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A model-based analysis of the impact of Cohesion Policy expenditure 2000–06: Simulations with the QUEST III endogenous R&D model

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ABSTRACT

More than a third of the EU budget is devoted to Cohesion Policy with the objective to foster economic and social cohesion in the European Union. Large-scale fiscal transfers are used to support investment in infrastructure, R&D and human capital. This paper provides a model-based assessment of the potential macroeconomic impact of these fiscal transfers using a DSGE model with semi-endogenous growth (Jones, 1995) and endogenous human capital accumulation. The simulations show the potential benefits of Structural Funds with significant output gains in the long run due to sizeable productivity improvements.
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1. Introduction

Cohesion Policy is one of the key pillars of the European Union. Greater economic and social cohesion among the EU member states and its regions was formalised as objective in the Single European Act (1986) and has since then become one of the most important and most debated EU policies. An increasing share of the European budget is allocated to this goal and the Structural and Cohesion Funds are now the second-largest item, receiving around one-third of the total EU budget.

Cohesion Policy provides the basis for substantial cross-country transfers of resources from richer to poorer countries in the EU. The resources are targeted on public and private investment in physical and human capital, and designed to increase economic and social cohesion among member states, enhancing a faster catch-up process of the less-developed member states in terms of income per capita. With the adoption of the "Lisbon Strategy" by the European Council in Lisbon in March 2000 – with its focus on growth, employment and innovation – this became more and more the leitmotiv of many EU policies and formed the momentum for a paradigm shift in Cohesion Policy. And with the enlargement of the EU in 2004 came increased disparities in income, as the average GDP per capita in these new member states was under half the EU average and almost all their territories were eligible for the highest possible level of support from the Structural and Cohesion Funds.

This paper provides a model-based assessment of the potential impact of cohesion expenditure in the programming period 2000–06, using a multi-country version of the QUEST III model, the model of DG Economic and Financial Affairs of the European Commission (see Ratto et al. (2009)). The model belongs to the class of New-Keynesian micro-founded dynamic general equilibrium (DGE) models that are now widely used in economic policy institutions[1]. The version of QUEST III used here is a large-scale version which includes each of the EU27 member states, and one region representing the rest of the world. The explicit modelling of cross-country linkages through bilateral trade relationships allows us to capture spillovers and interactions between EU member

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[1] These models include full microeconomic foundations, i.e. model equations are equilibrium conditions that are explicitly derived under assumptions of optimising behaviour and include fully consistent stock-flow dynamics. In contrast to the earlier generation of Real Business Cycle models in which markets continuously cleared, they include nominal and real rigidities in the New-Keynesian fashion, as well as financial frictions in the form of financial constraints, that give a role to aggregate demand in output determination. As a consequence, they are better able to match some basic regularities found in time series data and also give scope for active policy intervention. Other examples of DSGE models at policy institutions are the GIMF model at the IMF (Kumhof and Laxton, 2007), the NAWM at the ECB (Christoffel et al., 2008) and the SIGMA model at the Fed (Erceg et al., 2006).

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Table 1
Cohesion Policy payments 2000–06 programming period.

	Structural funds					Cohesion Fund (CF)	Total Cohesion Policy
	European Regional Development Fund (ERDF)	European Social Fund (ESF)	European Agricultural Guidance and Guarantee Fund (EAGGF)	Financial Instrument for Fisheries Guidance (FIFG)	Total Structural Funds		
Czech Rep.	0.98	0.40	0.17	0.00	1.55	0.81	2.37
Cyprus	0.03	0.02	0.00	0.00	0.05	0.03	0.08
Estonia	0.23	0.07	0.06	0.01	0.37	0.29	0.66
Hungary	1.23	0.45	0.31	0.00	2.00	0.82	2.82
Lithuania	0.58	0.19	0.12	0.01	0.90	0.59	1.49
Latvia	0.38	0.13	0.09	0.02	0.63	0.51	1.14
Malta	0.05	0.01	0.00	0.00	0.06	0.02	0.08
Poland	4.95	2.01	1.19	0.17	8.31	3.05	11.37
Slovenia	0.14	0.08	0.02	0.00	0.24	0.16	0.40
Slovakia	0.60	0.32	0.18	0.00	1.11	0.54	1.65
Germany	15.47	11.73	3.65	0.14	31.00	0.00	31.00
Italy	17.39	7.80	3.22	0.34	28.76	0.00	28.76
Ireland	1.93	1.04	0.20	0.06	3.23	0.53	3.76
Portugal	13.01	4.88	2.24	0.21	20.33	2.17	22.50
Greece	14.36	4.77	2.69	0.19	22.00	1.79	23.80
Spain	26.27	11.72	5.68	1.78	45.44	8.86	54.30
Total	97.60	45.63	19.83	2.95	166.00	20.18	186.18

Note: Total payments Structural and Cohesion Funds over the period 2000–09, in billion euros.

states, both beneficiaries as well as paying member states, of cohesion expenditure.

The version of the QUEST model we use in this study is an extension of QUEST III with human capital accumulation and endogenous technological change. The model has been used extensively for the analysis of structural reforms in the EU (the Lisbon Strategy for Growth and Jobs) and is described in Roeger et al. (2008). It is particularly suitable for an evaluation of the type of structural policies that form the core of Cohesion Policy interventions. The model incorporates productive infrastructure investment that captures the productivity enhancing effects of public capital. It also employs the product variety framework proposed by Dixit and Stiglitz (1977) and applies the Jones (1995) semi-endogenous growth framework to explicitly model the underlying development of R&D. The endogenous modelling of R&D allows us to analyse the impact of R&D promoting policies on growth. Furthermore, the endogeneity of human capital accumulation in the model can capture the effects of policies promoting vocational education and training.

The paper is structured as follows. The first section briefly reviews previous model evaluations of EU Cohesion policy. The next section gives an overview of the Structural and Cohesion Funds in the period 2000–06 and the size of the fiscal transfers involved. Section 4 describes the model, and focuses on those features of the model which enable us to carry out the impact assessment of the fiscal transfers. The model results for recipient countries are presented in detail in the following section. The next section includes a sensitivity analysis and the last section concludes.

2. Model-based assessments of EU Cohesion Policy

Macroeconomic models can take into consideration externalities and spillover effects of individual projects onto the rest of the economy and have therefore frequently been used to assess the economy-wide feedbacks and interactions of the fiscal transfers at the aggregate level and the structural changes in productive potential of the economy as a whole[2]. An example of a study using single country models to evaluate cohesion spending is Pereira and Gaspar (1999). They find in a two-sector endogenous growth model calibrated to Portugal, that EU funds inflows of around 3.5% of GDP during the period 1989–93 increased growth by about 1/2 percentage point a year (both in the short and long run). They also conclude that the impact on growth was maximized when EU funds were spent on infrastructure rather than on private physical or human capital accumulation.

Many country assessments of Structural Funds have relied on HERMIN models of the beneficiary countries (e.g. Bradley et al., 1995). These models were specifically designed to carry out an analysis of the impact of cohesion policy expenditure on the beneficiary countries. The HERMIN models generate large positive short run impacts of cohesion policy through hybrid output equations (Bradley and Fitz Gerald, 1988) where cohesion policy expenditure is directly added to domestic absorption, while gradually building-up long run output effects are modelled through terms added to these hybrid output equations that capture output externalities associated with infrastructure and human capital. World demand is exogenous in these single country models and private sector demand is not based on intertemporal optimising behaviour but modelled in a traditional Keynesian fashion (e.g. consumption as a fixed share of disposable income). With interest rates and exchange rates exogenous the output effect in HERMIN models is directly determined by the given increase in absorption and the assumed long run output and productivity parameters.

In the Fourth Cohesion report (European Commission, 2007) results from three models were reported in an ex-ante assessment of potential effects of Cohesion expenditure over the programming years 2007–13. These included HERMIN models of individual member states (Bradley et al., 2007), the QUEST II model, the global macroeconomic model of DG Economic and Financial Affairs of the European Commission and the predecessor of the current QUEST III model (in 't Veld, 2007), and the EcoMod model, a dynamic-recursive CGE model (Bayar, 2007). All three models showed positive output effects from cohesion expenditure, but the demand effects were in the short run smaller in the micro-founded QUEST II model than in the HERMIN model. The long run output effects were similar in the QUEST and HERMIN, but larger in EcoMod, while the employment effects in QUEST were smallest

[2] In this section we focus on past model-based evaluations. A wider overview, including empirical studies using growth regressions, can be found in the working paper version (Varga and in 't Veld, 2009b) and, in the online version, in the Appendix. For an extensive literature overview, see e.g. Herve and Holzmann (1998).

Table 2
Yearly payment profile 2000–09.

