The long run-effects of the Poland's accession to the eurozone. Simulation using POLDYN - a dynamic computable general equilibrium model.

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Simulation using POLDYN - a dynamic computable general equilibrium model.

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Abstract

The aim of this paper is to assess the non-monetary effects of the euro accession of Poland. The literature identifies two channels that potentially may affect the economy: (i) diminishing of investment risk premia through lower interest rates and cost of capital services and (ii) trade creation effects due to elimination of currency transaction spreads, better price comparability and elimination of currency risk. We employ a dynamic general equilibrium model with perfect foresight multiple households, adjustment cost of capital, disaggregated labor market. We directly model trade-driven productivity spillovers. Our simulations show a long run GDP gain from the euro accession at the level of 7.5% of benchmark GDP of which 90% is realized in first 10 years. The main factor behind growth is investment that leads to an extra 12.6 percent of extra capital accumulated in the long run. The welfare gains amount to roughly 2% of the value of GDP each year. The sensitivity analysis proves that the model behavior is reasonably resistant to parameter changes.

1 Introduction

Accession to the euro zone implies that for the joining country that: (i) there are no longer exchange rate adjustments possible against other participants of the monetary union; (ii) monetary policy is set by the common central bank whose policy may not be optimal for the acceding country because as it targets the euro zone aggregate inflation, the preferences of the central bank may not be fully compatible with all the member states (iii) participating in the monetary union could require that

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fiscal flexibility is restrained because of the necessary adoption of fiscal stringency measures like the Maastricht Treaty and the Stability and Growth Pact. These are the commonly quoted costs of the monetary integration and the literature on the subject seems very ample. However, the evidence on the possible benefits from monetary integration, especially those related to the euro zone and the accession of the new EMU member states is quite scarce. These benefit estimates should be compared to the cost estimates when deciding on the timing of monetary integration.

The aim of this paper is to provide some stylized estimates on the magnitude of gains that may stem from monetary integration. We briefly survey the literature for possible channels through which these gains may manifest itself. The most often quoted ones are trade creation effects due to elimination of currency transaction spreads, better price comparability and elimination of currency risk. On top of that, evidence suggests that in faster developing economies with higher interest rates, monetary integration leads to a decrease in the long-run interest rates through elimination in the risk premia. This affects the costs of capital and the level investment.

To assess the possible effects of Polish accession to the EMU, we decided to employ a computable general equilibrium model. The model is dynamic, in the sense that the households maximize their lifetime utility given their long run income with perfect foresight. The model encompasses many features that let us provide disaggregated results: we model multiple households and multiple sectors. Production technology is based on capital and three labor types, and we model household labor supply. We assume that Poland is a small open economy and we treat separately trade flows with the euro zone, rest of the European Union and the rest of the world. We directly model trade driven knowledge spillovers that affect labor productivity.

Our simulations suggest that the long run GDP gain from the euro accession amounts to 7.5% of benchmark GDP of which 90% is realized in first 10 years. The main factor behind growth is investment that leads to an extra 12.6 percent of extra capital accumulated in the long run. As investment demand is very high in the first periods under consideration, imports go up considerably. Over time, with capital accumulation and falling production costs, exports go up to reach a level higher by almost 13% than the benchmark scenario. The welfare gains amount to roughly 2% of the value of GDP each year. The poor households gain slightly more than the non-poor households due to the fact that they loose relatively less risk premium revenues. Consumption is expected to go up by 3.7% in the long run. The production structure of the economy shifts towards market services and the economy-wide production becomes more capital intensive.

We perform a sensitivity analysis that checks how the results are affected by the choice of key parameters of the model. The performed simulation suggest that the model behavior is reasonably resistant to parameter changes. The imposed variation in parameters leads to a variation in key macroeconomic variables by roughly 1pp.

The paper is structured as follows. The section two provides short literature review. Section three gives a introduction into CGE modelling concept and describes the model structure. Section four covers the data and calibration techniques. Sections five and six follow with simulation results and sensitivity analysis. Section six concludes the paper.

2 Literature review

The mainstream of the literature on monetary integration is related to the question of the optimality of common currency in the presence of asymmetric shocks and dis-alignment of the business cycle among the members of the currency union. This relates to the optimum currency areas (OCA) literature, that is mostly due to Mundell (1961). A survey of the literature dealing with the analysis of the Poland's exposure to asymmetric shocks and other related literature is given in Borowski (2004), who also identifies the possible benefits of Poland's Euro accession. He claims that main benefits of eurozone accession come from the elimination of the currency risk premium and the impact on the transaction costs and foreign trade. The study published by NBP (2004), provides an overview of costs and benefits of the eurozone accession. While the analyzed costs mainly stem from loosing autonomous monetary policy and from the necessary budgetary tightening to satisfy the Maastricht criteria, the benefits that the report identifies are the decrease of the macroeconomic risk, integration of the financial markets, increase in the degree of competition, elimination of the currency exchange risk and lowering of transaction costs. This is expected on one hand to cause an increase in the rate of investment through lowering of risk premia and interest rates, and on the other, boost international trade. The assessment foresees long-run effects on the stock of capital and labor productivity.

Our paper focuses on two channels of possible effects of the EMU accession: trade creation effects and the lower risk premium effects. The literature related to the Euro trade effects partially overlaps with the broader strand of empirical literature analyzing trade impact of currency unions. Most of the literature is based on variations of the gravity model of trade, where impact of exogeneous factors on trade potential is analyzed. The pioneer study in this respect was the analysis by Rose (2000) who found that other things equal, the two countries that share the same currency, trade three times more than countries with different currencies. The paper has been criticized from many angles, mainly the choice of the countries in the original dataset, data errors, and, more importantly, possible endogeneity of monetary unions that stems from, among other sources, the colonial past.

Rose and van Wincoop (2001) try to refine the empirical model. They use the Anderson and van Wincoop (2003) methodology that resolves some problems of the misspecification of the gravity equation by using panel data (Rose's original work was performed using the cross-section data). The estimated effects on trade of having the same currency are 250%, the estimated trade costs stemming from different currencies amount to 26% of trade value. This amounts to roughly half of the so called "border-costs" as estimated by Anderson and van Wincoop (2003). The methodology allows the authors to estimate the trade effect of different potential currency unions, even those that have not yet been created. For the case of the EMU, Rose and van Wincoop find that the increase in trade would be of the order of 60 percent.

Persson (2001) suggests that the results in Rose (2000) may be biased due to effects of some of the explanatory variables being non-linear and to the fact that the likelihood that two countries will adopt a common currency is not random, and may depend on some of the explanatory variables. For example, the likelihood of forming currency unions may be larger for small countries. His methodology is based on matching. He first estimates the propensity to form a currency union for each country pair. Then, for each observed currency union he finds a pair of other countries having similar characteristics and therefore highly likely to form a currency union. He estimates the effect of currency union on trade, using only the matched observations. Using this methodology, he finds the effect of currency union on trade to be 65 percent.

Micco, Stein, and Ordoez (2003) estimate the early effects of the EMU on trade. They use a panel dataset that includes information on bilateral trade for 22 developed countries from 1992 through 2002, and therefore it includes the 12 countries that entered the currency union in 2000. They find that, controlling for other factors, the effect of EMU on bilateral trade between member countries ranges between 5 and 10 percent, when compared to trade between all other pairs of countries, and between 9 and 20 percent, when compared to trade among non-EMU countries. They do not find any evidence of trade diversion (switching from non-EMU to EMU trade partners). Their results suggest that the monetary union increases trade not just with EMU countries, but also with the rest of the world. Similar study was performed by Maliszewska (2004) who analyzes the trade flows between EU and Central and Eastern European countries for the period 1992-2002, and her estimates suggest the euro accession elasticity of trade at the level of 23%.

The above survey of the gravity-type literature is by no means complete. A very comprehensive survey on trade effects of the currency unions is provided by Baldwin (2006) and the general conclusion is that the effects of currency unions on trade of the order of 10% of the volume of trade seem reasonable (although the evidence the size of the effects vary a lot, especially in the early works). The more recent empirical work by Cieślik, Michałek, and Mycielski (2008) analyzes the trade effects of EMU in a gravity framework. They use a generalized gravity model estimated on the data for the period 1993-2006 for over 100 countries. They look at both the effects of EMU accession but also on the effects of pegging exchange rates against the euro. The obtained results suggest that immediately after the accession, the Polish exports will rise by around 12% and the total volume of trade by around 9%.

Mroczek (2008) identifies the possible channels that may cause the EMU trade creation. They are: elimination of the currency exchange risk, lowering of transaction costs and increasing price transparency. He notes that the EMU countries have experienced a considerable increase in trade over the period of its existence, but this may be at least partially due to other factors. He expects, that the increase in trade after EMU accession will be the most pronounced in countries where the share of trade with EMU members in total trade is the highest and since the Central and Eastern European countries trade on average more with the EMU than EMU members among themselves, the trade creation effects may be higher that in the original EMU-12 group.

Bukowski, Dyrda, and Kowal (2008) calculate the possible savings in transaction costs stemming from the bid-ask spread on currency transactions amounting to 2-3% of the value of transactions. They project that solely from the introduction of the common currency, the direct impact on the costs of exporters amounts to 1-1.5% of GDP and the long run impact on the level of GDP simulated using a dynamic stochastic general equilibrium model is 0.66%. This does not take into account any additional possible effects, such as greater international price comparability or exchange rate risk in international transactions and can be treated as a lower-bound estimate.

