CHAPTER 6

The QUEST III R&D Model

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6.1 Introduction

The QUEST III model is a global DSGE model from the Directorate-General Economic and Financial Affairs (DG ECFIN) of the European Commission employed for the quantitative analysis of various types of policies. More specifically the model has been used by DG ECFIN to analyse reforms such as the increase of the employment of low-skilled workers, the change in the skill composition of the labour force, fiscal measures for increasing investment in knowledge, the removal of entry barriers and administrative burdens in certain markets, and the effects of financial market imperfections.[1] QUEST III is a useful and robust

[1] For more information about the different applications of QUEST III, visit https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/economic-research/macroeconomic-models_en.

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tool to (i) explicitly model the reforms in terms of concrete and quantifiable policy measures, such as taxes, benefits, subsidies and education expenditures, administrative costs faced by firms (for both entrants and incumbents) and regulatory indices; (ii) assess the impact of each policy measure on a comprehensive set of macroeconomic indicators such as GDP growth, employment, the composition of investment and skill premia in the short, medium and long run; and (iii) provide insights into the transmission mechanisms of various structural and fiscal measures.

6.2 The model

The version of QUEST III presented in this book captures both investment in tangibles and intangibles (R&D), while also disaggregating employment into various skill categories.[2] The framework adopted is the Jones (1995, 2005) extension of the Romer (1990) model, augmented with mark-ups for the final goods sector and entry costs for the intermediate sector. The equations in the model are explicitly derived from intertemporal optimisation under technological, institutional and budgetary constraints, while the model incorporates nominal, real and financial frictions in order to fit the data. In the model, there are two types of households, namely liquidity and non-liquidity constrained, a feature which has become standard in Dynamic Stochastic General Equilibrium modelling. Three types of labour skills, low, medium and high, are considered that allow to conduct more detailed human capital reforms. The model also includes a fiscal and monetary authority with the appropriate decision rules. Importantly, the model is multi-country, with individual country blocks interlinked via international trade and knowledge spillovers.[3] While Jones (1995, 2005) were theoretical, illustrative models, QUEST III is brought to the data and calibrated on actual data of the countries of interest.

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

[2] This section draws heavily from the description contained in Roeger et al. (2014).

[3] The model can be used in a one-country, open-economy version and it can also be extended to more regions (e.g. Euro Area and non-Euro Area blocks of the EU, US, Asia, major oil-exporters). Individual European Union member states can also be modelled separately in interaction with the rest of the EU.

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. Non-liquidity constrained 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 commonly available domestic and foreign stock of knowledge. Technological change is modelled as increasing product variety in the tradition of Dixit and Stiglitz (1977).

6.2.1 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.[4] The remaining share ϵ of households is liquidity constrained and indexed by $k \in [1-\epsilon, 1]$. These households cannot trade in financial and physical assets and consume their disposable income each period. The members of both types of households offer low-, medium- and high-skilled labour services indexed by $s \in \{L, M, H\}$. For each skill group, we assume that both types of 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 households face adjustment costs for changing wages.

[4] It is important to note that in a semi-endogenous model, the number of intermediate good varieties (A_t) can be interpreted in multiple ways. It corresponds to the total number of designs (or patents) invented by the R&D sector but at the same time, it can be interpreted as the stock of ideas or as the stock of knowledge (or intangible) capital in the economy. Also, it can be considered as an endogenous total factor productivity element.

Non-liquidity constrained households

Non-liquidity constrained households maximise an intertemporal utility function in consumption and leisure subject to a budget constraint. These households make decisions about consumption $C_{i,t}$, labour supply $L_{i,t}$, purchases of investment good $J_{i,t}$ and government bonds $B_{i,t}$, the renting of physical capital stock $K_{i,t}$, the purchases of new patents from the R&D sector $J_{A,i,t}$, and the licensing of existing patents $A_{i,t}$, and receives wage income $W_{s,t}$, unemployment benefits $bW_{s,t}$, transfer income from the government $TR_{i,t}$, and interest income, i_t, $i_{K,t}$ and $i_{A,t}$.[5] Hence, non-liquidity constrained households face the following Lagrangian

$$\max_{\left\{\begin{matrix} C_{i,t}, L_{i,s,t}, B_{i,t}, J_{i,t}, \\ K_{i,t}, J_{A,i,t}, A_{i,t} \end{matrix}\right\}_{t=0}^{\infty}} V_{i,0} = E_0 \sum_{t=0}^{\infty} \left(U(C_{i,t}) + \sum_{s \in \{L,M,H\}} V(1 - L_{i,s,t}) \right)$$