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Czech Rep.	0.00	0.01	0.03	0.07	0.26	0.20	0.45	0.48	0.47	0.02
Cyprus	0.00	0.00	0.00	0.00	0.04	0.06	0.10	0.14	0.17	0.00
Estonia	0.00	0.11	0.13	0.18	0.64	0.91	1.22	1.06	0.92	0.00
Hungary	0.00	0.05	0.06	0.06	0.29	0.45	0.83	0.84	0.40	0.05
Latvia	0.00	0.11	0.18	0.23	0.79	1.28	1.09	1.83	1.14	0.05
Lithuania	0.00	0.09	0.20	0.17	0.60	0.89	0.94	1.37	1.49	0.09
Malta	0.00	0.00	0.00	0.00	0.14	0.11	0.32	0.61	0.36	0.00
Poland	0.00	0.02	0.08	0.09	0.52	0.41	0.78	1.08	0.87	0.10
Slovakia	0.00	0.02	0.09	0.10	0.45	0.52	0.67	0.79	0.78	0.00
Slovenia	0.00	0.01	0.04	0.03	0.12	0.21	0.31	0.23	0.29	0.02
Germany	0.05	0.14	0.16	0.16	0.18	0.19	0.18	0.17	0.14	0.01
Greece	0.00	1.53	0.92	0.82	1.37	1.23	1.61	2.05	2.24	0.07
Ireland	0.20	0.39	0.47	0.40	0.36	0.27	0.23	0.13	0.16	0.01
Italy	0.13	0.05	0.12	0.26	0.28	0.29	0.29	0.28	0.28	0.04
Portugal	1.10	1.28	2.07	2.24	2.22	1.80	1.53	1.30	1.77	0.18
Spain	0.05	0.78	1.09	1.05	0.96	0.84	0.56	0.52	0.50	0.04

Note: Total Structural and Cohesion Funds as % of GDP.

Table 3
Fields of interventions Structural Funds (% of total spending 2000–09).

	Agriculture, industries and services	Human resources	Research and development	Infrastructure	Technical assistance
Czech Republic	31.7	26.5	1.3	37.1	3.3
Cyprus	40.0	41.7	0.0	14.7	3.5
Estonia	30.4	19.4	8.9	37.3	4.0
Hungary	30.5	21.7	4.9	38.5	4.5
Latvia	41.4	21.0	3.1	31.7	2.8
Lithuania	35.0	15.8	5.2	40.8	3.2
Malta	21.4	13.8	0.3	59.3	5.2
Poland	27.9	23.4	2.7	44.0	2.0
Slovakia	24.3	28.8	0.9	37.7	8.3
Slovenia	42.5	27.9	6.2	19.0	4.4
Germany	30.7	37.1	7.2	22.0	3.0
Greece	22.3	20.4	1.8	52.0	3.6
Ireland	20.3	27.5	6.5	45.1	0.6
Italy	35.5	27.1	3.6	29.5	4.4
Portugal	30.2	21.7	4.5	41.9	1.7
Spain	25.1	25.5	6.2	42.4	0.8

Note: Total Structural Funds only.

as in this model productivity gains are passed on into higher wages[3].

There have also been earlier applications based on New-Keynesian dynamic general equilibrium models. In Varga and in 't Veld (2009a), we apply the version of the QUEST III model that we use in this paper to an evaluation of the effects of cohesion spending in the new member states over the period 2007–13. Allard et al. (2008) use the GIMF model, the dynamic general equilibrium model of the IMF, for an assessment of cohesion spending on new member states. They pay particular attention to the ongoing convergence process of the NMS and compare the impact of EU transfers to households to public infrastructure investment, finding a stronger impact of the latter on long term growth. QUEST and GIMF are similar in that both are micro-founded global open-economy models and similar mechanisms are at play in these models. Utility maximising households smooth their consumption and this leads to a lower impact of transfers in the short run, while public investment boosts productivity and generates higher growth in the medium run. The main difference is that in the version of the QUEST III model used here the supply side effects are modelled in greater detail with human capital accumulation and endogenous technological change.

3. The European Union's Cohesion Policy programme 2000–06

EU Cohesion policy programmes consist of four Structural Funds (the European Regional Development Fund (ERDF), the European Social Fund (ESF), the European Agricultural Guidance and Guarantee Fund (EAGGF), and the Financial Instrument for Fisheries Guidance (FIFG)) as well as the Cohesion Fund (CF). In the programming period 2000–06 more than €250 billion was spent in total on regional policy structural instruments for the 15 Member States, pre-accession aid and structural interventions for the new member states (NMS). This amounted to approximately 37% of the EU budget. The objectives of Cohesion Policy are defined as promoting the development and structural adjustment of regions whose development is lagging behind (Objective 1), supporting the economic and social conversion of areas facing structural difficulties (Objective 2), and supporting the adaptation and modernisation of policies and systems of education, training and employment (Objective 3).

In this paper we consider the impact of Structural funds and the Cohesion fund in all Member States that receive large allocations of these funds (see Table 1). Portugal, Spain, Greece, Ireland as well as Italy and Germany received funds over the full programme period. The new member states already received pre-accession assistance from 2001 onwards, and cohesion spending in these countries increased after accession in 2004. The expenditure is mainly through Objective 1 programmes, but includes for the Czech Republic (Prague), Spain, Italy and Germany also Objective 2. Total spending considered here amounted to €186 billion.

Due to delays in member states submitting programmes and delays in decision making, actual cohesion policy payments were spread over a longer period than the official programming period 2000–06, and continue for two to three more years. Table 2 gives the yearly payment profiles as percentage of GDP for each of the member states.

The fields of interventions of Structural Funds are divided into three main categories (and the following sub-categories in brackets): 1) Infrastructure investment (transport, environmental, telecommunication, urban rehabilitation, social infrastructure and health); 2) Investment in human resources (education, labour market programmes, social inclusion, entrepreneurship, actions for women) and 3) Investment in productive environment (business support, tourism, RTDI). Interventions under Cohesion Funds are all in infrastructure investment.

In total 41% of the investment was spent on infrastructure, of which just under half was allocated to transport and about a third to environment, 33.8% was allocated to creating a productive environment for enterprises and 24.5% to human resources (see Table 3)[4].

[3] Larger long run positive employment effects in HERMIN are driven by the technical assumption that the output elasticity of public infrastructure investment exceeds the productivity elasticity.

[4] A detailed breakdown of all interventions can be found in the Supplementary Appendix.

4. Model description

The model used in this exercise is an extension of the QUEST III model with semi-endogenous growth. Technological change is modelled as increasing product variety in the tradition of Dixit and Stiglitz (1977) and the model applies the Jones (1995) semi-endogenous growth framework to explicitly model the underlying development of R&D. This modelling framework recognises that innovative start-ups are the engines of long term economic growth and net job creation. The structure of the model is described in detail in Roeger et al. (2008). 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 domestic and imported 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 domestic and foreign ideas.

Below we describe in more detail the modelling of households, firms, human capital and the government budget constraint, which constitute the key elements for modelling the Structural Funds interventions. One extension to the model made here is an explicit formulation of human capital accumulation following Jones (2002) in order to account for the significant part of Structural Fund investments in various human resource programmes.

4.1. Households

The household sector consists of a continuum of households $h\in[0,1]$. A share $(1-\varepsilon)$ of these households are not liquidity constrained and indexed by $i\in[0,1-\varepsilon]$. They have access to financial markets where they can buy and sell domestic and foreign assets (government bonds), accumulate physical capital which they rent out to the intermediate sector, and they also buy the patents of designs produced by the R&D sector and license them to the intermediate goods producing firms. Non-liquidity constrained household members 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 $k\in[1-\varepsilon,1]$. These households cannot 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 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.

4.1.1. Non-liquidity constrained households

Each non-liquidity constrained household maximises an intertemporal utility function in consumption and leisure subject to a budget constraint. These households makes decisions about consumption (C_t^i), labour supply (L_t^i), investments into domestic and foreign financial assets (B_t^i and $B_t^{F,i}$), the purchases of investment good (J_t^i), the renting of physical capital stock (K_t^i), the corresponding degree of capacity utilisation ($ucap_t^i$), 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 ($b_t^s W_t^{i,s}$)[5], transfer income from the government (TR_t^i),and interest income (i_t, i_t^K and i_t^A). Hence, non-liquidity constrained households face the following Lagrangian

$$
\underset{\left\{\begin{array}{l} C_t^i, L_t^i, B_t^i \\ B_t^{F,i}, J_t^i, K_t^i \\ J_t^{A,i}, A_t^i, ucap_t^i \end{array}\right\}_{t=0}^{\infty}}{\mathrm{Max}} \quad V_0^i = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left(U(C_t^i) + \sum_s V(1-L_t^{i,s}) \right) \tag{1}
$$

$$
-\mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t^i \beta^t \left(\begin{array}{l}
(1+t_t^c)P_t^C C_t^i + B_t^i + E_t B_t^{F,i} + P_t^I (J_t^i + \Gamma_J(J_t^i)) + P_t^A J_t^{A,i} \\
-(1+r_{t-1})B_{t-1}^i - (1+r_{t-1}^F - \Gamma_{B^F}(E_t B_{t-1}^F / Y_{t-1}))E_t B_{t-1}^{F,i} \\
-\sum_s (1-t_t^{w,s}) W_t^{i,s} L_t^{i,s} - b_t^s W_t^{i,s}(1-NPART_t^{i,s} - L_t^{i,s}) + \Gamma_W(W_t^{i,s}) \\
-(1-t_{t-1}^K)(i_{t-1}^K ucap_{t-1}^i - rp_{t-1}^K - \Gamma_U(ucap_{t-1}^i))P_t^I K_{t-1}^i - t_{t-1}^K \delta^K P_t^I K_{t-1}^i - \tau^K P_t^I J_t^i \\
-(1-t_{t-1}^K)(i_{t-1}^A - rp_{t-1}^A)P_t^A A_{t-1}^i - t_{t-1}^K \delta^A P_t^A A_{t-1}^i - \tau^A P_t^A J_t^{A,i} \\
-TR_t^i - \sum_{j=1}^{n} PR_{j,t}^{f,i} - \sum_{j=1}^{A_t} PR_{j,t}^{x,i}
\end{array} \right) s\in\{M,H\}
$$

$$
-\mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t^i \xi_t^i \beta^t (K_t^i - J_t^i - (1-\delta^K)K_{t-1}^i) - \mathrm{E}_0 \sum_{t=0}^{\infty} \lambda_t^i \psi_t^i \beta^t (A_t^i - J_t^{A,i} - (1-\delta^A)A_{t-1}^i)
$$