The second channel of the single currency impacts on the Polish economy, that we look at in our simulations, is lowering the interest rate risk premium. In the literature risk premium is often calculated as the spread between rates of return for the 10 year bond (bond yields). In theory, the introduction of the single currency should lead to greater integration of financial markets and a decline in spreads.

Reininger and Walko (2005) indicate that the convergence in rates of return of 10-year bonds for eurozone candidate countries (Poland, Hungary, the Czech Republic) may be close to the convergence process, which took place for Italy, Greece, Portugal, Spain prior to the adoption of the single currency by those countries at the beginning of 2001. Euro adoption resulted in the full convergence of bond yields for the countries of the so-called Club-Med to the rates of return of 10-year bonds for Germany. More than two thirds of the decline in spreads occurred two years before introduction of the euro. A lower degree of integration of the Polish market with the market of the euro zone may increase potential benefits.

Bukowski, Dyrda, and Kowal (2008) estimate that as a result of the adoption of a single currency, the nominal interest rates will decrease by about 0,6-0,8 pp. The long run impact simulated using a dynamic stochastic general equilibrium model on the level of GDP is small - 0,45% increase and the level of investments is higher by 0,39%.

3 The model

3.1 The baseline Ramsey model:

Our model is a straightforward extension of the simple Ramsey model presented by Lau, Pahlke, and Rutherford (2002) and Paltsev (1999). Consider an economy with one infinitely lived agent deriving his lifetime utility from consumption of one good (c_t). The lifetime utility function is given by:

$$U = \sum_{t=0}^{\infty}(\frac{1}{1+\rho})^t W(c_t), \tag{1}$$

where t - time periods, ρ- individual time preference parameter, W - period utility function. The agent is endowed with a labor endowment in each period (L_t) and an initial stock of capital K_0. Total output produced in the economy with technology given by the production function $F(K_t, L_t)$ is used either for consumption or investment (I_t):

$$c_t = F(K_t, L_t) - I_t.$$

Capital depreciates at rate δ and accumulates over time according to a simple formula:

$$K_{t+1} = K_t(1-\delta) + I_t.$$

A social planner problem is maximizing the utility subject to resource constraints. The problem can be set up as a maximization of the following Lagrange function:

$$\Im = \sum_{t=0}^{\infty}(\frac{1}{1+\rho})^t W(c_t) - \sum_{t=0}^{\infty}\lambda_{1,t}(F(K_t, L_t) - I_t - c_t) - \sum_{t=0}^{\infty}\lambda_{2,t}(K_t(1-\delta) + I_t - K_{t+1}) \tag{2}$$

The first order conditions are:

$$\frac{\partial \Im}{\partial c_t} = (\frac{1}{1+\rho})^t \frac{\partial W(c_t)}{\partial c_t} - \lambda_{1,t} = 0 \tag{3}$$

$$\frac{\partial \Im}{\partial K_t} = \lambda_{1,t}\frac{\partial F}{\partial K_t} - \lambda_{2,t-1} + \lambda_{2,t}(1-\delta) = 0 \tag{4}$$

$$\frac{\partial \Im}{\partial I_t} = -\lambda_{1,t} + \lambda_{2,t} = 0. \tag{5}$$

In a utility maximization problem and cost minimization problem the Lagrange multipliers correspond to the marginal utility and marginal cost respectively. If the production and utility functions satisfy the requirements for the existence of competitive equilibria, the social planner solution above corresponds to a competitive equilibrium. In a competitive equilibrium price equal marginal costs. The conditions 3-5 can be therefore rewritten as:

$$p_t = (\frac{1}{1+\rho})^t \frac{\partial W(c_t)}{\partial c_t}$$

$$pk_t = (1-\delta)pk_{t+1} + p_t \frac{\partial F(K_t, L_t)}{\partial K_t}$$

$$p_t = pk_{t+1},$$

where p_t is a price of output (and therefore consumption and investment good), pk_t is a price of a unit of capital in period t and pk_{t+1} is a price of capital in period $t+1$. In a competitive equilibrium, the prices of factors of production clear the factor market and the price of goods clears the goods market. The unit cost function $C(rk_t, w_t)$ is a solution to the cost minimization problem: $\min(w_t L_t + rk_t K_t)$ subject to $F(K_t, L_t) = 1$, where rk_t is the rental price of capital. The demand function $D(P_t, M)$ is a solution to a lifetime utility maximization problem subject to the budget constraint: $\sum_{t=0}^{\infty} p_t c_t = M$, where M is the consumer income.

The competitive equilibrium is given by the following system of conditions. The following equations correspond to **zero profit conditions:**

$$p_t = pk_{t+1}$$

$$pk_t = rk_t + (1-\delta)pk_{t+1},$$

$$C(rk_t, w_t) = p_t$$

Market clearing conditions follow.

$$Y_t = D(p_t, M) + I_t$$

$$L_t = Y_t \frac{\partial C(rk_t, w_t)}{\partial w_t}$$

$$K_t = Y_t \frac{\partial C(rk_t, w_t)}{\partial rk_t}$$

(where Y_t is supply in period t) and the system is completed by the **income balance condition**:

$$M = pk_0 K_0 + \sum_{t=0}^{\infty} w_t L_t$$

3.2 The full model overview

The POLDYN model is a computable general equilibrium model that is standard in any ways. The basic functioning of the model relies on the assumptions that:

- Consumers maximize their lifetime utility by choosing each period consumption, labor supply and savings given the budget constraint. Consumers know the future paths of all prices and incomes (perfect foresight).
- Producers maximize profits, taking goods and factor prices as given (perfect competition).
- All markets clear.
- The economy is small and open: agents take foreign prices as given and at the going foreign prices they can demand and supply any amount of a given good.

The POLDYN model takes its intertemporal structure from the above version of the Ramsey model. It has been, however, extended in several ways. The full model, in the version that was used to prepare this study comprises the following features:

- Multiple households,
- Multiple production sectors based on CES technology,
- Endogeneous labor supply (leisure/consumption choice) and multiple labor types,
- Small open economy features with multiple trading partners, imperfect substitution between sources and destination and international borrowing,
- Public sector,
- Capital adjustment costs,

Figure 1: Utility structure

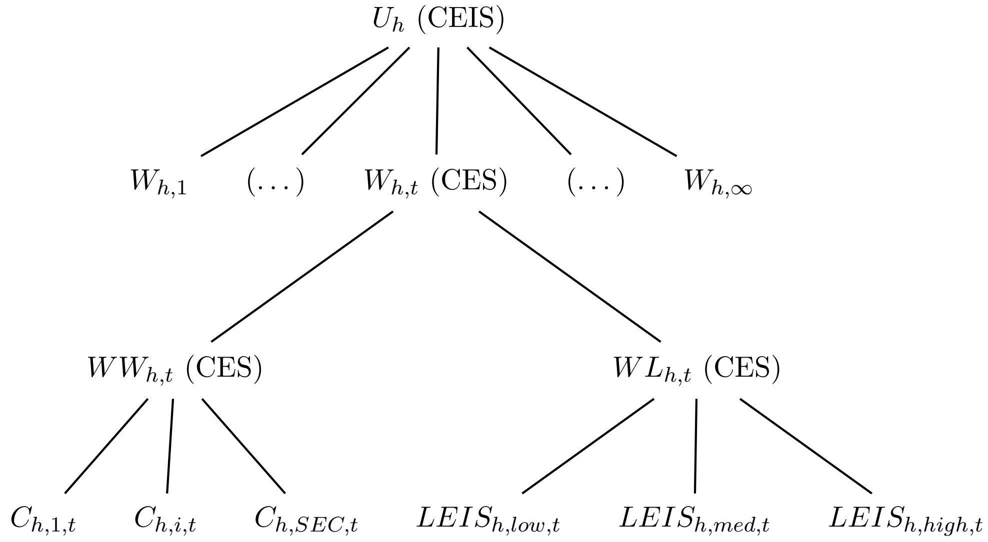
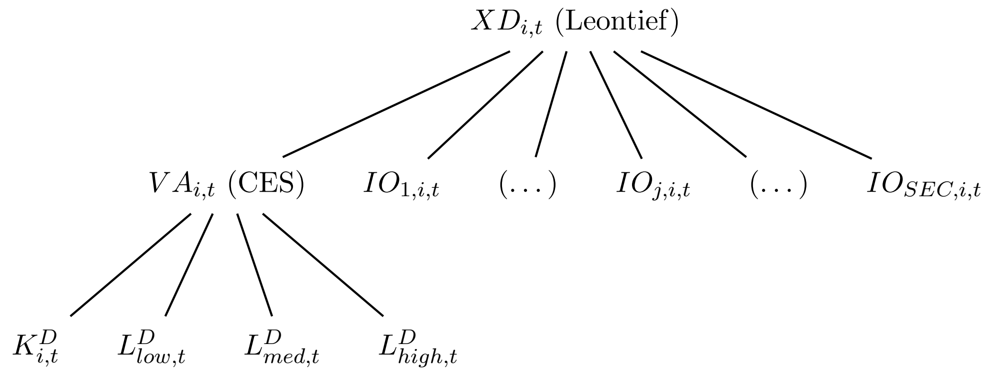


Figure 2: Production structure



- Spillover productivity effects stemming from international trade.