$$\begin{aligned}
&- E_0 \sum_{t=0}^{\infty} \lambda_{i,t} \frac{\beta^t}{P_t} \Big((1 + t_{C,t}) P_{C,t} C_{i,t} + B_{i,t} \\
&+ P_{i,t} \Big(J_{i,t} + \Gamma_J(J_{i,t}) \Big) P_{A,t} J_{A,i,t} \\
&- (1 + i_{t-1}) B_{i,t-1} \\
&- \sum_s \big((1 - t_{w,s,t}) W_{s,t} L_{i,s,t} \\
&+ bW_{s,t}(1 - NPART_{i,s,t} - L_{i,s,t}) \big) \\
&- (1 - t_K)\big(i_{K,t-1} - rp_K\big) P_{I,t-1} K_{i,t-1} \\
&- t_K \delta_K P_{I,t-1} K_{i,t-1} - \tau_K P_{I,t} J_{i,t} \\
&- (1 - t_K)\big(i_{A,t-1} - rp_A\big) P_{A,t-1} A_{i,t-1} \\
&- t_K \delta_K P_{A,t-1} K_{i,t-1} - \tau_K P_{A,t} J_{A,i,t} \\
&- TR_{i,t} - \int_0^N PR_{fin,j,i,t} dj
\end{aligned}$$

[5] 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 on 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.

$$
\begin{aligned}
&- \int_0^{A_t} PR_{int,m,i,t}\, dm\Big) \\
&- E_0 \sum_{t=0}^{\infty} \lambda_{i,t}\xi_{i,t}\beta^t \Big(K_{i,t} - J_{i,t} \\
&- (1-\delta_K)K_{i,t-1}\Big) \\
&- E_0 \sum_{t=0}^{\infty} \lambda_{i,t}\psi_{i,t},\, \beta^t \Big(A_{i,t} - J_{A,i,t} \\
&- (1-\delta_A)A_{i,t-1}\Big)
\end{aligned} \tag{6.1}
$$

where s is the index for the corresponding low- (L), medium- (M) and high-skilled (H) labour type respectively $(s \in \{L, M, H\})$. The budget constraints are written in real terms with prices for consumption, investment and patents $(P_{C,t},\ P_{I,t},\ P_{A,t})$ and wages $(W_{s,t})$ divided by the GDP deflator (P_t). All firms of the economy are owned by non-liquidity constrained households who share the total profit of the final and intermediate sector firms, $\int_0^N PR_{fin,j,i,t}\, dj$ and $\int_0^{A_t} PR_{int,m,i,t}\, dm$, 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 wage income taxes $(t_{w,s,t})$, consumption taxes $(t_{C,t})$ and t_K capital income taxes less tax credits $(\tau_K$ and $\tau_A)$ and depreciation allowances $(t_K\delta_K$ and $t_K\delta A)$ after their earnings on physical capital and patents. When investing into tangible and intangible capital, households demand risk premia rp_K and rp_A in order to cover the risk inherent to the return related to these assets.

The utility function is additively separable in consumption $C_{i,t}$ and leisure $1 - L_{i,s,t}$. Log-utility for consumption as well as the presence of habit persistence is assumed.

$$U(C_{i,t}) = (1 - habc)\log(C_{i,t} - habcC_{i,t-1}). \tag{6.2}$$

CES preferences with common labour supply elasticity are assumed for leisure, 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

$$V(1 - L_{i,s,t}) = \frac{\omega}{1-\kappa}(1 - L_{i,s,t})^{1-\kappa}, \quad \text{with} \quad \kappa > 0 \tag{6.3}$$

For the sake of brevity, the following derivations of the optimality equations focus only on the ones related to the R&D investments made by non-liquidity constrained households. These households buy new patents of designs produced by the R&D sector $I_{A,t}$ and rent their total stock of designs A_t at rental rate $i_{A,t}$ to intermediate goods producers in period t. Households pay income tax at a rate t_K on the period return of intangibles and receive tax subsidies at rate τ_A.[6] Hence, the first-order conditions with respect to R&D investments are given by:

$$\frac{\partial V_0}{\partial A_{i,t}}: \quad -\lambda_{i,t}\psi_{i,t} + E_t\Big(\lambda^i_{t+1}\psi^i_{t+1}\beta(1-\delta_A) + \lambda_{i,t+1}\beta\frac{P_{A,t}}{P_{t+1}}\big((1-t_K)(i_{A,t}-rp_A)+t_K\delta A\big)\Big) = 0 \tag{6.4}$$

$$\frac{\partial V_0}{\partial J_{A,i,t}}: \quad -\frac{P_{A,t}}{P_t}(1-\tau_A)+\psi_{i,t} = 0 \tag{6.5}$$