The budget constraints are written in real terms with all prices and wages normalized with P_t, the price of domestic final goods. All firms of the economy are owned by non-liquidity constrained households who share the total profit of the final and intermediate sector firms, $\sum_{j=1}^{n} PR_{j,t}^{f,i}$ and $\sum_{j=1}^{A_t} PR_{j,t}^{x,i}$, where n and A_t denote the number of firms in the final and intermediate sector respectively. As shown by the budget constraints, all households pay t_t^w wage income taxes and t_t^K capital 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

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

their earnings on physical capital and patents. There is no perfect arbitrage between different types of assets. When taking a position in the international bond market, households face a financial intermediation premium Γ_{B_F} (.) which depends on the economy-wide net holdings of internationally traded bonds. Also, when investing into tangible and intangible capital households require premia rp_t^K and rp_t^A in order to cover the increased risk on the return related to these assets. The real interest rate r_t is equal to the nominal interest rate minus expected inflation: $r_t = i_t - E_t(\pi_{t+1})$.

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

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

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

$$V(1 - L_t^{i,s}) = \frac{\omega_s}{1-\kappa}(1 - L_t^{i,s})^{1-\kappa}, \qquad \text{with } \kappa > 0. \tag{2b}$$

The investment decisions w.r.t. real capital and decisions w.r.t. the degree of capacity utilisation are subject to convex adjustment costs Γ_J and Γ_U, which are given by

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

$$\Gamma_U(ucap_t^i) = a_1(ucap_t^i - ucap_t^{ss}) + a_2(ucap_t^i - ucap_t^{ss})^2, \tag{4}$$

where $ucap_t^{ss}$ is the steady state capacity utilisation.

Wages are also subject to convex adjustment costs given by

$$\Gamma_W(W_t^{i,s}) = \sum_s \frac{\gamma_W L_t^{i,s}}{2}\frac{\Delta W_t^{i,s2}}{W_{t-1}^{i,s}} \tag{5}$$

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

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

$$\frac{\partial V_0}{\partial B_t^i} => -\lambda_t^i + \mathrm{E}_t(\lambda_{t+1}^i\beta(1 + r_t)) = 0, \tag{6b}$$

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

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

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

$$\frac{\partial V_0}{\partial ucap_t^i} => i_t^K - a_1 - 2a_2(ucap_t^i - ucap_t^{ss}) = 0. \tag{6f}$$

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

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

where Q_t is the present discounted value of the rental rate of return from investing in real assets

$$Q_t = \mathrm{E}_t\left(\frac{1-\delta}{1 + i_t - \pi_{t+1}^C}Q_{t+1} + \frac{(1-t_t^K)(i_t^K ucap_t^i - rp_t^K - \Gamma_u(ucap_t^i)) + t_t^K\delta^K}{1 + i_t - \pi_{t+1}^C}\right) \tag{7b}$$

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

Non-liquidity constrained households buy new patents of designs produced by the R&D sector (I_t^A) and rent their total stock of design (A_t) at rental rate i_t^A to intermediate goods producers in period t. Households pay income tax at rate t_t^K on 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

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

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

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

$$i_t^A \approx \frac{(1-\tau^A)(i_t - \pi_{t+1}^A + \delta^A) - t_t^K \delta^A}{(1-t_t^K)} + rp_t^A \quad \text{where } 1 + \pi_{t+1}^A = \frac{P_{t+1}^A}{P_t^A} \tag{7c}$$

Eq. (7c') states that 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.

4.1.2. Liquidity constrained households

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

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

4.1.3. 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[6]. 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

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

4.1.4. Aggregation

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

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

Hence aggregate consumption and employment is given by

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

and

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

4.2. Final goods production and public capital

We account for the productivity enhancing effect of infrastructure investment via the following aggregate final goods production function:

$$Y_t = A_t^{(1-\alpha)\left(\frac{1}{\theta}-1\right)} (K_t^P)^{1-\alpha} (L_{Y,t})^{\alpha} (K_t^G)^{\alpha_G} - FC_Y, \text{ where } \sum_{i=1}^{A_t} x_{i,t} = K_t^P \tag{13}$$

The final good sector uses a labour aggregate ($L_{Y,t}$) and intermediate goods ($x_{i,t}$) using a Cobb–Douglas technology, subject to a fixed cost FC_Y. Our formulation assumes that investment in public capital stock (K_t^G) increases total factor productivity with an exponent of α_G set to 0.10. Final output (Y_t) is produced using A_t varieties of intermediate inputs with an elasticity of substitution $1/(1-\theta)$. One unit of intermediate goods is

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

produced from one unit of private capital (K_t^P), therefore in a symmetric market framework the total output of the intermediate sector amounts to the total private capital stock as $\sum_{i=1}^{A_t} x_{i,t} = A_t x_t = K_t^P$.

Public infrastructure investment (I_t^G) accumulates into the public capital stock K^G according to

$$K_t^G = (1-\delta_G)K_{t-1}^G + I_t^G \tag{14}$$

where δ_G, the depreciation rate of public capital is set at 4%. Infrastructure investment is assumed to be proportional to output

$$I_t^G = (IGS_t + \varepsilon_t^{IG})Y_t \tag{15}$$

where ε_t^{IG} is an exogenous shock to the share of government investment (IGS_t). It is through this shock that we simulate the increase in infrastructure investment.

4.3. Intermediate production and the R&D sector

The intermediate sector consists of monopolistically competitive firms which have entered the market by buying licenses for 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. Intermediate goods producing firms sell their products to domestic final good producers. In symmetric equilibrium the inverse demand function of domestic final good producers is given as

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

where η_t is the inverse gross mark-up of the final goods sector.

Each domestic intermediate firm solves the following profit-maximisation problem.

$$PR_{i,t}^x = \max_{x_{i,t}}\{px_{i,t}x_{i,t} - i_t^K P_t^C k_{i,t} - i^A P_t^A - FC_A\}. \tag{17}$$

subject to a linear technology which allows to transform one unit of effective capital ($k_i \cdot ucap$) into one unit of an intermediate good $x_i = k_i$.

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

$$PR_{i,t}^x = PR_t^x = i_t^A P_t^A + (i_t^A + \pi_{t+1}^A)FC_t^A \tag{18}$$

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

$$P_t^A \frac{1}{1-t_t^K(1-\delta^A)+\tau^A} + FC_A = \sum_{\tau=0}^{\infty}\prod_{j=0}^{\tau}\left(\frac{1}{1+r_{t+j}}\right)PR_{t+\tau}^x. \tag{19}$$

For an intermediate producer, entry costs consist of 1. the licensing fee $i_t^A P_t^A$ for the design or patent, which is a prerequisite of production of innovative intermediate goods, and 2. the fixed entry cost FC_A.

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 $L_{A,t}$ and generates new designs according to the following knowledge production function:

$$\Delta A_t = \nu A_{t-1}^{*\varpi} A_{t-1}^{\phi} L_{A,t}^{\lambda}. \tag{20}$$

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

$$\max_{L_{A,t}} \sum_{t=0}^{\infty} d_t\left(P_t^A \Delta A_t - W_t^H L_{A,t} - \frac{\gamma_A}{2} W_t^H \Delta L_{A,t}^2\right) \tag{21}$$

Therefore the first order condition implies:

$$\lambda P_t^A \frac{\Delta A_t}{L_{A,t}} = W_t^H + \gamma_A (W_t^H \Delta L_{A,t} - d_t W_{t+1}^H \Delta L_{A,t+1}) \tag{22}$$

where d_t is the discount factor.