The consumer households are assumed to maximize a lifetime utility subject to a intertemporal budget constraint. The household utility is a nested concept (the structure of preferences is depicted in figure 1. The top tier of preferences of household h is given by a constant elasticity of intertemporal substitution (CEIS) function U_h that aggregates welfare levels in all the periods within the infinite horizon of the household $W_{h,t}$. The $W_{h,t}$ are sub-utility constant elasticity of substitution (CES) aggregates of the consumption of goods ($WW_{h,t}$) and leisure ($WL_{h,t}$). The two components of the period utility are again CES sub-utility functions of products of different sectors and leisure of different types respectively.

Production is also a multi-stage process. The top-level production function of the final output $XD_{i,t}$ is a fixed-coefficient Leontieff function of the value-added aggregate ($VA_{i,t}$) and intermediate inputs ($IO_{j,i,t}$). The value added production function is a CES function of capital ($K^D_{i,t}$) and all types of labor ($L^D_{l,i,t}$). Diagrammatically, the structure of the production technology is shown in figure 2.

We distinguish the following sets that describe the structure of the models:

- sectors (SEC),
- institutions (INST),
- households (INSTH),
- foreign partners (INSTF),
- factors of production (FAC),
- labor types (FACL).

The model is based on a social accounting matrix and the flows of funds and goods and services correspond to a circular flow in the economy where all the outflows have to be equal to all the inflows which corresponds to the "square" walrasian model setup. A sample SAM is shown in figure 3. Sums of the values in each of the rows (incomes) have to equal to sums of respective columns (expenditures).

For example, the row marked $INSTH$ depicts all the income flows that relate to households: factor income (in column FAC), transfers (from other households - $INSTH$, government - G, and from abroad - $INSTF$). The sum of all the income has to equal to total spending of households. All the household spending is given in column $INSTH$. They allocate their income into private consumption of goods coming from sectors SEC, transfers to other institutions (households and abroad), and savings $SAVE$. The sum of the row $SAVE$ depicting the economy savings of households, government and abroad has to, in turn, equal to total investment demand in the economy, given in the column INV. The total goods output in the economy (including intermediate demand, value added all the indirect taxes) plus imports (the sum of column SEC) is equal to the total demand in the economy (row SEC): intermediate use (row SEC), private consumption ($INSTH$), government consumption G together with subsidies TAX, investment demand (INV) and exports.

3.3 The model setup

Similarly as the baseline Ramsey model, the POLDYN model can be set up as a set of zero profit, market clearing and income balance conditions and the terminal conditions.

Zero profit conditions assure that the costs of purchase of inputs are equal to the revenue from sales of the outputs of any production process. This can also be applied to consumer utility maximization problem - the expenditure on the upper level of the utility aggregate has to be equal to the cost of purchase of the goods that this aggregate is composed of. The market clearing conditions assure that

Figure 3: A Social Accounting Matrix

	SEC	FAC	INSTH	G	TAX	INV	INSTF
SEC	Intermediate use		Private consumption	Public consumption	Subsidies	Investment demand	Exports
FAC	Value added						
INSTH		Factor income	Transfers	Transfers			Transfers
G				Tax revenues			Transfers
TAX	Indirect taxes	Factor taxes	Income tax				
SAVE			Household savings	Budget surplus			Foreign savings
INSTF	Imports		Transfers	Transfers			

the prices are at the level that equilibriates supply and demand in the market for goods and factors of production. The income balance conditions assure that the expenditures of agents are equal to the incomes of agents. This applies to households, the government, but also to the economy as a whole whole.

3.4 Supply side of the model

The final goods are produced using value-added together with intermediate inputs. We assume that at the aggregate level the production function is of the Leontieff type:

$$XD_{i,t} = \min(\alpha^{XD}_{VA,i,t} VA_{i,t}, \alpha^{VA}_{j,i,t} IO_{j,i,t}), \qquad i,j \in SEC,\, t \in T, \tag{6}$$

where $VA_{i,t}$, is the value added aggregate used in sector i, and $IO_{j,i,t}$ is the intermediate use sector j goods in sector i output. $\alpha^{XD}_{VA,i,t}$ and $\alpha^{VA}_{j,i,t}$ are respectively the share of value added in the production of sector i and the share of each intermediate good j used in the production of sector i. The services of factors used in production activities are rented from households and the intermediate goods are a composite of domestically produced and imported commodities.

The value added aggregate is produced using a constant elasticity of substitution (CES) production function of the following form:

$$VA_{i,t} = \left[\alpha^{VA}_{K,i} (K^D_{i,t})^{\frac{\sigma^{VA}_i - 1}{\sigma^{VA}_i}} + \sum_{m \in FACL} \alpha^{VA}_{m,i} (L^D_{m,i,t})^{\frac{\sigma^{VA}_i - 1}{\sigma^{VA}_i}} \right]^{\frac{\sigma^{VA}_i}{\sigma^{VA}_{i-1} - 1}}, \qquad i \in SEC,\, t \in T, \tag{7}$$

where $\alpha^{VA}_{K,i}$ and $\alpha^{VA}_{m,i}$ are the capital and labor shares in the formation of value added, σ^{VA}_i is the elasticity of substitution parameter and $K^D_{i,t}$ and $L^D_{m,i,t}$ are the factor use (demand for factors) in sector i respectively for capital and all labor types.

The final output is either delivered domestically or exported. The supply is driven by the constant elasticity of transformation (CET) output transformation function:

$$XD_{i,t} = [\gamma^{XD}_i E_{i,t}^{\frac{1+\eta^{XD}_i}{\eta^{XD}_i}} + (1-\gamma^{XD}_i)XDD_{i,t}^{\frac{1+\eta^{XD}_i}{\eta^{XD}_i}}]^{\frac{\eta^{XD}_i}{1+\eta^{XD}_i}}, \qquad i \in SEC,\, t \in T, \tag{8}$$

where $E_{i,t}$ is exports coming from sector i, $XDD_{i,t}$ is the supply to the domestic market, γ^{XD}_i is the share of exports in total output of sector i and η^{XD}_i is the elasticity of transformation. Exports are then supplied to all the possible destinations using a lower level CET function, :

$$E_{i,t} = \left(\sum_{f \in INSTF} \gamma^E_{i,f} \left(\frac{EE_{i,f,t}}{ax_{i,f,t}} \right)^{\frac{1+\eta^E_i}{\eta^E_i}} \right)^{\frac{\eta^E_i}{1+\eta^E_i}} \qquad i \in SEC,\, t \in T,$$

where $EE_{i,f,t}$ are exports t of sector i goods to destination f, market, $\gamma^E_{i,f}$ is the share of destination f in total exports of sector i and η^E_i is the elasticity of transformation between the different destinations. $ax_{i,f,t}$ is the efficiency parameter corresponding to the notion of an iceberg transport costs (if it is greater than one, less domestic output is required to satisfy the export demand and therefore the price of output goes up).

The value added price index that is dual to the value added production function is given by the following equation:

$$pva_{i,t} = \left[\alpha^{VA}_{K,i}((1+tfac_{K,i,t}+rp_t)rk_t)^{1-\sigma^{VA}_i} + \sum_{m \in FACL} \alpha^{VA}_{m,i}((1+tfac_{m,i,t})w_{m,t})^{1-\sigma^{VA}_i} \right]^{\frac{1}{1-\sigma^{VA}_i}}, \qquad i \in SEC,\, t \in T, \tag{9}$$

where the left hand side of the equation, $pva_{i,t}$ is the price of the value added aggregate and the right hand side corresponds to the unit cost of production of this aggregate (rk_t is the rental rate of capital and $w_{m,t}$ is the wage rate of labor of type m and $tfac_{m,t}$ and $tfac_{K,t}$ are the factor tax rates). rp_t is the wedge on the earnings of capital that corresponds to the investment risk premium. Similarly, the net unit revenues from the final output have to be equal to unit costs of production:

$$(1 - tsec_{i,t} + subs_{i,t})pxd_{i,t} = \alpha^{XD}_{VA,i,t} pva_{i,t} + \sum_{j \in SEC} \alpha^{VA}_{j,i,t} px_{j,t}, \qquad i \in SEC,\, t \in T, \tag{10}$$

where the left hand-side is the unit price of final output ($pxd_{i,t}$) net of the output tax $tsec_{i,t}$ and output subsidies $subs_{i,t}$ and the right hand side is the Leontieff price index of the cost components of final output - value added and the composite Armington good (see later) priced at $px_{j,t}$.

The revenues from sales to the domestic and foreign market have to be equal to the cost of production of the total output. Therefore, the following zero profit condition can be written:

$$pxd_{i,t} = [\gamma_i^{XD} pe_{i,t}^{1+\eta_i^{XD}} + (1-\gamma_i^{XD}) pxdd_{i,t}^{1+\eta_i^{XD}}]^{\frac{1}{1+\eta_i^{XD}}}, \qquad i \in SEC,\, t \in T, \tag{11}$$

The right hand-side of the above equation is the cost of production of final output and the right hand-side is the standard CET revenue function over the domestic and foreign market. $pe_{i,t}$ is the price of the exports aggregate and $pxdd_{i,t}$ is the price of supply to the domestic market. Similarly, the delivery to all foreign markets has to generate zero profits:

$$pe_{i,t} = [\sum_{f \in INSTF} \gamma_{i,f}^{E} (ax_{i,f,t} pfx_{f,t})^{1+\eta_i^E}]^{\frac{1}{1+\eta_i^E}}, \qquad i \in SEC,\, t \in T, \tag{12}$$

where $pfx_{f,t}$ is the foreign price level at destination f.

