1.98	2.10	2.44	2.80	3.47	4.62	6.44	7.67
Wages	1.20	3.69	4.13	4.47	4.78	5.36	6.32	7.80	8.80
-low	0.98	3.31	3.97	4.34	4.66	5.24	6.20	7.69	8.68
-medium	1.02	3.16	3.55	3.89	4.21	4.80	5.79	7.32	8.33
-high	2.43	7.75	7.99	8.24	8.49	8.94	9.73	10.98	11.83
R&D price	40.35	36.46	33.03	30.09	27.45	22.91	16.08	6.89	1.49
Int. price	1.59	2.31	2.09	2.01	1.95	1.83	1.61	1.19	0.86
R&D intensity	0.91	1.06	1.04	1.02	1.00	0.97	0.92	0.86	0.82

Table 8: US-EU gaps explained by differences in exogenous variables

	Y/L	Skill premium high vs. medium	R&D intensity
Increase mark up (intermediates)	0.00	1.76	0.12
Lower mark up (final goods)	2.85	0.27	0.06
Reducing entry barrier	1.43	0.71	0.30
Reducing risk premia	1.34	1.55	0.27
R&D subsidies	0.34	0.36	0.06
Total	5.96	4.65	0.82
Initial gap	13.00	4.40	0.76

5 Conclusions

Reaching approximately US levels of productivity and R&D spending are among the most prominent Lisbon targets agreed by EU governments in the year 2000. This paper uses a semi-endogenous growth model to identify possible sources for the productivity and the R&D spending gap between the EU and the US as well as larger skill premia for high skilled workers in the US. Identifying the main causes for these differences is a prerequisite for defining possible reform areas which would contribute mostly towards closing these gaps. 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. Another important obstacle to higher productivity levels are entry barriers in innovating sectors. Reducing these 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 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 capture innovation rents and they must therefore be seen as the outcome of innovative activities of firms, leading to products which are more complicated to imitate by competitiors. The factors which explain productivity and knowledge investment differentials between the US and the EU also explain the difference in the skill premium between high and medium skilled workers. Our analysis thus suggest that closing the productivity gap with the US would be associated with a slightly larger wage inequality. The structural features we have concentrated on in this paper can explain a significant share of the productivity gap between the EU and the US. Our model calibration also shows that there are other differences between the two economies related to human capital endowments, in particular a larger share of high skilled workers and a larger efficiency dispersion across skill groups in the US. These are largely orthogonal to the structural features and policies we have concentrated on in this paper and are most likely related to differences in education and migration policies. Assessing the impact of these differences would be an interesting task for future research.

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

The Economic Environment

For illustration purposes we consider a simplified structure of the original economic model with two types of labour, low- and high-skilled and Ricardian households with inelastic labour supply.

We assume that monopolistically competitive firms in the final goods sector use an A_t variety of intermediates and an aggregate (L^Y) of the low- and high-skilled labour types L^{LY} and L^{HY} in the production process

$$Y_t = \left(\int_0^{A_t} x_t(i)^\theta di \right)^{(1-a)/\theta} L_t^Y \tag{A1}$$

with unit elasticity of substitution between skills

$$L_t^Y = (L_t^{LY})^{\alpha_L} (L_t^{HY})^{\alpha_H}, \quad \alpha_L + \alpha_H = \alpha.$$

High-skilled workers can work in the final goods and the R&D sector (L_t^{HA}):

$$L_t^H = L_t^{HY} + L_t^{HA}$$

and the total labour force grows exogenously:

$$L_t^{LY} + L_t^{HY} + L_t^{HA} = L_t = L_0 e^{nt}. \tag{A2}$$

Tangible and intangible capital accumulation follow:

$$K_t = \int_0^{A_t} x_t(i) di, \tag{A3}$$
$$\dot{K}_t = Y_t - C_t - \delta K_t$$

$$\dot{A}_t = \nu A_t^{w\xi} A_t^\phi \left(L_t^{HA} \right)^\lambda. \tag{A4}$$

The representative household optimizes its utility function over time:

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

Demand of final goods sector for low and high-skilled labour are

$$W_t^H = \alpha_H \eta \frac{Y_t}{L_t^{HY}}$$
$$W_t^L = \alpha_L \eta \frac{Y_t}{L_t^{LY}}, \tag{A6}$$

where η denotes the inverse gross mark-up in the final goods sector. Finally, the arbitrage condition of entering into the intermediate sector is

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

where $g_{P_A} = \frac{\dot{P}_t^A}{P_t^A}$, 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

$$\frac{\dot{A}_t}{A_t} = \nu A_t^{w\xi} A_t^{\phi-1} \left(L_t^{HA}\right)^{\lambda} \rightarrow g_A = \frac{\lambda}{1-\phi-\zeta} n. \tag{A8}$$

From the symmetric structure of the model follows that

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

for all varieties.