4.4. Human capital accumulation

The labour aggregate $L_{Y,t}$ is composed of three skill-types of labour force:

$$L_{Y,t} = \left(s_L^{\frac{1}{\sigma_L}} (h_t^L L_t^L)^{\frac{\sigma_L - 1}{\sigma_L}} + s_M^{\frac{1}{\sigma_L}} (h_t^M L_t^M)^{\frac{\sigma_L - 1}{\sigma_L}} + s_{H,Y}^{\frac{1}{\sigma_L}} (h_t^H L_t^{HY})^{\frac{\sigma_L - 1}{\sigma_L}} \right)^{\frac{\sigma_L}{\sigma_L - 1}} \tag{23}$$

Parameter s_s is the population share of the labour force in subgroup s (low-, medium- and high-skilled), L^s denotes the employment rate of population s, h_t^s is the corresponding accumulated human capital (efficiency unit), and σ_L is the elasticity of substitution between different labour types[7]. An individual's human capital is produced by participating in education and Λ_t^s represents the amount of time an individual spends accumulating human capital:

$$h_t^s = h_s e^{\psi \Lambda_t^s}, \ \psi > 0 \tag{24}$$

The exponential formulation used here adapts Jones (2002) into a disaggregated skill-structure by incorporating human capital in a way that is consistent with the substantial growth accounting literature with adjustments for education[8]. The ψ parameter has been studied in a wealth of microeconomic research. Interpreting Λ_t^s as years of schooling, the parameter corresponds to the return to schooling estimated by Mincer (1974). The labour market literature suggests that a reasonable value for ψ is 0.07, which we apply here. Investments in human capital can then be modelled by increasing the years of schooling (Λ_t^s) for the respective skill groups (for details see the Appendix).

4.5. Trade

A specific feature of the model used in this exercise is the explicit modelling of bilateral trade. The economies trade their final goods. Private and public consumption (C, G) and investment (I, IG) are aggregates of domestic and foreign varieties of goods expressed by the following CES functions where the elasticity of substitution between bundles of domestic and foreign goods Z^D and Z^F is σ and s is the corresponding share parameter:

$$Z_t = \left((1-s)^{\frac{1}{\sigma}} (Z_t^D)^{\frac{\sigma-1}{\sigma}} + s^{\frac{1}{\sigma}} (Z_t^{IM})^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, Z \in \{C, I, G, IG\} \tag{25}$$

To account for the high degree of trade openness of many of the EU Member States we include trade in intermediate goods. Thus, aggregate imports are given by

$$IM_t = s \left(\frac{P_t^C}{P_t^{IM}} \right)^{\sigma} (C_t + I_t) + s^G \left(\frac{P_t^C}{P_t^{IM}} \right)^{\sigma} (G_t + IG_t) + IM_t^{INT} \tag{26}$$

where intermediate imports IM_t^{INT} are assumed to be proportional to output.

Total exports of country c is the sum of the quantities imported by all its trading partners, $IM_t^{c \to c'}$:

$$EX_t^c = \sum\nolimits_{c' \neq c} IM_t^{c \to c'}. \tag{27}$$

The total imports from all trading partners is given by

$$IM_t^c = \left(\sum\nolimits_{c \neq c'} (sim^{c \to c'})^{\frac{1}{\sigma_i}} (IM_t^{c \to c'})^{\frac{\sigma_i - 1}{\sigma_i}} \right)^{\frac{\sigma_i}{\sigma_i - 1}} \tag{28}$$

and the corresponding *bilateral* import demand and import price equations are

$$PIM_t^c = \left(\sum_{c' \neq c} sim_t^{c' \to c} \left(\frac{E_t^{c'} PX_t^{c' \to c}}{E_t^c} \right)^{1-\sigma_i} \right)^{\frac{1}{1-\sigma_i}} \tag{29}$$

[7] Note that high-skilled labour in the final goods sector L_t^{HY} is total high-skilled employment minus the high-skilled labour working in the R&D sector ($L_{A,t}$).

[8] See Barro and Sala-i-Martin (1995).

$$IM_t^{c\to c'} = sim_t^{c'\to c}\left(\frac{E_t^{c'}PX_t^{c'\to c}}{E_t^cPIM_t^c}\right)^{-\sigma_i} IM_t^{c\to c'} \tag{30}$$

Finally, the net foreign assets evolve according to

$$E_tB_t^F = (1+r_t^F)E_tB_{t-1}^F + P_t^{EX}EX_t - P_t^{IM}IM_t. \tag{31}$$

4.6. Policy

For the government sector various expenditure and revenue categories are separately modelled. On the expenditure side we assume that government consumption (G_t), government transfers (TR_t) and government investment (I_t^G) are proportional to GDP and unemployment benefits (BEN_t) are indexed to wages. The government provides subsidies (S_t) on physical capital and R&D investments in the form of a tax-credit and depreciation allowances, with are exogenous in the model.

Government revenues (R_t^G) are made up of taxes on consumption as well as capital and labour income. Fiscal transfers for NMS received from the EU are denoted by COH_t (which is negative for the net contributors). Labour taxes gradually adjust to stabilise the debt to GDP ratio in the long run according to the following rule

$$\Delta t_t^L = \tau^B\left(\frac{B_{t-1}}{Y_{t-1}} - b^T\right) + \tau^{DEF}\Delta\left(\frac{B_t}{Y_t}\right) \tag{32}$$

where b^T is the government debt target, τ^B and τ^{DEF} are coefficients. Therefore, government debt (B_t) evolves according to

$$B_t = (1+r_t)B_{t-1} + G_t + IG_t + TR_t + BEN_t + S_t - R_t^G - COH_t. \tag{33}$$

It is assumed that the additional contributions to the EU budget are financed in the donor countries through an increase in labour taxes.

Cohesion policy programmes are subject to the condition of additionality and co-financing. Additionality requires that Structural Funds are additional to domestically-financed expenditure and are not used as a substitute for it. The co-financing principle means the EU provides only matching funds to individual projects that are part of the operational programmes and that the EU funds are matched to a certain extent by domestic expenditure. The problem with defining a proper benchmark means that in practice this principle of additionality is hard to verify and is thus not always binding. Member States are not required to create new budgetary expenditure to co-finance cohesion policy support. Existing national resources that were used to finance similar areas of interventions (and are thus concerned by the additionality requirement) can be "earmarked" to co-finance Structural Fund transfers. Total spending increases only by the amount of Structural Fund transfers.

More formally, assume a co-financing rate of c, i.e. the EU transfer COH_t has to be matched by domestically-financed expenditure $c.COH$. The additionality and co-financing principles can be expressed as the following condition for total government spending in a beneficiary country:

$$TOTEXP_t = COH_t + \max(EXP_0, c\cdot COH_t) \tag{34}$$

where $TOTEXP_t$ is total expenditure, COH_t is the fiscal transfer received from the EU cohesion funds, EXP_0 domestically-financed expenditure in the counterfactual situation (without Structural and Cohesion Funds), and c is the co-financing rate. Examining the additionality tables of Member States, it is apparent that national public expenditure concerned by additionality usually exceeds the co-financing needs by far. In this case $EXP_0 > c\cdot COH_t$, and total expenditure is given by[9]

$$TOTEXP_t = COH_t + EXP_0 \tag{36}$$

As spending on infrastructure and education typically exceeds the co-financing requirements, this exercise takes domestically-financed expenditure EXP_0 in the counterfactual situation (without structural and cohesion funds) as the benchmark and only examines the impact of the fiscal transfer COH_t received from the EU cohesion funds.

Monetary policy is modelled via a Taylor rule, which allows for some smoothness of the interest rate response to the inflation and output gap, where the latter is defined as deviation of capital and labour utilisation from their long run trends (see Roeger et al., 2008).

$$\begin{aligned} i_t = {} & \tau_{lag}^{INOM} i_{t-1} + (1-\tau_{lag}^{INOM})[r^{EQ} + \pi^T + \tau_\pi^{INOM}(\pi_t^C - \pi^T) \\ & + \tau_{y,1}^{INOM} ygap_{t-1}] + \tau_{y,2}^{INOM}({}_tygap_{t+1} - ygap_t) + u_t^{INOM} \end{aligned} \tag{37}$$

For euro area members interest rates are set by the European Central Bank based on euro area wide developments. Slovenia, Cyprus, Malta and Slovakia joined the euro in 2007, 2008 and 2009 respectively. Bulgaria, Latvia, Lithuania and Estonia peg their currencies to the euro and the Taylor rule is replaced by an exchange rate targeting equation.

4.7. Calibration and implementation of the interventions

For simulating Cohesion Policy expenditure in the EU, we use a multi-country version of the model with 28 regions (each of the 27 member states and one region representing the rest of the world). The calibration of this model is described in detail in Roeger et al. (2008) and D'Auria

[9] Herve and Holzmann (1998) criticise earlier model-based studies of structural funds for exaggerating the total impact because they assumed that the full Structural Fund spending is additional to investment in the counterfactual situation $TOTEXP = COH_t + c\cdot COH_t + EXP_0$ while the correct formulation of the additionality principle is given by Eq. (36).

Table 4
Matching fields of interventions and model variables.

Field	Variable to implement the shock
Infrastructure	Temporary increase in I^G, government investment (via ε_t^{IG})
Agriculture, industry and services	Temporary increase in other government expenditures (G_t)
	Reducing fixed costs of tangible capital costs faced by final goods firms (FC_Y and rp^K, permanent or temporary reductions)
RTD	Reducing the fixed costs or risk-premia faced by the users of R&D products, (FC_A and rp^A, permanent or temporary reductions)
Human resources	Raising human capital and government transfers expenditures
	– investment in high-skilled human capital (h_t^H via Λ_t^H)
	– educational investments in all skills (h_t^s via Λ_t^s)
Technical assistance	Temporary increase in government consumption (G_t)

et al. (2009). In calibrating the model, we follow the literature of dynamic general equilibrium modelling and set the key steady state ratios equal to their empirical counterparts for each region. While the calibration of the main steady state ratios (private consumption to output, investment to output, etc.) is based on EUROSTAT and OECD data, structural parameters are taken from the estimated version of the model (Ratto et al., 2009) or directly tied down by the equations of the model. This calibration of each of the individual country models uses country-specific structural characteristics based on year 2000 data. The country models are linked together using bilateral trade data from the trade-matrix of 2004[10].