The demand equation for the value added aggregate is due to the Leontieff production function and assures proportional factor use, therefore:

$$VA_{i,t} = \alpha_{VA,i}^{XD} XD_{i,t}, \qquad i \in SEC,\, t \in T., \tag{13}$$

Demand for the intermediate use of the good i in the production of good j is similar:

$$IO_{i,j,t} = \alpha_{i,j}^{XD} XD_{j,t}, \qquad i,j \in SEC,\, t \in T, \tag{14}$$

Demand for capital services is equal to:

$$K_{i,t}^{D} = \alpha_{K,i}^{VA} VA_{i,t} \left(\frac{pva_{i,t}}{rk_t(1 + tfac_{K,i,t} + rp_t)} \right)^{\sigma_i^{VA}}, \qquad i \in SEC,\, t \in T. \tag{15}$$

Similarly, demand for labor type l by industry i is given by:

$$L_{l,i,t}^{D} = \alpha_{K,i}^{VA} VA_{i,t} \left(\frac{pva_{i,t}}{w_{l,t}(1 + tfac_{l,i,t})} \right)^{\sigma_i^{VA}}, \qquad l \in FACL,\, i \in SEC,\, t \in T. \tag{16}$$

Supply of the domestic market is of the form:

$$XDD_{i,t} = (1-\gamma_i^{XD}) XD \Big(\frac{pxdd_{i,t}}{pxd_{i,t}} \Big)^{\eta_i^{XD}}, \qquad i \in SEC,\, t \in T. \tag{17}$$

whereas the supply to a foreign destination is given by:

$$ee_{i,f,t} = \gamma^E_{i,f}\gamma_i^{XD} XD\Big(\frac{pe_{i,t}}{pxd_{i,t}}\Big)^{\eta_i^{XD}} \Big(\frac{ax_{i,f,t}pfx_{f,t}}{pe_{i,t}}\Big)^{\eta_i^E}, \qquad i \in SEC,\ f \in FACL,\ t \in T. \tag{18}$$

3.5 Investment behavior

Capital is assumed to accumulate according to the following standard equation:

$$K_{t+1} = K_t(1-\rho) + I_t \qquad t \in T. \tag{19}$$

We assume that the investment entails an installation cost of capital. Therefore we distinguish net investment (I_t) and gross investment (J_t).The relation between the two includes a quadratic adjustment cost (Uzawa, 1969):

$$J_t = I_t(1 + \phi\frac{I_t}{2K_t}), \tag{20}$$

where ϕ is a cost adjustment parameter. Therefore, the higher is the investment as compared to the stock of capital, the larger is the cost $\phi\frac{I_t}{2K_t}$.

Gross investment demand is a Cobb-Douglas aggregate of sectoral output (a composite of domestically produced and imported goods):

$$J_t = \prod_{i \in SEC} INV_{i,t}^{\alpha_i^J},$$

where $INV_{i,t}$ is the investment demand for sector i goods and α_i^J is the share of sector i in the total gross investment.

The demand for investment good is therefore:

$$INV_{i,t} = \frac{\alpha_i^J pj_t J_t}{px_{i,t}}, \tag{21}$$

where pj_t is the investment good price index given by a Cobb Douglas aggregate:

$$pj_t = \prod_{i \in SEC} px_{i,t}^{\alpha_i^J}. \tag{22}$$

The investment block is completed by the following equations. The zero profit condition for the capital accumulation is a variation of the respective equation in the baseline Ramsey model, modified by the capital adjustment costs (in order to add one unit of capital in the next period, the additional $\phi\frac{I_t}{K_t}$ of investment is necessary to cover adjustment costs):

$$pk_{t+1} = pj_t(1 + \phi\frac{I_t}{K_t}) \tag{23}$$

Similarly, the prices of capital and the rental ratio have to guarantee zero profits:

$$pk_t = pk_{t+1}(1-\delta) + rk_t + \frac{\phi}{2}\frac{I_t^2}{K_t^2}pj_t. \tag{24}$$

The interpretation of the above equation is as follows. On the left hand-side pk_t is the value of one unit of capital at time t. What is left of this unit of capital after depreciation is worth in the next period $pk_{t+1}(1-\delta)$ and the rental revenues in period t are equal to rk_t. The last term is related to the reduction in adjustment costs - increase in investment in period t reduces adjustment costs for all units of capital. Therefore the price pk_t has to include that adjustment premium.

3.6 Imports and the Armington good.

We assume that the demand for imports is driven by a multilevel structure of preferences. We impose an Armington assumption, i.e. we assume that imports are imperfect substitutes to domestically produced goods and at the same time imports are differentiated by the region of origin (original text is Armington (1969), more on the subject can be found in e.g. Francois and Reinert, 1997). The Armington composite is produced according to the following CES function:

$$X_{i,t} = [\alpha_i^X IM_{i,t}^{\frac{\sigma_i^X-1}{\sigma_i^X}} + (1-\alpha_i^X)XDD_{i,t}^{\frac{\sigma_i^X-1}{\sigma_i^X}}]^{\frac{\sigma_i^X}{\sigma_i^X-1}}, \qquad i \in SEC,\, t \in T,$$

where α_i^X is the share of imports in the total domestic demand, σ_i^X is the substitution elasticity, $IM_{i,t}$ are the total imports of goods produced by industry i.

Imports are differentiated by origin according to the following CES function:

$$IM_{i,t} = \left(\sum_{f\in INSTF} \alpha_{i,f}^{IM}\left(am_{i,f,t,}IMM_{i,f,t}\right)^{\frac{\sigma_i^{IM}-1}{\sigma_i^{IM}}}\right)^{\frac{\sigma_i^{IM}}{\sigma_i^{IM}-1}}, \qquad i \in SEC,\, t \in T,$$

where $\alpha_{i,f}^{IM}$ is the share of imports from source f in the total imports of sector i goods and $am_{i,f,t}$ is the import augmenting technical change. If $am_{i,f,t}$ goes up, less of $IMM_{i,f,t}$ is required to build a unit of the imports composite $IM_{i,t}$. Therefore, the price of $IMM_{i,f,t}$ goes down and so does the price of $IM_{i,t}$.

The zero profit condition for the composite Armington goods is given by:

$$px_{i,t} = [\alpha_i^X pim_{i,t}^{1-\sigma_i^X} + (1-\alpha_i^X)pxdd_{i,t}^{1-\sigma_i^X}]^{\frac{1}{1-\sigma_i^X}}, \qquad i \in SEC,\, t \in T.$$

Zero profit condition for each of the import composites is given by:

$$pim_{i,t} = [\sum_{f \in INSTF} \alpha^{IM}_{i,f}((1 + tariff_{i,f,t})\frac{pfx_{f,t}}{am_{i,f,t}})^{1-\sigma^{IM}_i}]^{\frac{1}{1-\sigma^{IM}_i}}, \qquad i \in SEC,\, t \in T,$$

where $pfx_{f,t}$ is the overall price level in partner country f.

The demand for imports can be derived from the CES utility function and has the following nested form:

$$IMM_{i,f,t} = \alpha^X_i \alpha^{IM}_{i,f} X_{i,t} \left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma^X_i} \left(\frac{am_{i,f,t} pim_{i,t}}{pfx_{f,t}(1 + tariff_{i,f,t})}\right)^{\sigma^{IM}_i}, \qquad i \in SEC,\, f \in INSTF\, t \in T,$$

where $tariff_{i,f,t}$ is an import tariff levied on good i from partner country f.

The demand for domestic output is given by:

$$XDD^D_{i,t} = \alpha^X_i X_{i,t} \left(\frac{px_{i,t}}{pxdd_{i,t}}\right)^{\sigma^X_i}, \qquad i \in SEC,\, t \in T$$

3.7 Technology spillover

We assume that involvement in international trade generates productivity improvements due to spillovers of knowledge. We assume that these productivity improvements are proportional to the openness ratio given by the ratio of the total volume of trade to GDP:

$$\begin{aligned} tsp_{i,t} = \alpha^{TSP}_i / tsp_0 (&\sum_{f \in INSTF} \sum_{i \in SEC} \left(\gamma^E_{i,f} \gamma^{XD}_i XD \Big(\frac{pe_{i,t}}{pxd_{i,t}}\Big)^{\eta^{XD}_i} \Big(\frac{ax_{i,f,t} pfx_{f,t}}{pe_{i,t}}\Big)^{\eta^E_i} \right) \\ &+ \sum_{f \in INSTF} \sum_{i \in SEC} \left(\alpha^X_i \alpha^{IM}_{i,f} X_{i,t} \left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma^X_i} \left(\frac{am_{i,f,t} pim_{i,t}}{pfx_{f,t}(1 + tariff_{i,f,t})}\right)^{\sigma^{IM}_i} \right)) / GDP_t, \end{aligned}$$

where α^{TSP} is the elasticity of the technical progress with respect to changes in the openness ratio and tsp_0 is the normalizing factor assuring that the spillover is zero in the benchmark equilibrium. The spillover parameter enters the labor supply equations of the households.