Neglecting second-order terms, it can be shown that the rental rate of intangible capital is:

$$i_{A,t} \approx E_t\frac{(1-\tau_A)\big(i_t-\pi_{A,t+1}+\delta_A(1+\pi_{A,t+1})\big)-t_K\delta_A}{1-t_K} + rp_A \tag{6.6}$$

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

Hence, households 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.

Liquidity constrained households

Liquidity constrained households do not optimise but simply consume their current income at each date. Real consumption of household k is

[6] For a more detailed description of all the optimality conditions, the reader is again referred to Roeger et al. (2014).

thus determined by the net wage income plus net transfers

$$(1+t_{C,t})P_{C,t}C_{k,t} = \sum_{s\in L,M,H}\Big(\Big(1-t_{w,s,t}\Big)W_{s,t}L_{k,s,t} + bW_{s,t}(1-NPART_{k,s,t}-L_{k,s,t})\Big) + TR_{k,t}. \tag{6.7}$$

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 $\frac{1}{\eta_{s,t}}$ over the reservation wage.[7] The reservation wage is equal to 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 reads

$$\frac{U_{1-L,h,st}}{U_{C,h,s,t}}\frac{1}{\eta_{s,t}} = \frac{W_{s,t}(1-t_{w,s,t}-b)}{P_{C,t}(1+t_{C,t})} \qquad \text{for} \qquad h\in\{i,k\} \text{ and } s\in\{L,M,H\}. \tag{6.8}$$

Aggregation

The aggregate of any household-specific variable $X_{h,t}$ in per capita terms is given by

$$X_t = \int_0^1 X_{h,t}\,dh = (1-\epsilon)X_{i,t} + \epsilon X_{k,t}, \tag{6.9}$$

Hence, aggregate consumption and employment is given by

$$C_t = (1-\epsilon)C_{i,t} + \epsilon C_{k,t} \text{ and } L_t = (1-\epsilon)L_{i,t} + \epsilon L_{k,t}. \tag{6.10}$$

[7] 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 indexes the growth rate of wages π_W to wage inflation in the previous period $\eta_{s,t} = 1-\frac{1}{\sigma_s}-\frac{\gamma_W}{\sigma_s}\big(\beta(sfw\pi^w_{W,t+1}-(1-sfw)\pi_{W,t-1})-\pi_{W,t}\big)$.

6.2.2 Firms

Final output producers

Since each firm j 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.[8] Final output Y_t is produced using A_t varieties of intermediate inputs $x_{m,t}$ with an elasticity of substitution $\frac{1}{1-\theta} > 1$. The final good sector uses labour aggregate $L_{Y,t}$ and intermediate goods with Cobb-Douglas technology, subject to a fixed cost FC_Y and overhead labour FC_L

$$Y_t = \left(L_{Y,t} - FC_L\right)^{\alpha}\left(\int_0^{A_t}\left(x_{m,t}\right)^{\theta} dm\right)^{\frac{1-\alpha}{\theta}} KG_t^{\alpha_G} - FC_Y, \quad 0 < \theta < 1 \tag{6.11}$$

with

$$L_{Y,t} = \left(\Lambda_L^{\frac{1}{\mu}}\left(\chi_L L_{L,t}\right)^{\frac{\mu-1}{\mu}} + \Lambda_M^{\frac{1}{\mu}}\left(\chi_M L_{M,t}\right)^{\frac{\mu-1}{\mu}} + \Lambda_{HY}^{\frac{1}{\mu}}\left(\chi_{HY} L_{HY,t}\right)^{\frac{\mu-1}{\mu}}\right)^{\frac{\mu}{\mu-1}}. \tag{6.12}$$

where $L_{L,t}$, $L_{M,t}$ and $L_{HY,t}$ denote the employment of low, medium and high-skilled in final goods production, respectively. Parameter Λ_z is the corresponding share parameter of every skill group, χ_z is the corresponding efficiency unit and μ is the elasticity of substitution between different labour types. Note that high-skilled labour can be allocated to both the final goods and the R&D sector, therefore the total number of high-skilled workers is equal to the high-skilled employed in the final goods and the R&D sector. The employment aggregates L_t^s combine varieties of differentiated labour services supplied by individual household

$$L_t^s = \left(\int_0^1 L_t^{s,h^{\frac{\sigma_s-1}{\sigma_s}}} dh\right)^{\frac{\sigma_s}{\sigma_s-1}} \tag{6.13}$$

[8] From this point onwards, notation is slightly simplified by removing the j subscript, as in equilibrium production is symmetrical across all firms.