The fiscal transfers under the Structural and Cohesion Policy programmes are modelled as lump-sum transfers between governments. Table 4 below shows the main fields of interventions and the way each of the interventions are captured as shocks to the model[11]. Investment in public infrastructure is modelled via a temporary increase in government investments ε_t^{IG}. Support to agriculture, industry and services-related programmes are introduced via a temporary or (depending on the nature of the programme) permanent decrease in fixed costs or tangible capital costs of final goods firms (FC_Y, rp^K). R&D promoting spending is modelled similarly, via decreasing the fixed costs faced by the intermediate sectors (FC_A) temporarily or permanently, depending on the nature of the programme. Concerning human capital investments we distinguish three sub-categories of payments based on the detailed payment profile. Part of the funds devoted to human resources are spent on educational investments without specific skill-specification, and allocated in the model to all skill groups. A smaller share directly targeted investments in high-skilled human capital and captured in the model as a shock to Λ_t^H. The remainder is accounted for as temporary increase in government transfers to households. On the basis of available data on country-specific education expenditures an estimate can be made of the additional years of schooling (increment to Λ_t^s) that can be financed by the fiscal transfers. In order to account for the additional time spent on training, we assume that the last cohort of student population stays longer in the education system and enter into the active labour force later. Finally technical assistance is introduced as a temporary increase in government consumption.

The spending on cohesion policy is financed from the EU budget, to which all member states contribute. In this modelling exercise it is assumed that all countries that were a member of the European Union in 2000 contribute equally to the EU budget and these contributions are assumed to be proportional to GDP[12]. The contributions required to finance Cohesion expenditure amount to roughly 0.2% of each country's GDP and are assumed to be financed by increases in labour taxes.

5. Macroeconomic impact of cohesion spending

The simulated GDP effects from cohesion spending are reported in Table 5 and Fig. 1[13]. They show a gradual build-up of output gains in the beneficiary countries over time, while output in donor countries declines. In the short run the spending gives an immediate impulse to demand, but this is partly offset by the effects of higher inflation, rising capital costs and (real) appreciations. Gradually in the medium run productivity improvements boost potential output. In the receiving countries, consumption spending increases, in particular for non-constrained “Ricardian” consumers who anticipate higher permanent income and who with access to financial markets can already raise their consumption early on. Liquidity constrained consumption is driven by employment and wage developments and is also generally higher. Wages grow in the long run in line with productivity and as productivity gains become stronger over time, incomes rise. In donor countries, higher contributions to the EU budget lead to an increase in government indebtedness and this in turn leads to a gradual increase in labour taxes, which has a negative impact on employment growth. However, higher growth in net-recipient countries boosts tax revenues. For the largest net recipients this effect outweighs the former and the fall in government debt creates room to lower labour taxes, giving rise to positive employment effects. Corporate investment is generally crowded out by the increase in cohesion spending in the short run. In the medium run productivity enhancing effects come to dominate and investment spending increases. There is generally upward pressure on inflation as the demand effects dominate in the short run, but in the medium term, as potential output increases, inflationary pressures subside. Imports are boosted by the increase in demand while the increase in spending leads to a sizeable real appreciation in the largest recipient countries and the loss in competitiveness reduces exports growth. As a result of this, trade balances deteriorate and current account deficits become larger.

Fig. 1 shows the impact of cohesion spending on GDP broken down into the different categories of spending. In this figure each band represents the results from a model simulation in which one additional category of spending is added, i.e. the lowest band shows the results when only spending on agriculture, industry & services, and technical assistance is taken into account, the second band adds infrastructure spending to these simulations, the third adds R&D and the fourth investment in human capital. These charts illustrate the net contribution of each field of intervention and the time profile over which the output effects for each of these categories materialise. In general, the impact of infrastructure investment comes through

[10] The main parameters are summarised in the Appendix. A detailed analysis of the calibration and country features of the model can be found in D'Auria et al. (2009).

[11] A detailed list of 118 fields of interventions can be found in the Appendix. We assume that these shares of the fields of interventions are constant for all the years of the payment horizon 2000–09.

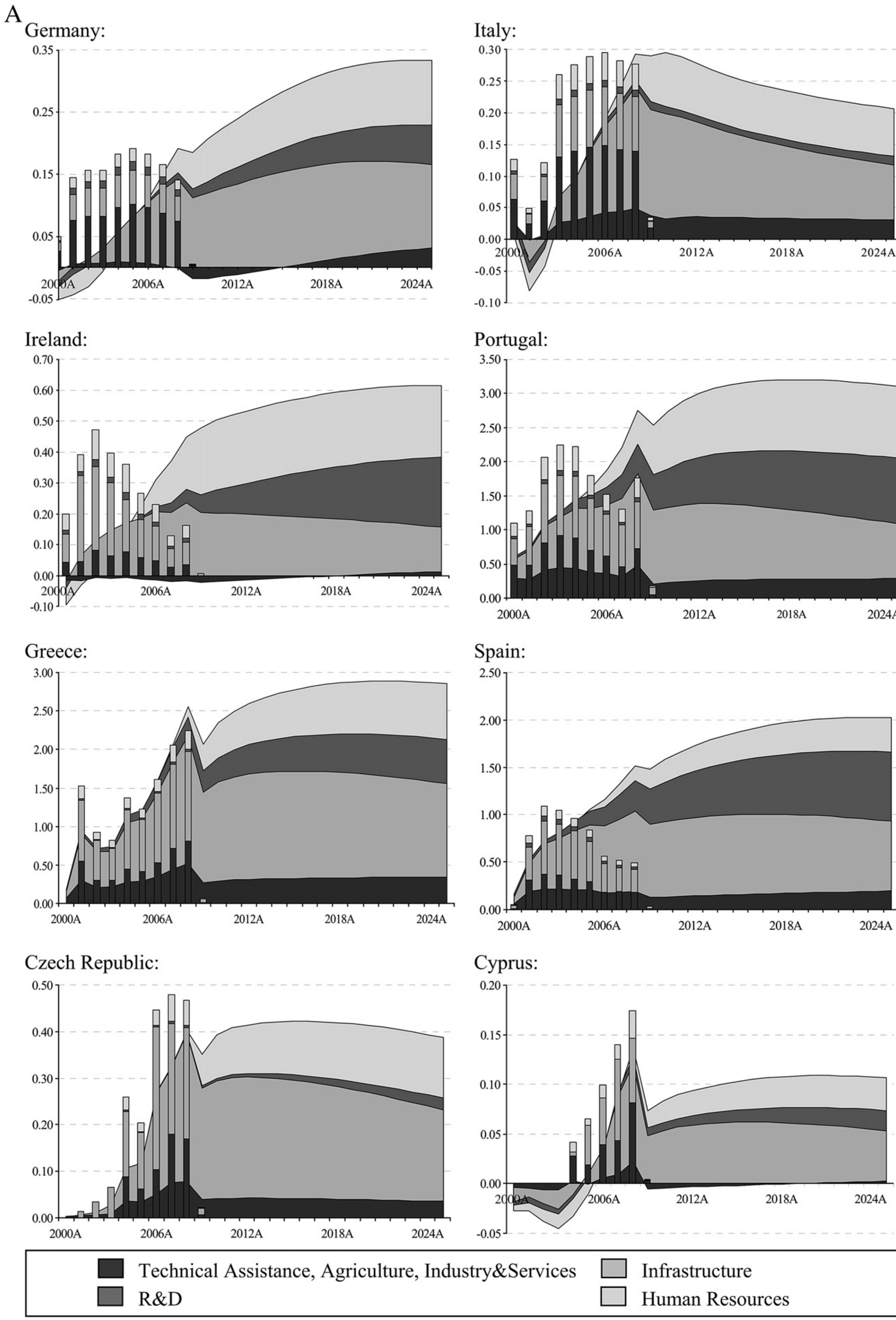
[12] Although net contributions differ widely across member states, a detailed modelling of contributions to the EU budget falls outside the scope of this paper. The assumption of financing through labour taxes is considered closest to reality but is of course only one possible option. The distortionary nature of labour taxes depends in the model on labour market parameterisation and indexation rules for benefits and transfers (see D'Auria et al., 2009). Financing through corporate profits taxes (or consumption taxes) would be more (less) distortionary.

[13] Detailed country results can be found in the working paper version of this paper (Varga and in 't Veld, 2009b) and, in the online version, in the Appendix.