3.8 The government

The government is raising revenue through output, factor and income taxes, import tariffs and foreign transfers. The government purchases goods and services, subsidizes output and transfers funds to other institutions. The aggregate of government consumption is of the Cobb-Douglas form:

$$WG_t = \prod_{i \in SEC} CG_{i,t}^{\alpha_i^G}, \qquad t \in T, \tag{25}$$

where α_i^G is the share of sector i in total government consumption. The demand for total government consumption is given by a simple budget constraint:

$$WG_t pwg_t = MG_t, \qquad t \in T, \tag{26}$$

where pwg_t is the price index of government consumption and MG_t is the government income. The price index pwg_t is given by:

$$pwg_t = \prod_{i \in SEC} px_{i,t}^{\alpha_i^G}, \qquad t \in T, \tag{27}$$

and the government demand for the good i is given by:

$$CG_{i,t} = \alpha_i^G WG_t \frac{pwg_t}{px_{i,t}}, \qquad i \in SEC,\ t \in T,$$

The government income in period t is given by the sum of all tax revenues together with net transfers. The government budget has to balance each period, so the gap between the revenues and expenditures is financed by a lump-sum tax from the households ($GDEF_t$). All the components of the government income are given below.

$$\begin{array}{rclc} MG_t & = & \sum_{i \in SEC}((tsec_{i,t} - subs_{i,t}) XD_{i,t} pxd_{i,t}) & \text{output tax and subsidies} \\ & + & \sum_{i \in SEC}(tfac_{K,t} K_{i,t}^D rk_t + \sum_{l \in FACL} tfac_{l,t} L_{l,i,t}^D w_{l,t}) & \text{factor taxes} \\ & + & \sum_{h \in INSTH} INCTAX_{h,t} & \text{income taxes} \\ & + & \sum_{i \in SEC} \sum_{f \in INSTF}(tariff_{i,f,t} IM_{i,f,t} pfx_{f,t}) & \text{import tariffs} \\ & + & \sum_{k \in INST}(TRANS_{k,G,t} - TRANS_{G,INST,t}) & \text{transfers} \\ & + & GDEF_t & \text{government deficit} \end{array} \tag{28}$$

The WG_t is chosen exogeneously as a share of real GDP :

$$WG_t / GDP_t = \alpha_t^{WG}, \qquad t \in T. \tag{29}$$

3.9 Consumer households

Consumers are assumed to maximize their lifetime utility subject to intertemporal budget constraint. They derive utility from the consumption of physical goods and services and leisure. They have perfect foresight concerning the future path of consumption. The utility function of consumer h is of the CEIS (constant elasticity of intertemporal substitution) form:

$$U_h = \left(\sum_{t=0}^{\infty} (\frac{1}{1+\rho})^t W_{h,t}^{\frac{\sigma_h^u - 1}{\sigma_h^u}} \right)^{\frac{\sigma_h^u}{\sigma_h^u - 1}} \qquad h \in INSTH,$$

where $W_{h,t}$ is the so-called period utility (or a consumption aggregate) in period t consumed by household h, ρ is a discount parameter, and σ_h^u is the elasticity of intertemporal substitution.

Period utility is a CES function of goods and leisure consumption:

$$W_{h,t} = \left(\alpha_h^W WW_{h,t}^{\frac{\sigma_h^W - 1}{\sigma_h^W}} + (1 - \alpha_h^W) WL_{h,t}^{\frac{\sigma_h^W - 1}{\sigma_h^W}} \right)^{\frac{\sigma_h^W}{\sigma_h^W - 1}}, \qquad h \in INSTH, \, t \in T,$$

where α_h^W is the share of goods consumption in the total utility of consumers, $WW_{h,t}$ is the aggregate consumption of goods and services and $WL_{h,t}$ is the aggregate of utility derived from consumption of all types of leisure. On the lowest level of preferences, goods coming from different sectors are aggregated by a CES sub-utility function:

$$WW_{h,t} = \left(\sum_{i \in SEC} \alpha_{i,h}^{WW} C_{i,h,t}^{\frac{\sigma_h^{WW} - 1}{\sigma_h^{WW}}} \right)^{\frac{\sigma_h^{WW}}{\sigma_h^{WW} - 1}}, \qquad h \in INSTH, \, t \in T,$$

where $C_{i,h,t}$ is the consumption of goods from sector i, by household h, $\alpha_{i,h}^{WW}$ is the share of sector i in the total goods and services consumption by household h and σ_h^{WW} is the elasticity of substitution parameter.

The sub-utility from leisure is given by the following CES aggregate:

$$WL_{h,t} = \left(\sum_{l \in FACL} \alpha_{l,h}^{WL} LEIS_{l,h,t}^{\frac{\sigma_h^{WL} - 1}{\sigma_h^{WL}}} \right)^{\frac{\sigma_h^{WL}}{\sigma_h^{WL} - 1}} \qquad h \in INSTH, \, t \in T, ,$$

where $LEIS_{l,h,t}$ is the consumption of leisure of type l by household h,$\alpha_{l,h}^{WL}$ is the share of leisure type l in total leisure consumed and σ_h^{WL} is the elasticity parameter.

The household derives income from factors of production and transfers from other institutions. Households transfer funds to other institutions and pay income taxes. The budget constraint is:

$$
\begin{aligned}
M_h =& pk_0 K_{h,0} \\
&+ \sum_{t=0}^{\infty} (\sum_{l \in FACL} w_{l,t} L^E_{h,t} + rp_t rk_t K_{h,t} \\
&+ \sum_{k \in INST} TRANS_{h,k,t} - \sum_{k \in INST} TRANS_{k,h,t} - INCTAX_{h,t} - GDEF_t), \; h \in INSTH
\end{aligned}
$$

where M_h is the lifetime income, $K_{h,0}$ is the capital stock at time 0 owned by household h, pk_0 is the price of capital at time 0, $w_{l,t}$ is the wage of labor type h, $L^E_{h,t}$ is the endowment of labor type l of household h, $rp_t rk_t K_{h,t}$ are the household revenues from the risk premium, $TRANS_{h,k,t}$ are the nominal transfers from institution h to institution k and $INCTAX_{h,t}$ are the income taxes.

There are two issues that require further explanation. In a competitive equilibrium with perfect foresight, $pk_0 K_{h,0}$ captures the stream of all future capital income. This formulation is more convenient in a setting with capital adjustment costs, because otherwise the lifetime income constraint would have to include the adjustment costs. The second issue is related to the fact that the lifetime income includes not only the labor income but the total valuation of labor endowment at the market wage rate. This is due to the fact that as households derive utility from leisure, they value it at market (best alternative use) price. Therefore, given the total value of time endowment, households decide whether to "buy" some leisure or to exchange it for some consumer goods.

Since it is infeasible to solve the model for the infinite number of periods, the model is solved for a finite number of periods and a terminal constraint is imposed on the last period in order for the agents to behave in a consistent fashion towards the end of the time horizon. If T is the last period of the time horizon, the income up to time T would have to be adjusted by the value of capital stock at time T, otherwise the households will be inclined to turn all the capital into consumption and disinvest. Therefore, the adjusted lifetime income is of the form:

$$
\begin{aligned}
M_h =& pk_0 K_{h,0} - pk_T K_{h,T} \\
&+ \sum_{t=0}^{T} (\sum_{l \in FACL} w_{l,t} L^E_{h,t} + rp_t rk_t K_{h,t} \\
&+ \sum_{k \in INST} TRANS_{h,k,t} - \sum_{k \in INST} TRANS_{k,h,t} - INCTAX_{h,t} - GDEF_t). \; h \in INSTH
\end{aligned}
$$

Income tax is determined by looking at the period income of the household:

$$INCTAX_{h,t} = inctax_{h,t}((1+rp_t)rk_tK_{h,t} + \sum_{l\in FACL} w_{l,t}L^E_{h,t} + \sum_{k\in INST} TRANS_{h,k,t} - \sum_{k\in INST} TRANS_{k,h,t}),$$
$$h \in INSTH,\ t \in T,$$

where $inctax_{h,t}$ is the (period) income tax rate.

The household shares in the total capital stocks are determined exogeneously:

$$K_{h,t} = \alpha^K_h K_t, \qquad h \in INSTH,\ t \in T. \tag{30}$$

At the top level of preferences utility is assumed to have an elasticity of one w.r.t. income:

$$M_h = U_h pu_h, \qquad h \in INSTH$$

where $pu_h$is the intertemporal price index of household h consumption. This price index is due to the CEIS aggregate:

$$pu_h = \left(\sum (\frac{1}{1+r})^t_{t\in T} (pw_{h,t})^{1-\sigma^U_h}\right)^{\frac{1}{1-\sigma^U_h}}, \qquad h \in INSTH \tag{31}$$

where $pw_{i,h,t}$ is the period t consumer price index of household h. Demand for period t consumption by household h is given by:

$$W_{h,t} = U_h(\frac{1}{1+\rho})^t \left(\frac{pu_h}{pw_{h,t}}\right)^{\sigma^U_h}, \qquad h \in INSTH,\ t \in T. \tag{32}$$

The consumer price index is a composite of the price indices of leisure and consumption:

$$pw_{h,t} = \left(\alpha^W_h pww_{h,t}^{1-\sigma^W_h} + (1-\alpha^W_h)pwl_{h,t}^{1-\sigma^W_h}\right)^{\frac{1}{1-\sigma^W_h}}, \qquad h \in INSTH,\ t \in T, \tag{33}$$

Demands for each of the components is given by:

$$WW_{h,t} = \alpha^W_h W_{h,t}\left(\frac{pw_{h,t}}{pww_{h,t}}\right)^{\sigma^W_h}, \qquad h \in INSTH,\ t \in T,$$

and

$$WL_{h,t} = \alpha^W_h W_{h,t}\left(\frac{pw_{h,t}}{pwl_{h,t}}\right)^{\sigma^W_h}, \qquad h \in INSTH,\ t \in T.$$

.