Therefore the aggregate production function can be rewritten as

$$Y_t = A_t^{\sigma} L_t^Y K_t^{1-\alpha}, \quad \sigma = \left(\frac{1}{\theta} - 1\right)(1-\alpha). \tag{A1'}$$

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:

$$\begin{aligned} \lambda \frac{P_t^A \dot{A}_t}{L_t^{HA}} &= W_t^H, \text{ or} \\ \lambda P_t^A g_A A_t &= W_t^H L_t^{HA} \end{aligned} \tag{A11}$$

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

$$s_A = \frac{P_t^A \dot{A}_t}{Y_t} \tag{A12}$$

or equivalently

$$s_A = \frac{1}{\lambda} \cdot \frac{W_t^H L_t^{HA}}{Y_t}.$$

Dividing (A11) by A_t and differentiating we can solve for $\frac{\dot{P}_t^A}{P_t^A} = g_{P_A}$:

$$\frac{\dot{P}_t^A}{P_t^A} = g_Y - g_A. \tag{A13}$$

The arbitrage equation can be rewritten as

$$(1 + fc_a)P_t^A = \frac{(1-\tau)\pi_t}{r - (g_Y - g_A)}. \tag{A7'}$$

Intermediate sector's profit

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

$$i^K = \theta\eta(1-a)\left(\int_0^{A_t} x_t(i)^\theta di\right)^{(1-a)/\theta-1} L_t^Y x_t(i)^{\theta-1}, \tag{A14}$$

where from the symmetric structure of the model 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:

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

Notice that P_t^A can be expressed from (A12) as $P_t^A = \frac{s_A Y_t}{\dot{A}_t} = \frac{s_A Y_t}{g_A A_t}$ and substitute it back to (A16):

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

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 8 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^{HA}/L^{HY} ratio

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

$$s_{L,A/Y} = \frac{L_t^{HA}}{L_t^{HY}} = \frac{W_t^H L_t^{HA}}{W_t^H L_t^{HY}} = \frac{\lambda s_A Y_t}{\alpha\eta Y_t} = \frac{\lambda}{\alpha\eta}s_A = \frac{\lambda\left(1+mp_f\right)s_A}{\alpha}$$

We can rewrite this ratio as

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

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.

Skill premium

From the ratio of high-skilled R&D employment relative to the final goods sector's high-skilled employment $s_{L,A/Y}$, we can express L_t^{HA} as

$$L_t^{HA} = \frac{s_{L,A/Y}L_t^H}{1+s_{L,A/Y}} \tag{A21}$$

and L_t^{HY}:

$$L_t^{HY} = \frac{L_t^H}{1+s_{L,A/Y}} \tag{A22}$$

Using the first order conditions for employment in the final goods sector (eqs. A6), the skill premium is given by

$$\frac{W^H}{W^L} = \frac{\alpha_H}{\alpha_L}\frac{L_t^{LY}}{L_t^{HY}} = \frac{\alpha_H}{\alpha_L}\left(\frac{L_t^{LY}(1+s_{L,A/Y})}{L_t^H}\right) \tag{A23}$$

This expression shows, the skill premium is proportional to the output elasticity of skill specific labour in final goods production, it depends inversely on the relative supply of skilled labour and it is a positive function of the real R&D share (and therefore all the parameters which determine the real R&D share).

Labour productivity

First we determine the capital stock from the first order condition of the intermediate sector:

$$K = \left(\frac{\eta(1-\alpha)\theta}{r+\delta}\right)Y$$

Therefore labour productivity is given by

$$y_t = A_t^{\frac{\sigma}{\alpha}}\left(\frac{\eta(1-\alpha)\theta}{r+\delta}\right)^{\frac{1-\alpha}{\alpha}}\left(\left(\frac{L_t^{LY}}{L}\right)^{\alpha_L}\left(\frac{L_t^{HY}}{L}\right)^{\alpha_H}\right)^{\frac{1}{\alpha}} \tag{A24}$$

using (A1') and (A3). Along the balanced growth path, the stock of knowledge can be obtained from (A8)

$$A_t = \left(\frac{\nu}{g_A}A_t^{w\xi}\left(\frac{s_{L,A/Y}L_t^H}{1+s_{L,A/Y}}\right)^{\lambda}\right)^{\frac{1}{1-\phi}} \tag{A8'}$$