Table 5
GDP effects of Cohesion Policy Programme 2000–06 for EU Member States.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GDP effects																					
Austria	−0.10	−0.13	−0.14	−0.14	−0.14	−0.14	−0.14	−0.14	−0.14	−0.15	−0.14	−0.14	−0.13	−0.12	−0.11	−0.09	−0.08	−0.07	−0.06	−0.05	−0.05
Belgium	−0.12	−0.16	−0.17	−0.18	−0.18	−0.18	−0.17	−0.16	−0.15	−0.15	−0.14	−0.13	−0.12	−0.11	−0.09	−0.08	−0.07	−0.05	−0.04	−0.03	−0.02
Denmark	−0.01	−0.05	−0.07	−0.09	−0.11	−0.12	−0.13	−0.13	−0.13	−0.13	−0.12	−0.11	−0.11	−0.10	−0.09	−0.08	−0.08	−0.07	−0.06	−0.06	−0.05
Finland	−0.14	−0.17	−0.16	−0.15	−0.14	−0.14	−0.14	−0.14	−0.13	−0.14	−0.14	−0.14	−0.14	−0.13	−0.12	−0.11	−0.10	−0.09	−0.08	−0.07	−0.06
France	−0.19	−0.30	−0.35	−0.40	−0.45	−0.50	−0.55	−0.59	−0.62	−0.65	−0.67	−0.69	−0.69	−0.69	−0.68	−0.67	−0.66	−0.64	−0.61	−0.59	−0.56
Germany	−0.05	−0.04	−0.03	−0.01	0.03	0.07	0.11	0.15	0.19	0.19	0.21	0.22	0.24	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33
Greece	0.19	0.87	0.66	0.69	1.10	1.20	1.60	2.06	2.55	2.07	2.34	2.50	2.60	2.67	2.73	2.77	2.81	2.84	2.86	2.88	2.89
Ireland	−0.10	−0.03	0.01	0.08	0.15	0.23	0.31	0.37	0.45	0.48	0.50	0.52	0.53	0.54	0.56	0.57	0.58	0.58	0.59	0.60	0.60
Italy	0.01	−0.08	−0.04	0.03	0.07	0.13	0.19	0.24	0.29	0.29	0.29	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.23	0.22
The Netherlands	−0.10	−0.11	−0.10	−0.09	−0.08	−0.08	−0.08	−0.08	−0.07	−0.07	−0.07	−0.07	−0.06	−0.06	−0.05	−0.05	−0.04	−0.03	−0.03	−0.02	−0.02
Portugal	0.56	0.64	0.96	1.13	1.41	1.62	1.89	2.20	2.75	2.53	2.74	2.90	3.00	3.08	3.13	3.16	3.18	3.20	3.20	3.20	3.20
Spain	0.16	0.47	0.66	0.76	0.91	1.06	1.16	1.33	1.51	1.48	1.58	1.66	1.73	1.79	1.84	1.88	1.92	1.95	1.97	1.99	2.01
Sweden	−0.04	−0.12	−0.16	−0.20	−0.23	−0.26	−0.27	−0.28	−0.28	−0.28	−0.27	−0.26	−0.24	−0.23	−0.22	−0.20	−0.19	−0.17	−0.16	−0.14	−0.13
UK	0.00	−0.03	−0.05	−0.06	−0.07	−0.08	−0.08	−0.08	−0.08	−0.08	−0.07	−0.06	−0.06	−0.05	−0.05	−0.04	−0.04	−0.03	−0.03	−0.03	−0.02
Bulgaria	−0.07	−0.06	−0.04	−0.02	0.01	0.03	0.05	0.07	0.08	0.05	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05
Cyprus	−0.03	−0.03	−0.04	−0.05	−0.03	−0.01	0.02	0.09	0.14	0.07	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11
Czech Republic	0.00	0.00	0.00	0.00	0.06	0.07	0.23	0.29	0.40	0.35	0.39	0.41	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.41
Estonia	−0.07	−0.03	0.00	0.05	0.23	0.39	0.63	0.74	0.89	0.69	0.77	0.81	0.82	0.81	0.80	0.79	0.77	0.76	0.74	0.72	0.70
Hungary	0.01	0.03	0.04	0.05	0.13	0.26	0.49	0.67	0.70	0.70	0.75	0.79	0.82	0.84	0.86	0.88	0.89	0.90	0.90	0.90	0.90
Latvia	0.03	0.12	0.20	0.33	0.67	1.23	1.64	2.33	2.59	2.51	2.64	2.69	2.72	2.72	2.72	2.71	2.70	2.68	2.66	2.63	2.60
Lithuania	0.03	0.11	0.21	0.27	0.49	0.80	1.02	1.41	1.78	1.55	1.68	1.77	1.83	1.88	1.92	1.95	1.98	2.00	2.02	2.03	2.04
Malta	−0.05	−0.09	−0.10	−0.09	−0.03	−0.01	0.12	0.31	0.34	0.28	0.31	0.32	0.33	0.33	0.34	0.34	0.35	0.35	0.35	0.35	0.35
Poland	0.00	0.00	0.02	0.01	0.20	0.29	0.63	1.04	1.38	1.41	1.51	1.57	1.61	1.64	1.67	1.69	1.70	1.70	1.70	1.69	1.67
Romania	0.00	−0.01	−0.01	−0.01	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Slovakia	−0.02	−0.07	−0.05	−0.04	0.11	0.24	0.40	0.55	0.71	0.49	0.57	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.67	0.68
Slovenia	0.00	−0.01	−0.01	−0.02	0.01	0.05	0.16	0.20	0.27	0.19	0.22	0.23	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23
EU	−0.03	−0.03	−0.01	0.00	0.04	0.07	0.11	0.16	0.21	0.19	0.22	0.23	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33

Note: Percentage difference from baseline.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Ireland:
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Portugal:
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Technical Assistance, Agriculture, Industry&Services
R&D
Infrastructure
Human Resources

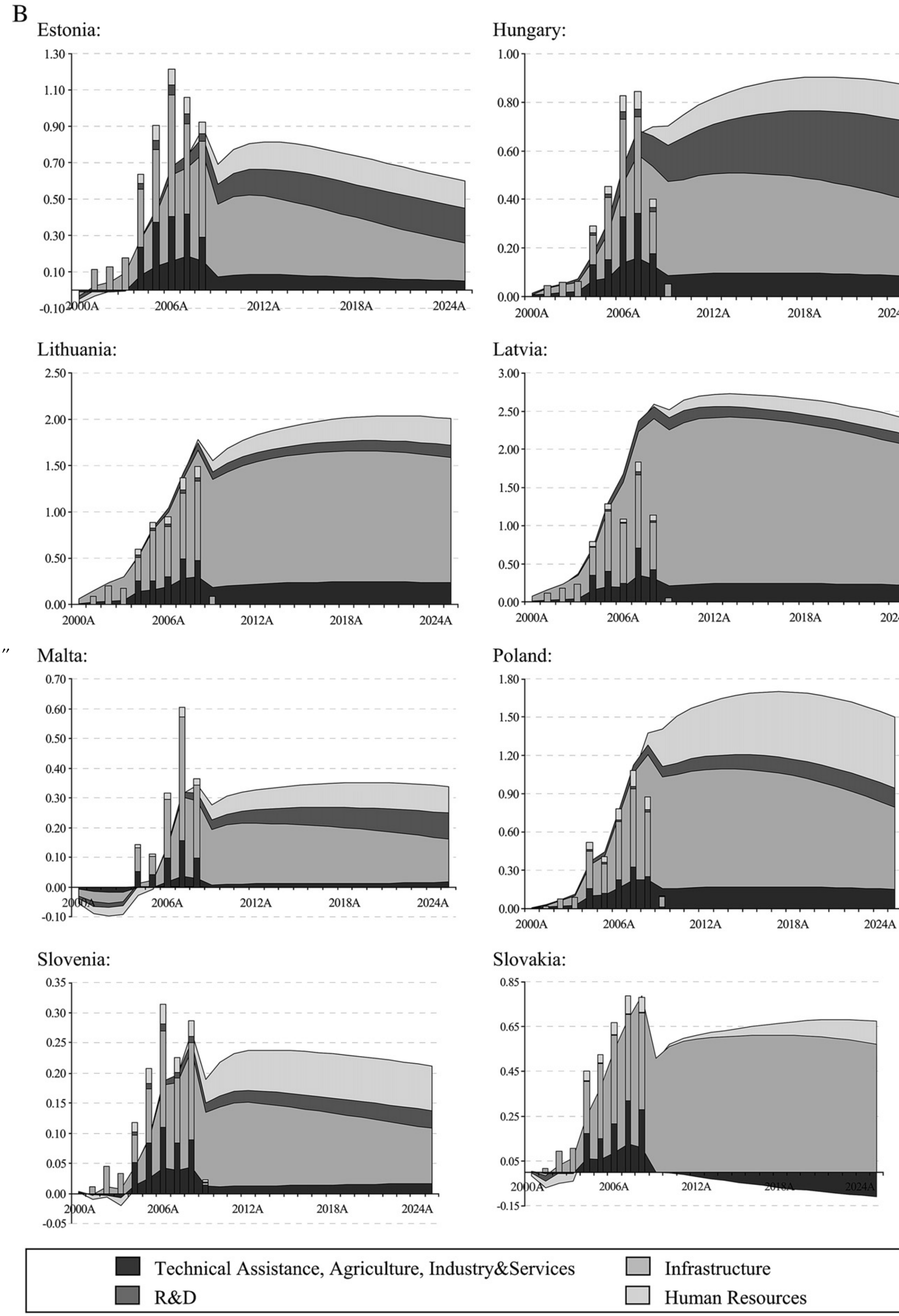

Fig. 1. Cohesion receipts (% of GDP) and GDP impact by category.

fastest, while R&D and human capital investment effects take longer to materialise. Note that these results include spillover effects from other countries.