The $pww_{h,t}$, the consumer price index derived from consumption of goods and services and $pwl_{h,t}$ the consumer price index derived from leisure are given by:

$$pww_{h,t} = \left(\sum_{i \in SEC} \alpha^{WW}_{i,h} C^{1-\sigma^{WW}_h}_{i,h,t} \right)^{\frac{1}{1-\sigma^{WW}_h}}, \qquad h \in INSTH,\, t \in T, \tag{34}$$

and

$$pwl_{h,t} = \left(\sum_{l \in FACL} \alpha^{WL}_{l,h} LEIS^{1-\sigma^{WL}_h}_{l,h,t} \right)^{\frac{1}{1-\sigma^{WL}_h}}, \qquad h \in INSTH,\, t \in T, \tag{35}$$

The household demand for sector i goods is then given by:

$$C_{i,h,t} = \alpha^{WW}_{i,h} WW_{h,t} \left(\frac{pww_{h,t}}{px_{i,t}} \right)^{\sigma^{WW}_h}, \qquad i \in SEC,\, h \in INSTH,\, t \in T,. \tag{36}$$

The household h factor supply is:

$$FACSUP_{l,h,t} = ENDOW_{l,h,t}(1+tsp_t+tp_{l,t}) - \alpha^{WL}_{l,h} WL_{h,t} \left(\frac{pwl_{h,t}}{w_{l,t}} \right)^{\sigma^{WW}_h}, \; l \in FACL,\, h \in INSTH,\, t \in T,$$

where $FACSUP_{l,h,t}$ is the factor supply of labor type l, the $ENDOW_{l,h,t}$ is the labor endowment of type l of household h and the last component is the leisure demand at the going market wage $w_{l,t}$. $tp_{l,t}$ is the labor type-specific technical progress, tsp_t is the economy wide knowledge-spillover driven labor augmenting technical progress.

3.10 Transfers

Transfers are exogeneously determined as shares of GDP:

$$TRANS_{k,h,t} = \alpha^{TRANS}_{k,h,t} GDP_t, \qquad k, h \in INST, t \in T. \tag{37}$$

3.11 The market clearing

The model is completed with four major market clearing conditions:

1. Market clearing conditions for domestic output
2. Market clearing for the composite Armington good.
3. Market clearing for labor

4. Market clearing for capital

5. International balance.

Market clearing for domestic output The domestic supply has to equal to the demand generated by the Armington composite:

$$\alpha_i^X X_{i,t}\left(\frac{px_{i,t}}{pxdd_{i,t}}\right)^{\sigma_i^X} = (1-\gamma_i^{XD})XD\Big(\frac{pxdd_{i,t}}{pxd_{i,t}}\Big)^{\eta_i^{XD}},\ i \in SEC, t \in T. \tag{38}$$

Market clearing for the composite Armington good The demand for Armington goods includes the intermediate use, household consumption demand and investment demand components. Any demanded quantity will be supplied at the given foreign price:

$$\begin{array}{rclc}
X_{i,t} & = & \sum_{h \in INSTH}\left(\alpha_{i,h}^{WW} WW_{h,t}\left(\frac{pww_{h,t}}{px_{i,t}}\right)^{\sigma_h^{WW}}\right) & \text{household demand} \\
& + & \alpha_i^G WG_t \frac{pwg_t}{px_{i,t}} & \text{government demand} \\
& + & \sum_{j \in SEC}\left(\alpha_{i,j,t}^{XD} XD_{j,t}\right) & \text{intermediate demand} \\
& + & \alpha_i^J J_t \frac{pj_t}{px_{i,t}} & \text{investment demand}
\end{array} \tag{39}$$

Market clearing for labor Labor supply has to equal total labor demand in the economy:

$$\sum_{h \in INSTH} FACSUP_{h,l,t} = \sum_{i \in SEC}\left[\alpha_{K,i,t}^{VA} VA_{i,t}\left(\frac{pva_{i,t}}{w_{l,t}(1+tfac_{l,i,t})}\right)^{\sigma_i^{VA}}\right],\ l \in FACL, t \in T. \tag{40}$$

Market clearing for capital Capital stock at time t has to equal to the total demand by the industry:

$$K_{i,t} = \sum_{i \in SEC}\left[\alpha_{K,i,t}^{VA} VA_{i,t}\left(\frac{pva_{i,t}}{rk_t(1+tfac_{K,i,t}+rp_t)}\right)^{\sigma_i^{VA}}\right],\ t \in T. \tag{41}$$

International balance We assume that the international external account of the economy has to balance intertemporaly. Therefore the net sum of all international payments over all the periods has to be equal to zero. It may, however, deviate from zero in any of the periods to allow for international borrowing. Therefore the following condition has to be satisfied:

$$\begin{array}{lcr}
& \sum_{t\in T}\sum_{i\in SEC}\left(\alpha_i^X\alpha_{i,f}^{IM}X_{i,t}\left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma_i^X}\left(\frac{am_{i,f,t}pim_{i,t}}{pfx_{f,t}(1+tariff_{i,f,t})}\right)^{\sigma_i^{IM}}\right) & \text{imports} \\
+ & \sum_{t\in T}\sum_{k\in INST}TRANS_{k,f,t} & \text{outgoing transfers} \\
& = & \\
& \sum_{t\in T}\sum_{k\in INST}TRANS_{f,k,t} & \text{exports} \\
+ & \sum_{t\in T}\sum_{i\in SEC}\left(\gamma_{i,f}^E\gamma_i^{XD}XD\left(\frac{pe_{i,t}}{pxd_{i,t}}\right)^{\eta_i^{XD}}\left(\frac{ax_{i,f,t}pfx_{f,t}}{pe_{i,t}}\right)^{\eta_i^E}\right) & \text{incoming transfers}
\end{array} \tag{42}$$

3.12 Determination of GDP

Real GDP is the sum of all demand components:

$$\begin{array}{lclr}
GDP_t & = & \sum_{h\in INSTH}\left(\alpha_{i,h}^{WW}WW_{h,t}\left(\frac{pww_{h,t}}{px_{i,t}}\right)^{\sigma_h^{WW}}\right) & \text{private consumption} \\
& + & \sum_{i\in SEC}\alpha_i^J J_t\frac{pj_t}{px_{i,t}} & \text{investment demand} \\
& + & \sum_{i\in SEC}\alpha_i^G WG_t\frac{pwg_t}{px_{i,t}} & \text{government demand} \\
& + & \sum_{f\in INSTF}\sum_{i\in SEC}\left(\gamma_{i,f}^E\gamma_i^{XD}XD\left(\frac{pe_{i,t}}{pxd_{i,t}}\right)^{\eta_i^{XD}}\left(\frac{ax_{i,f,t}pfx_{f,t}}{pe_{i,t}}\right)^{\eta_i^E}\right) & \text{exports} \\
& - & \sum_{f\in INSTF}\sum_{i\in SEC}\left(\alpha_i^X\alpha_{i,f}^{IM}X_{i,t}\left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma_i^X}\left(\frac{am_{i,f,t}pim_{i,t}}{pfx_{f,t}(1+tariff_{i,f,t})}\right)^{\sigma_i^{IM}}\right) & \text{imports}
\end{array} \tag{43}$$

Nominal GDP is calculated from the production side:

$$\begin{array}{lclr}
NGDP_T & = & \sum_{i\in SEC}VA_{i,t}pva_{i,t} & \text{value added} \\
& + & \sum_{i\in SEC}(tsec_{i,t}-subs_{i,t})pxd_{i,t}XD_{i,t} & \text{output taxes} \\
& + & \sum_{f\in INSTF}\sum_{i\in SEC}tariff_{i,f,t}pfx_{f,t}\left(\alpha_i^X\alpha_{i,f}^{IM}X_{i,t}\left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma_i^X}\left(\frac{am_{i,f,t}pim_{i,t}}{pfx_{f,t}(1+tariff_{i,f,t})}\right)^{\sigma_i^{IM}}\right) & \text{import tariffs}
\end{array}$$

3.13 Terminal conditions

In order to make sure that the model behaves in a fashion consistent with the infinite horizon, a restriction has to be imposed on the model to assure the non-zero capital accumulation beyond the (finite) horizon of the computation model. Following Bohringer et al. (1997) and Lau et al. (2002) we impose the following terminal condition:

$$\frac{J_T}{J_{T-1}} = \frac{K_T}{K_{T-1}}.$$

The above condition assures that the growth rate of all the variables in the terminal period is equal to the steady state growth rate.