Denote $\frac{L_t^H}{L_t} = s_H$ and note that $\frac{L_t^{HY}}{L} = \frac{s_H L_t}{1+s_{L,A/Y}}$ and $L_t^{HA} = \frac{s_H L_t}{1+\frac{1}{s_{L,A/Y}}}$, therefore

$$y_t = A_t^{\frac{\sigma}{\alpha}}\left(\frac{\eta(1-\alpha)\theta}{r+\delta}\right)^{\frac{1-\alpha}{\alpha}}(1-s_H)^{\frac{\alpha_L}{\alpha}}\left(\frac{s_H L_t}{1+s_{L,A/Y}}\right)^{\frac{\alpha_H}{\alpha}} \tag{A25}$$

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

$$s_K = \frac{\theta\eta(1-\alpha)\left(n+g_k+\delta\right)}{r+\delta} \tag{A26}$$

Finally, combining (A25) and (A8') 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

$$y_t = \left(\frac{\nu\left(1-\phi-\zeta\right)}{\lambda n}A_t^{w\xi}\right)^{\frac{\sigma}{\alpha}\frac{1}{1-\phi}}\left(\frac{\theta\eta(1-\alpha)}{r+\delta}\right)^{\frac{1-\alpha}{\alpha}}(1-s_H)^{\frac{\alpha_L}{\alpha}}\left(\frac{s_H L_t}{1+s_{L,A/Y}}\right)^{\frac{\alpha_H}{\alpha}}\left(\frac{s_H L_t}{1+\frac{1}{s_{L,A/Y}}}\right)^{\frac{\sigma}{\alpha}\frac{\lambda}{1-\phi}}. \tag{A27}$$

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 in discrete time setting can be summarized as

$$\Delta A_t = \nu {A_{t-1}^{w}}^{\xi} A_{t-1}^{\phi} \left(L_t^{HA}\right)^{\lambda} \tag{a}$$

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

$$\lambda \cdot P_t^A \Delta A_t = W_t^H \cdot L_t^{HA} \tag{c}$$

$$rdi_t = \frac{P_t^A g_A A_{t-1}}{P_t Y_t} \tag{d}$$

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

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

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

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.

We set the level of domestic stock of knowledge (A) for the EU at 1 and the US domestic stock of knowledge 30% higher, at 1.3 which roughly corresponds to the US vs. EU ratio of the number of patents in force registered by the World Intellectual Property Organization (WIPO). Although we do not have direct estimates of ν, ϖ, ϕ and λ for each region respectively, 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_t^{HA}) and on the R&D intensity $\left(\frac{P_t^A \Delta A_t^D}{P_t Y_t}\right)$ is obtained from EUROSTAT, the values of g_A and g_n are given in our baseline model[15]. Note that in our model the output elasticity of research labour (λ) corresponds to the wage share of R&D labour in the total R&D spending (equation c). These values together with the restrictions of the balanced growth dynamics and other variables of the baseline pin down 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 second step we use

[15] 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.

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[16]. In the last step we subtract this value from the sum of ϕ and ϖ as we calculated from equation (b) earlier. Finally, we normalize the stock of foreign ideas to one and therefore ν can be obtained from expression (a).

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 the stock of domestic ideas (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[17]. 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:

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

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

[17] 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.

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 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 (6) 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) and the labour-supply elasticity ($1/\kappa$). The following tables compare the baseline simulations with two 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)) and b.) by imposing more and c.) less elastic labour supply (setting κ to 3 and 5 instead of 4). The simulations suggest that under the empirically plausible range of the elasticity of substitution between skill-groups and of the elasticity of labour supply, the results do not change significantly.

Table 9: Productivity gap under higher EOF between skill groups

	Y/L	Skill premium high vs. medium	R&D intensity
Lower mark up (final goods)	2.86	0.22	0.06
Increase mark up (intermediates)	0.01	0.57	0.12
Reducing entry barrier	1.48	1.43	0.30
Reducing risk premia	1.37	1.26	0.27
R&D subsidies	0.34	0.29	0.06
Total	6.06	3.78	0.81
Initial gap	10.90	4.40	0.76

Table 10: Productivity gap under with less elastic labour supply

	Y/L	Skill premium high vs. medium	R&D intensity
Lower mark up (final goods)	2.90	0.36	0.06
Increase mark up (intermediates)	0.00	0.78	0.12
Reducing entry barrier	1.44	1.95	0.30
Reducing risk premia	1.35	1.73	0.27
R&D subsidies	0.34	0.40	0.06
Total	6.03	5.22	0.81
Initial gap	10.90	4.40	0.76

Table 11: Productivity gap under with more elastic labour supply

	Y/L	Skill premium high vs. medium	R&D intensity
Lower mark up (final goods)	2.85	0.27	0.06
Increase mark up (intermediates)	0.00	1.76	0.12
Reducing entry barrier	1.43	0.71	0.30
Reducing risk premia	1.34	1.55	0.27
R&D subsidies	0.33	0.36	0.06
Total	5.95	4.65	0.82
Initial gap	10.90	4.40	0.76