The category *Technical assistance, agriculture, industry and services* includes a diverse range of interventions. Examples are support to processing and marketing of agricultural and fisheries products, agricultural waste resources management, co-financing of state aids to industries and services, supporting plant and equipment investment, as well as expenditure on technical assistance related to preparation, implementation, monitoring and evaluation. Some of these interventions are modelled as reductions in fixed costs (lowering startup costs and increasing entry of new firms) or as lower capital costs for tangible capital (increasing investment and capital accumulation). Another part of this spending is modelled as unproductive government spending, like e.g. technical assistance, monitoring and evaluation costs. The latter only has a growth boosting effect in the short run, i.e. during the years of the programming period when the spending occurs, but the former has a permanent output enhancing effect even after spending has discontinued.

Infrastructure spending is assumed in the model to have a positive productivity effect and accounts for a large share of the total output enhancing effects in the model simulations. This category includes investment in transport, telecommunications, energy and environmental infrastructure, as well as social infrastructure. All this spending is modelled as government investment with the exception of social infrastructure investment which we treat in the first instance as unproductive government consumption (this is a relatively small category and the effects when we model this as productive investment are only slightly larger — see section on sensitivity analysis). In the short run the effects of government investment (productive) and government consumption (unproductive) are similar. Both lead to higher aggregate demand but are partly crowded out by lowering private consumption and private investment and some of the demand impulse leaks abroad through higher imports. However, in the medium term government investment raises productivity (this in contrast to unproductive government consumption) and the output enhancing effects of infrastructure investment become stronger in the following years. As can be seen in the charts, when investment is discontinued, the productivity effect slowly declines due to depreciation of public capital.

Support to R&D includes all spending on research, technological development and innovation (RTDI), including the establishment of networks and partnerships between businesses and/or research institutes. In the model this is captured as reductions in fixed costs and reductions in intangible capital costs for the intermediate sector, the users of the output of the R&D sector. The mechanism through which this R&D spending supports growth in the model is as follows. By reducing costs, the cohesion programme spending makes it easier for new start-ups to enter the market and so support the introduction of new products. This is because although both existing firms and newcomers face similar problems when marketing new products, start-ups typically have less access to capital markets and have to overcome administrative hurdles (and costs) to set up a new business. By supporting innovation, high-skilled workers are reallocated in the model from the production sector to the R&D sector. Initially, this reallocation reduces final goods production and has a negative impact on growth, but over time the positive output effects dominate as productivity increases, and this also stimulates physical investment. It is interesting to note that while it takes time for these effects to become apparent, the output gains are significant and, importantly, continue to increase long after spending is discontinued (reflecting the endogenous growth nature of the modelling approach). From Fig. 1 it is also clear that there can be cross-country spillover effects. Cyprus, and to a lesser extent Malta, have no (or only a small) allocation for R&D interventions, yet the simulation in which R&D spending is added to cohesion expenditure shows positive output effects, illustrating the international R&D spillovers as modelled in the knowledge production function (Eq. (20)).

Expenditure on *human resources* includes all spending on educational and vocational training as well as more generally defined labour market policies and spending on social inclusion. This is partly modelled as non-productive government spending and direct transfers to households, but the productivity enhancing effects are captured through their effects on skills. Total human capital in the models depends on the efforts individuals spend on accumulating human capital and an increase in the years of schooling (participation in training) for a respective skill group raises the skill efficiency of that group (see Appendix). The effects of this on average skill efficiencies take time to build-up, taking into account cohort effects, and the gains are only becoming apparent in the medium term, not dissimilar to those of R&D spending, but they are equally significant and highly persistent. The efficiency effects depreciate according to the exit rate of working age population in the long run. However, there may be an underestimation of the depreciation rate if a large part of vocational training targets unemployed or inactive people in older age groups, with a shorter remaining productive working life. Also, the impact of training on skill efficiencies depend on the subsequent employment status and human capital may depreciate faster after training if they remain unemployed/inactive or become unemployed after a short period of employment. For these reasons the simulated effects should be considered an upper bound of the likely outcomes[14].

A comparison across countries shows GDP effects roughly proportional to the funds received, when the financing of EU contributions is also taken into account. Hence, the largest recipients, Portugal, Greece and Spain, show the largest increases in GDP. Portugal received EU Cohesion support for up to €22.5 billion over this period, amounting to between 1 and 2% of its GDP each year. In the model simulations this leads to a large increase in output. After a decade, GDP is 2.7% higher and output continues to increase in the years after spending is discontinued, reflecting the endogenous growth enhancing effects of R&D and human capital accumulation. The impact of R&D supporting policies on growth is reflected in an increase in “patents” A in the model. Higher productivity leads to an increase in wages, more so for high-skilled workers that benefit from the increase in R&D spending. Consumption increases and is almost 5% higher after 10 years. Inflation is up in the first years as the increase in demand exceeds the increase in supply, but when potential output gradually rises the inflationary pressures subside. Higher real interest rates in the medium run lead to higher capital costs and this depresses corporate investment spending, but in the long run investment increases. There is a real appreciation of the exchange rate and this leads to a decline in exports, while the increase in demand boosts imports. The trade balance deteriorates by 1.8% of GDP at its peak before slightly recovering in later years.

The results for Greece are similar to those for Portugal. Greece received a similar share of its GDP from EU Cohesion support but this was slightly more backloaded to later years in the programme. It therefore takes longer for the output effects to become apparent. But after a decade GDP is more than 2.3% higher in the model simulations and the effects become stronger in later years. Like for Portugal, the increase in R&D spending is reflected in an increase in “patents”, but with a smaller share devoted to R&D promotion, the increase in patents is lower than that in Portugal. Wages increase as productivity rises and consumption is higher for both non-constrained and liquidity constrained households. Corporate investment initially falls due to higher real interest rates which raises capital costs, but in later

[14] Note that the participation rate is exogenous in the model. Some of the labour market programmes and interventions could raise labour force participation and so increase the employment rate. To capture this effect, one would also have to endogenously model the participation decision.

years investment rises again supported by higher demand. There is an increase in inflation in the first years of the simulation. The real appreciation reduces export growth and imports are higher due to the increase in domestic demand. The trade balance deteriorates by up to 1.3% of GDP.

Spain received up to €54 billion from EU Cohesion support, amounting to up to 1% of its GDP each year of the decade. The model simulations show significant positive output effects, with GDP 1.6% higher after 10 years and continuing to increase in the years after. Consumption is higher for both constrained and unconstrained households, and while private investment is initially lower, investment increases in later years. Initially the additional spending leads to higher inflationary pressures while real wages increases due to higher productivity. The wage increase for high-skilled workers is strongest as there is an increase in R&D spending. The real appreciation of the exchange rate depresses exports, while higher demand boosts imports and this worsens the trade balance by up to 0.8% of GDP.

Ireland received up to 0.4% of GDP from Cohesion policy support, largely frontloaded to the first half of the decade, and became a net contributor in the last years of the programme. The model simulations show an increase in aggregate consumption as the positive effect on non-constrained consumption, due to higher permanent income, outweighs the negative effect on liquidity constrained consumption (due to higher taxes and lower employment). Initially corporate investment is depressed by higher capital costs but in later years private investment increases. Imports increase and exports decline and the current account worsens. After a decade of support, GDP is 0.5% higher.

It is interesting to notice that even in Germany, which is a net contributor to cohesion (EU budget) spending, the GDP effect is positive. Although labour taxes increase, and hence employment falls, the productivity enhancing effects of the cohesion spending come to dominate after three to four years. Consumption of non-constrained consumers rises as households anticipate the increase in permanent income, but consumption of liquidity constrained households falls as employment declines and taxes are raised. Real wage growth is higher as productivity rises. There is a small increase in inflation and a real appreciation reduces exports growth and boost imports, leading to a deterioration of the trade balance. After a decade, GDP is around 0.2% higher.

In Italy, the time profile of spending is such that it becomes a net contributor in 2001 and 2002, reducing the output effects from cohesion receipts, but these become positive again in later years. Consumption and corporate investment also increases in the medium term. There is an increase in real wage growth and inflation is higher. GDP is 0.3% higher after a decade, slightly more than in Germany, as net receipts in Italy exceed those of Germany. Consumption is 0.4% higher after a decade.

The *New Member States* only joined the EU in 2004 and became eligible for cohesion support from then onwards, but several countries already received pre-accession aid from 2001. For all these countries the model simulations show significant output gains. Consumption is higher, in particular that of Ricardian non-constrained households as permanent income increases. In countries with a free floating exchange rate, fiscal transfers are associated with nominal exchange rate appreciations and this has a detrimental effect on export competitiveness. But even in many of the countries that peg their currencies to the euro, as demand exceeds supply in the short run, inflation rises leading to a real appreciation of the exchange rate, which worsens current account deficits. For those countries that did not receive pre-accession aid (notably Malta and Cyprus) the model shows small negative GDP effects in the years prior to accession, due to negative trade effects, but the output effects become positive in later years. Note also that the results for Cyprus and Malta show positive international spillover effects from R&D spending, despite no (or low) allocations of their own funds to R&D investment. Of all the New Member States, Latvia, Lithuania and Poland show the largest output gains[15].