4 Data

Our model is based on a social accounting matrix that was developed under a joint project implemented by the National Bank of Poland, the Ministry of Finance, the Ministry of Economy and Labor and the World Bank (details are documented in Gradzewicz, Griffin, and Zolkiewski (2006)). The SAM matrix was updated and modified using data from i.a.:

- national accounts statistics by institutional sectors and sub-sectors for 2005
- foreign trade statistics (disaggregation EU into euro zone and the rest of EU)
- actual and projected (based on MF, 2007) GDP growth rates up until 2008.

SAM was aggregated/disaggregated to the needs of the dynamic model into:

- 4 production sectors: agriculture, industry, market services, non-market services
- 4 primary factors: 3 types of labor and capital
- domestic institutions: 2 household types: poor and non-poor, government, firms
- investment/savings
- foreign institutions: euro zone, rest of EU and rest of the world
- taxes levied on factors, income and consumption

5 Steady state and calibration

In the steady state all the variables grow at the exogeneous rate g which corresponds to the growth of labor productivity. Along a balanced growth path with growth rate g and depreciation rate δ, the following condition has to be true:

$$I_{SS} = (g + \delta)K_{SS}. \tag{44}$$

The marginal cost of investment equals in this case $1 + \phi(g + \delta)$, because for each additional unit of capital, investors have to invest one unit plus $\phi(g + \delta)$ to cover adjustment costs. Therefore in the steady state, the base year capital price is $pk_{SS} = (1 + r)[1 + \phi(g + \sigma)]$. An increase in the stock of capital decreases the cost of investment. The marginal impact of an increase of the stock of capital on the cost of investment is therefore: $\frac{\partial J}{\partial K} = -\frac{\phi I^2}{2K^2}$ (obtained by differentiation of equation

20). Substituting the equation (44), we obtain the investment premium equal to $\frac{\phi(g+\delta)^2}{2}$. Therefore, equation (24) becomes in the steady state:

$$pk_{SS} = rk_{SS} + \frac{\phi(g+\delta)^2}{2} + (1-\delta)\frac{pk_{SS}}{1+r},$$

which reduces to:

$$rk_{SS} = \delta + r + \phi(g+\delta)(r + (\delta - g)/2),$$

which defines the **long run cost of capital services** as a function of depreciation, real interest rate and the installation costs of capital.

The definition of J_{ss} is:

$$J_{SS} = I_{SS}(1 + \phi I_{SS}/(2K_{SS})$$

The steady state volumes of J and $rk_{ss}K_{ss}$ at time zero have to correspond to the respective values in the SAM. The parameters δ, g, ϕ and r have to be chosen exogeneously. We choose depreciation δ to be 0.067, which is consistent with other CGE and DSGE studies on the Polish economy (e.g. Gradzewicz, Griffin, and Zolkiewski, 2006 or Gradzewicz and Makarski, 2008), g, the long run growth rate of labour productivity in the economy, at the level of 0.04, which is roughly in line with the NBP projections of potential growth and ϕ, the adjustment cost parameter, at the level of 0.8 which seems a reasonable choice based on the literature. The parameter r is chosen so that the capital and investment steady state values correspond with the SAM.

One the steady state growth path is calibrated, the rest of the parameters of the model has to be chosen, so that the model in equilibrium replicates the SAM in the first period. All the equations in the model are expressed in the so-called *calibrated share form* which limits the number of the share parameters that have to be computed. More on this formulation of the model can be found in Rutherford (1998). For example, the zero profit condition for the output of the firm can be rewritten as:

$$XD0_i pxd_{i,t}^{1+\eta_i^{XD}} = E0_i pe_{i,t}^{1+\eta_i^{XD}} + XDD0_i pxdd_{i,t}^{1+\eta_i^{XD}}, \qquad i \in SEC,\, t \in T, \tag{45}$$

where $XD0_i$ is the value of final output of good i taken directly from the sum and $E0_i$ and $XDD0_i$ are the value of exports and domestic outputs of i respectively. In that way, all share parameters are replaced by direct substitution of the value of the respective flow in the base period SAM. Moreover, all equations are normalized, so that the equilibrium volumes of all variables are equal to 1 in the first period and they grow at the rate of g in the subsequent period and all the prices are normalized at 1 in the first period and $\frac{1}{(1+r)^t}$ in the subsequent periods.

The spillover parameter (α_i^{TSP}) was chosen at the level of 0.15. Therefore, one percent increase in the openness of the economy is making labor 0.15 percent more productive. The choice of that level of knowledge spillovers is motivated by the empirical work by Madsen (2005) who estimates the elasticity of productivity to the changes of the imports of knowledge at the level ranging of 0.15. Madsen (2007) later work leads to an elasticity ranging from 0.05 to 0.35.Diao, Rattso, and Stokke (2005) set the spillover parameter at the level of 0.3 in their study for Thailand, where the technology gap with its trade partners may be believed to be considerably higher. Our choice of the spillover parameter is threrefore roughly in the middle of the range provided by the literature. The provided sensitivity analysis checks robustness of results to the choice of this parameter. It has to be emphasized here, that our formulation of the technology spillovers is consistent with the balanced growth path of the economy, as technology spillovers only affect the transition path and not the steady-state growth rate.

The SAM does not provide information on the labor endowments of households, nor gives any information on the consumption of leisure. The data on the utilization of time endowment comes from Gradzewicz et al. Gradzewicz, Griffin, and Zolkiewski, 2006 and was used in the construction of the static general equilibrium model of the National Bank of Poland. Similarly, all the elasticities used for the POLDYN model are based either on the Gradzewicz et al. (supply elasticities, factor substitution elasticities) or taken from the data published on the Center for Global Trade Analysis (GTAP) website.

6 Simulation scenarios

Our simulation scenarios look directly on two channels of possible effects of the Euro accession of Poland. We assume that the accession to the euro zone takes place in the 5th period of the simulation, where the 1st period of the simulation correspond to the period when the decision is taken and agents form their beliefs. We define three simple scenarios:

- Scenario A - the risk premium goes down by 1pp. This is based on the analysis of the difference between the Polish and euro zone long term bond interest rate. The change is introduced gradually, as the risk premium is expected to fall before the actual accession (see Reininger and Walko (2005) for the experience of other Euro acceding countries) and fully realizes in the fifth period of the simulation.

- Scenario B - the *iceberg* costs of trade fall. We base our scenario on the claim by Bukowski, Dyrda, and Kowal (2008) who estimates the transaction costs to amount to 2-3% of the value of trade. We assume that the decrease in the transaction costs amounts to 2% of the value of trade with the eurozone but also, due to other effects such as better price transparency and elimination of the currency risk, there is additional effect of 1% that affects both the trade with the eurozone and the rest of the world.
- Scenario AB - combined scenarios A and B.

7 Simulation results

Table 1 shows the simulated **GDP changes** amounting to around 7.5% increase in its level with respect to the benchmark scenario (without monetary integration) in the long run. GDP slightly drops below the benchmark growth rate in the first period and rises after that. The breakdown of long-run changes is as follows: 4.1pp. of the increase is attributed to the risk premium elimination, while the remainder is attributed to the lowering of trade and transaction costs (note that these percentages given in scenario A and B does not necessarily sum up to the results given in the AB scenario due to the nonlinear nature of the model).The shocks imposed on the model lead to a considerable structural change in the economy. The breakdown of the basic macroeconomic variables is given in table 1. All the GDP components are pictured in figure 4. Most of the shocks are realized in the 5th period of the simulation and this is where most of the changes are concentrated.

The major growth driver of the model is **investment**. It increases in a rather spectacular fashion by around 20% in the periods 3 and 4 to stay at the level higher by 12.6% than the baseline scenario in the long run. A large proportion (8.8pp.) is attributed to the change in the risk premium, while the trade creation scenario alone generates around 3.5pp. of investment increase in the long run. The lowering of the risk premia leads immediately to a lower cost of capital services for firms, which causes larger demand for capital services in all periods. Since capital stock cannot be imported, it has to be built through the increased level of investment. With the perfect foresight of consumers, given the new path of relative prices, most of the extra savings are done in the initial period. The trade creation scenario is also capital-enhancing. Since international borrowing is possible, with diminishing trade costs, it is cheaper to import investment goods in the first periods, in order to build up capital and repay the loans later in time with exports.

Figure 4: GDP components. AB scenario.