The parameter $\sigma_s > 1$ determines the degree of substitutability among different types of labour.[9]

The production function above is based on the product variety framework proposed by Dixit and Stiglitz (1977), widely applied in the literature of international trade and R&D diffusion.[10] The underlying structure of R&D is explicitly modelled through the semi-endogenous framework of Jones (1995, 2005).[11]

The objective of the firm is to maximise profits

$$PR_t = P_t Y_t - \left(W_{L,t} L_{L,t} + W_{M,t} L_{M,t} + W_{H,t} L_{HY,t}\right) - \int_0^{A_t} (px_{m,t} x_{m,t} dm), \tag{6.14}$$

where px is the price of intermediate inputs, $W_{s,t}$ is a wage index corresponding to the CES aggregate $L_{s,t}$ and P_t is the price of domestic final goods.

Intermediate good producers

The intermediate sector consists of monopolistically competitive firms which enter 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 $i_{K,t}$. Firms which have acquired a design can transform each unit of capital into a single unit of an intermediate input. In a symmetric equilibrium, intermediate producers face the following inverse demand function from final good producers

$$px_{m,t} = \eta(1-\alpha)(Y_t + FC_Y)\left(\int_0^{A_t} \left(x_{m,t}\right)^{\theta} dm\right)^{-1} \left(x_{m,t}\right)^{\theta-1}$$
$$\text{where } \eta = 1 - \frac{1}{\sigma_d}. \tag{6.15}$$

[9] The productivity-enhancing effects of public infrastructure investment are accounted in the production function where the public capital stock ($K_{G,t}$) and its elasticity (α_G) enters externally.

[10] See Grossman and Helpman (1991) and Aghion et al. (1998).

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

Taking demand as given, each domestic intermediate firm solves the following profit-maximisation problem

$$PR^{x}_{m,t} = \max_{x_{m,t}} \left(px_{m,t}x_{m,t} - i_{K,t}P_{C,t}k_{m,t} - i_A P_{A,t} - FC_A \right) \tag{6.16}$$

subject to a linear technology which allows to transform one unit of capital k_m into one unit of an intermediate good $x_{m,t} = k_{m,t}$. As a standard result of these types of models, intermediate good producers set prices as a mark-up over marginal cost, i.e. $px_{m,t} = \frac{i_{K,t}}{\theta}$.

The no-arbitrage condition requires that entry into the intermediate goods producing sector takes place until the present discounted value of profits is equated to the fixed entry costs plus the net value of patents, or

$$PR_{int,m,t} = i_{A,t}P_{A,t} + \left(i_{A,t} + \pi_{A,t+1}\right)FC_A, \quad \forall m. \tag{6.17}$$

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.

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:

$$\Delta A_t = \nu A^{*\varpi}_{t-1} A^{\phi}_{t-1} L^{\lambda}_{A,t}. \tag{6.18}$$

International R&D spillovers are present, 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^*_t and A_t, respectively. Negative value for these parameters can be interpreted as the *fishing out* effect, implying negative research spillovers, while positive values refer to the *standing on the shoulders of giants* effect, implying positive research spillovers. Note that $\phi = 1$ would yield 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 to the number of researchers L_A. The international stock of knowledge grows exogenously at rate g_{A^*}. It is assumed that the R&D sector is operated by a research institute which employs high-skilled labour at their market wage rate, $W_{H,t}$. It is also assumed that the

research institute faces an adjustment cost γ_A for hiring new employees and maximises the following discounted profit-stream

$$\max_{L_{A,t}} \sum_{t=0}^{\infty} d^t \left(P_{A,t} \Delta A_t - W_{H,t} L_{A,t} - \frac{\gamma_A}{2} W_{H,t} (\Delta L_{A,t}^2) \right) \tag{6.19}$$

where d^t is the discount factor.[12] The first-order condition of this problem reads

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

6.2.3 Policy

On the expenditure side, it is assumed that consumptionG_t, investment IG_t and transfers TR_t from the government are proportional to GDP, while unemployment benefits BEN_t are indexed to wages as follows

$$BEN_t = \sum_{s \in L,M,H} bW_{s,t}(1 - NPART_{s,t} - L_{s,t}),$$

where b is the replacement rate.