Table 5 also shows the GDP effects on *donor countries*. Output falls in these net contributors due to the distortionary effects from higher taxes that are required to pay for EU cohesion policy. While this is partly offset by higher export growth for those countries that have close trading links to the recipient countries, the overall effect on output is in most cases negative, and this is largest for France. For the EU as a whole, the GDP effects become positive by 2004, when the gains in recipient countries more than outweigh the losses in donor countries. Assuming no differentiated population growth rates across EU countries, these results also indicate a convergence in GDP per capita, with poorer countries catching up relative to the EU average.

6. Sensitivity analysis

This section explores the sensitivity of the results with respect to two factors: 1) the value of the output elasticity of public capital (infrastructure)α_G, and 2) the share of liquidity constrained consumers. Fig. 2 shows the impact on GDP for Portugal[16].

There exists much uncertainty about the appropriate value for the output elasticity of public capital (infrastructure)α_G. There is a large literature on infrastructure investment and economic growth, starting with Aschauer's (1989, 1990) estimates for the U.S. that a 1% increase in the public capital stock would raise output by 0.39%. Many economists have questioned these estimates as implausibly high and this has given rise to a large literature[17]. Econometric problems relating to common trends, missing variables, simultaneity bias and reverse causation hamper a proper identification of this elasticity from macroeconomic timeseries. Studies using pooled time series, cross-section data across states, have generally yielded lower estimates with an implied rate of return on public investment equal to the rate of return on private capital or lower (e.g. Bougheas et al., 2000). Estimated effects of other infrastructure investment like telecommunications are often smaller. The extremely wide range of estimates found in the literature means these production function based studies are of little use from a policy perspective (Romp and de Haan (2005) p.43).

Gramlich (1994) argues there is a "logical" problem with the high implied econometric rates of return and makes a case for an identical rate of return on private and public capital[18]. This is the assumption adopted in the model and the output elasticity of public capital is set such that the marginal product of public capital is identical to that of private capital ($\alpha_G = 0.10$) [19].

To see the impact of a higher elasticity on the overall results, we raise the elasticitity by 50% to 0.15. As infrastructure spending amounts for a large share of overall spending (between 30 and 40%) this has a significant impact on the results. As can be seen in Fig. 2, in the case of Portugal it raises the long term GDP effect from 3.1% to 3.7%.

The model distinguishes two types of households. The first group of households, Ricaridians or non-constrained, base their consumption decisions on intertemporal optimisation and smooth their consumption over time. They are assumed to have access to capital markets and can borrow against future income. A second group of households is liquidity constrained and cannot borrow, but can only consume their disposable income each period. It is assumed in this version of the model that this group corresponds to the group of low-skilled workers, while medium and high-skilled workers are non-

[15] The appendix includes a comparison of cumulative multipliers.

[16] Results for all other countries are reported in the Appendix.

[17] For an overview see the surveys by Gramlich (1994), Sturm et al. (1996) and Romp and de Haan (2005).

[18] Gramlich (1994), p. 1187.

[19] Note that this does not exclude the possibility that the marginal product of capital (private and public) is higher in less-developed economies.

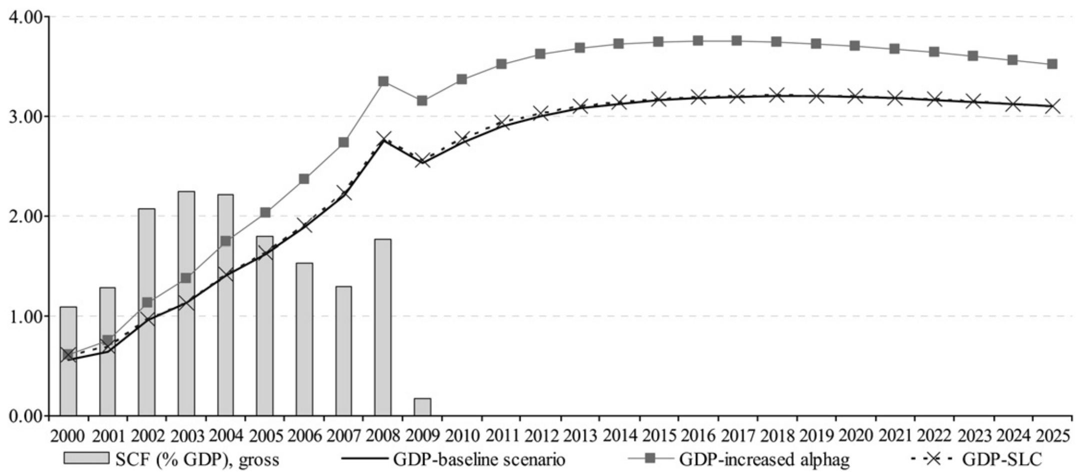

Fig. 2. Parameter sensitivity of GDP effects: Portugal.

constrained. The share of liquidity constrained households is generally an important parameter as it determines the degree of so-called non-Ricardian behaviour in the model for non-productive government spending shocks.

The lower the share of liquidity constrained households, the higher the degree of crowding out of government spending shocks due to an offsetting response of Ricardian households who raise their precautionary savings in anticipation of higher future tax liabilities.

The share of liquidity constrained households in the euro area is typically estimated to lie in the range between 0.2 and 0.4 (e.g. Ratto et al., 2008). The assumption in the model version used here, that this share is equal to the share of low-skilled workers, implies substantial differences across countries. Labour force data on skill groups shows a large dispersion in the share of low-skilled workers across countries and our model assumption implies a similar dispersion in the share of liquidity constrained households. As a sensitivity analysis we set the share of liquidity constrained households in all countries equal to 0.5[20]. As is clear from Fig. 2, the impact of this assumption on simulation results is not particularly large. The reasons for this small impact are twofold. First, cohesion spending is financed by fiscal transfers from the EU budget. This spending does not give rise to proportionally higher tax liabilities in the future but is a pure fiscal transfer from contributor counties to recipient countries. Second, consumption by Ricardian households is also positively affected as most spending is productive and leads to a rise in permanent incomes.

7. Conclusions

This paper shows how a modern dynamic general equilibrium model with endogenous growth and human capital accumulation can be used to analyse the effects of the EU Cohesion Policy programme over the period 2000–06. The analysis has shown there are potentially significant long run benefits from EU Cohesion Policy spending in the less-developed regions of the EU. These positive benefits become stronger in the medium and long run and are able to deliver a significant improvement in incomes and output in the regions supported.

However, these interventions are likely to bear fruit only in the medium term and significant effects from these policies should only be expected some years after implementation. In the short run, the additional spending could lead to crowding out of productive private investment due to intertemporal consumption-investment decisions and the transfers could give rise to real appreciations which lower export growth. R&D promoting policies could drive up wages of researchers and crowd-out high-skilled employment in other sectors. In addition, there is little benefit one can expect in the short run from training and other human capital investments. But in the medium term the productivity enhancing effects of infrastructure investment, R&D promoting policies, and human capital investments become gradually stronger and even when the programme is terminated and spending discontinued there are permanent positive output gains. Results shown here for the completed programming period 2000–06 are likely to apply similarly to the new programming period 2007–13, which is more directed to the new member states in Central and Eastern Europe.

The success or failure of EU Cohesion Policy programmes should obviously not exclusively be judged on the basis of its effect on GDP. The objective of Cohesion policy is to foster social and economic cohesion and to achieve real convergence in the Union. GDP is the yardstick most commonly used, and GDP per capita is the measure on which eligibility for Cohesions support is determined, and this is therefore the logical first measure to use in an assessment. But one should be aware that even as an indicator of market activity, gross domestic product is not a measure without flaws. Alternative measures like gross national product, which includes net capital paid to and from abroad, or net national income, which includes profits exported and imported, may be preferred. But more generally, other measures of wellbeing should also be taken into account in a wider assessment of EU Cohesion Policy.

It should also be stressed that these results are based on a macroeconomic analysis and depend crucially on the underlying assumption that the money is spent efficiently. Hence, this aggregate macroeconomic modelling approach gives an estimate of the *potential* effect of Cohesion spending and the long run output gains reflect the assumed productive impact of investment in infrastructure, human capital and R&D in the model. This modelling approach should be complemented with an analysis based on micro data from individual projects as only such a project-based analysis could shed light on the question whether the positive impacts shown here are achievable.

Acknowledgements

We thank Marco Ratto, Werner Roeger and Kai Stryczynski for their help and advice. The views expressed in this paper are those of

[20] The share of low-skilled workers is based on OECD data and kept unchanged in this experiment. Only the share of liquidity constrained households is fixed at 50%. An alternative but more ambitious step would be to endogenise the skill shares and that of liquidity constraint households: as a country spends more on education and training (possibly EU-funded), more households would graduate into the non-liquidity constrained, medium-skilled category, providing another source of endogenous growth and convergence.

the authors and should not be attributed to the European Commission.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.econmod.2010.06.004.

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