The government provides subsidies SUB_t on physical capital and R&D investments to firms in the form of tax credit and depreciation allowances

$$SUB_t = t_K \left(\delta_K P_{I,t-1} K_{i,t-1} + \delta_A P_{A,t-1} A_{i,t-1} \right) + \tau_K P_{I,t} J_{i,t} + \tau_A P_{A,t} J_{A,i,t}.$$

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

$$B_t = (1 + i_t) B_{t-1} + G_t + IG_t + TR_t + BEN_t + SUB_t - R_t^G.$$

[12] Note that, in equilibrium, high-skilled workers are paid the same wages across sectors: $W_{H,t} = W_{HY,t}$.

The labour tax $t_{w,t}$ adjusts to the debt to GDP ratio according to the following rule

$$\Delta t_{w,t} = \tau_B \left(\frac{B_{t-1}}{Y_{t-1}} - b^T \right) + \tau_{DEF} \Delta \left(\frac{B_t}{Y_t} \right)$$

where τ_B captures the sensitivity of the labour tax with respect to deviations from the government debt target, b^T, and τ_{DEF} controls the response of the tax to changes in the debt-to-output ratio.

Monetary policy is modelled via the following Taylor rule, which allows for a degree of smoothness of the interest rate response to the inflation and output gap,

$$i_t = \gamma_{ilag} i_{t-1} + \left(1 - \gamma_{ilag}\right)(r_{EQ} + \pi_{TAR} + \gamma_{inf}(\pi_{C,t} - \pi_{TAR}) + \gamma_{ygap} \hat{y}_t\right) \tag{6.20}$$

The central bank has a constant inflation target π_{TAR} and adjusts interest rates whenever actual consumer price inflation $\pi_{C,t}$ deviates from the target. It also responds to the output gap $\hat{y}_t$ via the corresponding γ_{inf} and γ_{ygap} coefficients.[13] There is also some inertia in the nominal interest rate determined by γ_{ilag}, both with respect to its past and the equilibrium real interest rate (r_{EQ}).[14]

6.2.4 *Trade*

In order to facilitate aggregation, it is assumed that households, the government and the final goods sector have identical preferences across goods used for private consumption, investment and public expenditure. Let $Z_t =\in \{C_t, I_t, G_t, IG_t\}$ be the demand of households, investors or the government as defined in the previous section, then their preferences

[13] The output gap is defined as deviation of capital and labour utilisation from their long-run trends.

[14] In QUEST's III multi-country setting, members of the euro area do not conduct independent monetary policy, and it is assumed that the European Central Bank sets the nominal interest rate by taking into account euro area wide aggregate inflation and output gap changes.

are given by the following utility function:

$$Z_t = \left(\left(1-\rho\right)^{\frac{1}{\sigma_{im}}} Z_{d,t}^{\frac{\sigma_{im}-1}{\sigma_{im}}} + \rho^{\frac{1}{\sigma_{im}}} Z_{f,t}^{\frac{\sigma_{im}-1}{\sigma_{im}}} \right)^{\frac{\sigma_{im}}{\sigma_{im}-1}} \tag{6.21}$$

where ρ is the share parameter and σ_{im} is the elasticity of substitution between domestic ($Z_{d,t}$) and foreign produced goods ($Z_{m,t}$).

6.2.5 *Calibration*

Behavioural and technological parameters are calibrated so that the model can replicate important empirical ratios such as labour productivity, investment, consumption to GDP ratios, the wage share, the employment rate and the R&D share, given a set of structural indicators describing market frictions in goods and labour markets, tax wedges and skill endowments. The specific approaches to calibration for each of the main parts of the model are:

- **Goods market**: the calibration of mark-ups is based on the method suggested by Roeger (1995). Concerning entry barriers, estimates provided by the *Doing Business Database* are used. In particular, entry costs are directly calibrated following the methodology developed by Djankov et al. (2002), who estimate the costs that new firms need to incur before starting to operate.[15]
- **Knowledge production technology**: the two main sources of empirical evidence on elasticities are Bottazzi and Peri (2007) and Pessoa (2005). In particular, estimates from the former are used to calibrate the knowledge elasticity parameters with respect to domestic and foreign knowledge capital. The authors estimate the ratios of $\lambda/(1-\phi)$ and $\omega/(1-\phi)$ where λ in the QUEST model corresponds to the wage cost share in total R&D spending.[16] Pessoa (2005) is used for obtaining the growth rate of ideas, with the

[15] The authors carry out a very thorough data work to construct a measure of the regulation of entry (expressed in GDP per capita terms) across a very large number of countries based on costed measures of the total number of procedures and the time it takes to complete them as well as the actual administrative costs incurred (e.g., registration fees). For a detailed discussion, please see Djankov et al. (2002).

[16] Country-specific elasticities are, however, not available.

assumption of a 5% obsolescence rate. The Bottazzi and Peri (2007) estimate, together with the long-run growth rate of intangible capital and λ, pin down the knowledge elasticity parameters. Specifically, λ is obtained from available data on the wage share of R&D labour in total R&D spending whereas ν is directly derived from the knowledge production function after estimating the other elasticities, normalising the initial stock of domestic and international knowledge, calibrating the growth rate of ideas and initialising the share of research labour. Likewise, the calibration of φ relies on both econometric estimations carried out in the literature and the theoretical restrictions/equations of the model in equilibrium. Hence, its final value will partly depend on the observed long-run growth rate of population and patents as well as on the relationship between other related parameters estimated in the literature.[17]

- **Labour market and the skill composition of the labour force**: Estimations in Ratto et al. (2009) are used to calibrate the adjustment parameters of the labour market. The labour force is disaggregated into three skill-groups: low-, medium- and high-skilled labour. High-skilled workers are defined as that segment of labour force that can potentially be employed in the R&D sector, namely engineers and natural scientists. The definition of low-skilled corresponds to the standard classification of ISCED 0-2 education levels and the rest of the labour force is considered as medium-skilled. Data on skill-specific population shares, participation rates and wages are obtained from the Labour Force Survey, SES, and the Science and Technology databases of EUROSTAT. The elasticity of substitution between different labour types μ is one of the major parameters addressed in the labour economics literature. Precise values are taken from Acemoglu and Autor (2011), who updated the seminal reference for this elasticity parameter by Katz and Murphy (1992). In the baseline calibration, low-skilled wages are obtained from the annual earnings of employees with low educational attainment (ISCED 0-2) irrespective of their occupation. High-skilled wages are approximated by the annual earnings of scientists and engineers with tertiary

[17] For a more detailed explanation of the parameter calibration and estimation procedure, see D'Auria et al. (2009). It is to be noted that at the time of writing, the elasticities of the knowledge production function are being revisited with updated datasets.

educational attainment employed as professionals or associate professionals in physical, mathematical, engineering, life science or health occupations (ISCO-08 occupations 21, 22, 31, 32). Earnings data of employees with tertiary educational attainment not working as scientists and engineers and employees with medium educational attainment (ISCED 3-4) irrespective of their occupation are taken to calculate wages for medium-skilled workers in the model.

- **Fiscal, monetary and trade variables**: EUROSTAT data are used for the breakdown of government spending into consumption, investment and transfers, whereas effective tax rates on labour, capital and consumption are used to determine government revenues. Estimates of R&D tax credits are taken from Warda (2009) and OECD (2014). Monetary policy parameters are adopted from Ratto et al. (2009), while bilateral trade data is obtained from the EUROSTAT/COMEXT database.

6.3 An Example: Simulating the Ex-ante Macroeconomic Impact of Horizon Europe

QUEST III has been recently used by the European Commission to assist policy makers with an ex-ante impact assessment of Horizon Europe Framework Programme 2021–2027.[18] This represents the continuation of the current Framework Programme Horizon 2020 and consists of a large set of interventions encompassing the allocation of R&D and innovation investments with the aim of harnessing the EU scientific and technological community increasing competitiveness, productivity and economic welfare.

The simulations of Horizon Europe are carried out assuming a continuation of Horizon 2020 budget with the same size, allocation and in constant prices but without UK contributions.[19] The cross-country spillovers, represented by international trade and knowledge spillovers, are based on trade statistics and elasticities taken from the relevant literature. Moreover, it has been assumed that both EU and nationally funded R&I have the same leverage and performance effects. In other words, EU-level

[18] Horizon Europe 2021–2027 is also known as Framework Programme FP9.

[19] For more details on Horizon Europe and the scenarios simulated the reader can refer to Chapter 5.

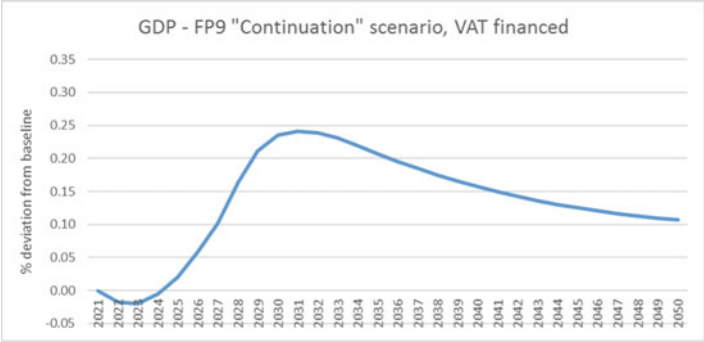

Fig. 6.1 GDP - VAT financed

coordination and optimisation of the funding across Member States is not taken into account in the simulation results, which may underestimate the impact of Horizon Europe.[20]

Based on different financing structures, two scenarios are simulated. In the first scenario, it is assumed that the financing of Horizon Europe relies on additionally raised Value Added Tax (VAT) revenues in the Member States (see Fig. 6.1). Instead, the second scenario assumes that the interventions are financed at the expense of lowering national public investment (see Fig. 6.2). Comparing the two figures, the results highlight the importance of the underlying financing assumptions. As VATs are some of the least distortive taxes, financing productivity enhancing R&D investments from these resources is unambiguously beneficial at the EU level in the medium and long run. GDP is up by 0.25% relative to the no-FP9 baseline towards the end of the Programme and gradually decreasing afterwards. Note that there is a small short-run output loss due to crowding-out effects in the beginning of the intervention period. This is because R&D subsidies stimulate innovation by helping R&D intensive companies to attract more high-skilled labour from traditional production into research with higher wages. In the second scenario, the expected GDP effects are less beneficial at the EU level. Similar to R&D investments, public investment is also productivity enhancing, therefore,

[20] This assumption is somewhat different to what has been assumed in similar impact assessment performed by RHOMOLO and NEMESIS models that are discussed in the other two chapters.

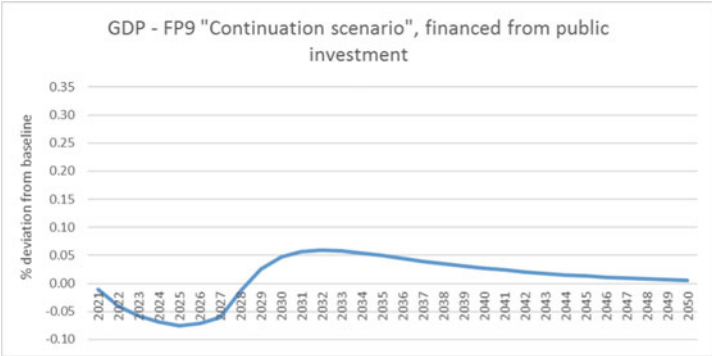

Fig. 6.2 GDP - Financed through public investment cuts

this type of financing is more costly for the Member States. As expected, changing from VAT financing to public investment cuts (e.g. roads, buildings), the Members States loose the potential productivity effects of these investments and the GDP results are much lower both in the short and long run. It also takes longer to compensate the short-run output loss; GDP is only about 0.05% higher relative to the no-FP9 scenario by the end of the Programming period. In both scenarios, the GDP gains gradually decrease after the Programming period due to the depreciation of tangible and intangible capital. Note that in the QUEST simulations EU and nationally funded R&I have the same leverage and performance effects.

The simulation obtained with QUEST III has been compared to the ones obtained with other two models widely used by the European Commission, RHOMOLO and NEMESIS. Nevertheless, as R&D investment decisions require a forward-looking dynamic approach, Di Comite and D'Artis (2015) consider the QUEST-R&D model to be the most suitable model for assessing the impact of R&D and innovation policies over time compared to the other macroeconomic models. However, as a main caveat, it does not distinguish between research undertaken by private or public R&I entities, and being an aggregate macroeconomic model, QUEST also misses the extensive regional details present in RHOMOLO.

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