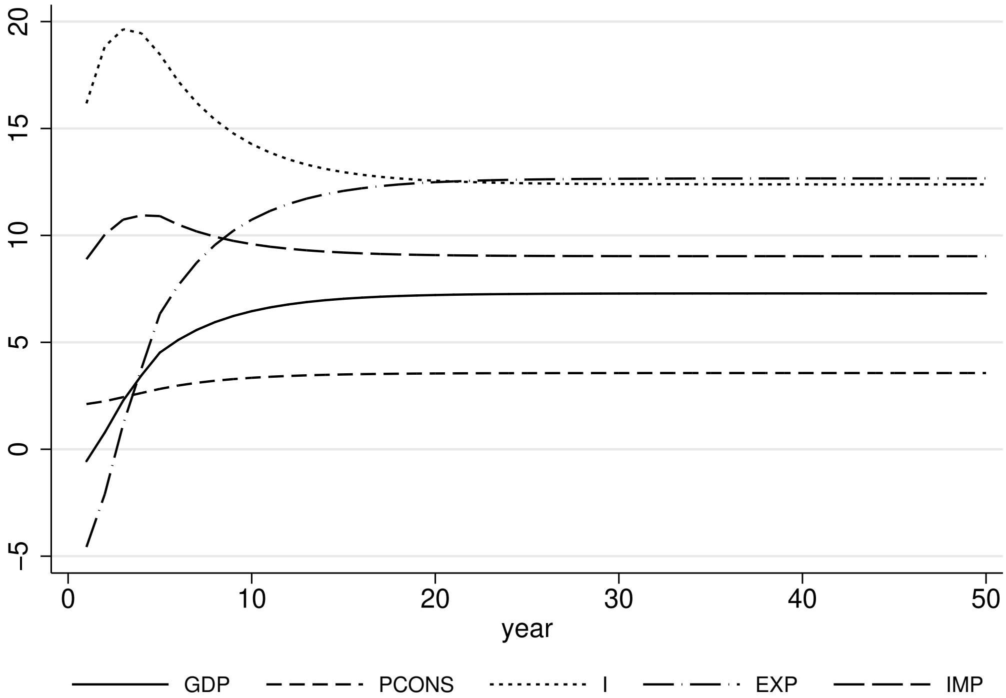


Table 1: Basic macro variables

Variable	Scenario	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
GDP	AB	-0.50	0.88	2.43	3.64	4.73	6.66	7.45	7.48
	A	-0.22	0.54	1.24	1.85	2.34	3.60	4.13	4.14
	B	-0.31	0.31	1.14	1.73	2.30	2.95	3.22	3.22
Private consumption	AB	2.25	2.39	2.59	2.79	2.98	3.51	3.73	3.73
	A	0.34	0.44	0.59	0.73	0.87	1.23	1.37	1.38
	B	1.91	1.94	1.98	2.03	2.09	2.26	2.33	2.34
Investment	AB	16.54	19.23	20.05	19.83	18.82	14.49	12.63	12.58
	A	12.89	14.56	14.43	13.92	12.85	10.04	8.82	8.79
	B	3.40	4.32	5.17	5.42	5.48	4.10	3.52	3.50
Government consumption	AB	-0.50	0.89	2.43	3.64	4.73	6.66	7.46	7.48
	A	-0.22	0.54	1.24	1.85	2.34	3.60	4.13	4.14
	B	-0.31	0.31	1.14	1.73	2.30	2.95	3.22	3.22
Imports	AB	9.13	10.28	10.98	11.17	11.13	9.78	9.22	9.21
	A	4.72	5.22	5.15	4.97	4.63	3.74	3.37	3.35
	B	4.19	4.81	5.56	5.92	6.23	5.81	5.63	5.63
Exports	AB	-4.64	-2.08	1.28	3.96	6.55	10.97	12.83	12.88
	A	-3.25	-2.13	-0.80	0.41	1.51	4.36	5.57	5.61
	B	-1.50	-0.04	2.00	3.44	4.90	6.36	6.97	6.99
Capital stock	AB	0.00	1.70	3.51	5.21	6.71	10.81	12.53	12.58
	A	0.00	1.33	2.69	3.90	4.93	7.61	8.75	8.79
	B	0.00	0.35	0.76	1.21	1.65	2.94	3.48	3.50
Employment	AB	-1.96	-1.19	-0.39	0.21	0.73	1.56	1.91	1.91
	A	-0.38	0.04	0.38	0.67	0.88	1.43	1.67	1.67
	B	-1.62	-1.26	-0.79	-0.47	-0.16	0.12	0.24	0.25
Current account(*)	AB	-5.21	-4.61	-3.57	-2.63	-1.66	0.41	1.25	1.27
	A	-3.00	-2.75	-2.21	-1.68	-1.14	0.22	0.79	0.81
	B	-2.15	-1.83	-1.33	-0.93	-0.50	0.19	0.48	0.49

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels.

(*) current account in percentage of GDP deviations from benchmark.

Both scenarios are trade improving in the long run. In the AB scenario, **imports** increase by over 9% and **exports** by almost 13%. The trade creation scenario contributes slightly more to both imports and exports increase. The increase in imports is caused directly by lowered trade costs and indirectly, through increasing domestic investment demand. Since the small open economy cannot affect the world prices, with booming domestic demand it is cheaper to import. The surge in imports in the first ten periods is quite substantial (over 11% in the 5th period), and leads to a short term decrease of domestic output. Exports also go down in the initial period, as the demand shifts towards investment, but pick up already in the 3rd period and steadily grow after that, to reach their long run level. The surge in imports and the temporary decrease in exports leads to a deterioration of current account in the initial periods of the run, while in the long run it is expected that the structural change of the economy will lead to a current account surplus. The effect of trade creation on output is less pronounced than on GDP, due to increased import penetration and increasing share of imports in intermediate consumption.

The initial drop in output due to a temporary import substitution leads to a short run drop of employment of about 2%. **Employment** picks up with exports and is expected to be higher by around 2% in the long run. There is, however, a considerable shift towards capital. Due to continuing high rate of investment, the stock of capital is expected to increase by almost 13% with respect to the baseline. Most of this change can be attributed to the change in the risk premium but it is also due to increasing labor productivity.

The total **welfare gain** from the two experiments amounts to 2% of the value of GDP in each period. This is calculated as equivalent variation, i.e. it is to be interpreted as the minimum transfer to the household that would make them as well-off in the absence of monetary integration as in the situation with the monetary integration. In other words, it is the consumer valuation on the joining the euro zone. This corresponds to increasing each period goods and leisure consumption by 1.1% and 1.8% for, respectively, poor and non-poor households. The reason for the gain being larger for the poorer households is that their capital earnings are lower than in the case of non-poor households and they loose less revenues from the risk premium (risk premium revenue is proportional to the share of ownership of the capital stock). At the same time, the demand for unskilled labor grows at a slower pace than other types of labor and therefore the poor households leisure consumption and thus welfare is higher than in the case of non-poor households.

The details on the **household** situation are given in table 2. Due to increased import competition and lower capital costs in the long run the prices of consumption bundles (relative to the GDP deflator) for both households go down by roughly 0.5%. At the same time, incomes of both households go up

Table 2: Households. AB scenario.

Household	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
Household consumption								
Non-poor	2.19	2.32	2.52	2.72	2.91	3.44	3.66	3.67
Poor	3.06	3.20	3.41	3.61	3.81	4.29	4.49	4.50
Labor supply								
Non-poor	-1.75	-1.01	-0.23	0.36	0.86	1.67	2.00	2.01
Poor	-5.02	-3.92	-2.78	-1.93	-1.19	-0.03	0.45	0.46
Consumption prices								
Non-poor	-0.15	-0.19	-0.23	-0.28	-0.33	-0.49	-0.56	-0.56
Poor	-0.33	-0.38	-0.43	-0.47	-0.51	-0.57	-0.60	-0.60
Household income								
Non-poor	-0.60	0.70	2.13	3.25	4.26	6.04	6.78	6.80
Poor	-2.16	-0.62	1.09	2.43	3.62	5.73	6.60	6.63
Activity rate								
Non-poor	-0.57	-0.32	-0.07	0.11	0.28	0.54	0.65	0.65
Poor	-1.20	-0.93	-0.66	-0.46	-0.28	-0.01	0.11	0.11

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels

by 6.6-6.8 percent in the long run. With the lifetime income going up, both households significantly increase their consumption (3.7-4.5% for non-poor and poor respectively).

Due to the initial drop in demand, both households supply less labor in the initial period, however, the non-poor households supply relatively more, in order to make up for the lost risk premium incomes. However, with the increase in output in the long run, the labor supply goes up and so does the activity rate. The change is not as pronounced as e.g. GDP and it is due to the shift of the economy towards capital due to increased investment and growing labor productivity.

The sectoral reaction to the shock seems to underline the importance of the increased import competition and the shift towards the capital intensive production mix. In the long run, market services are expected to experience the largest gain in output (6.3%), followed by non-market services (5.6%), manufacturing (5.3%) and agriculture (4.4%). The shift of the economy towards services stems from the fact, that they are less prone to import competition. The increased demand for non-market services is due to the fact that government consumption is following GDP and thus it creates some extra demand for non-market services. Even though services experience a large percentage increase in imports, the share of imports in demand is rather low and it does not have a significant impact on the level of output, whereas in agriculture and manufacturing, import penetration is considerably high, and the initial surge in imports affects output negatively. On the export side, the largest percentage changes are expected for market services (almost 14%), but due to the shares in total exports, it is obviously manufacturing that contributes to exports in the long run (12.5% increase compared to the benchmark).

Table 3: Output, exports and imports. AB scenario.

Sector	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
Output								
Agriculture	-1.89	-0.98	0.00	0.87	1.65	3.57	4.36	4.38
Manufacturing	-3.30	-1.85	-0.30	0.96	2.08	4.35	5.29	5.32
Market services	0.05	1.06	2.08	2.97	3.74	5.57	6.33	6.35
Non-market services	0.06	1.03	2.10	2.93	3.67	5.01	5.56	5.57
Imports								
Agriculture	5.14	6.12	7.09	7.59	8.01	7.65	7.51	7.51
Manufacturing	9.52	10.72	11.42	11.61	11.54	10.15	9.58	9.57
Market services	6.39	7.12	7.71	7.84	7.88	6.54	5.99	5.98
Non-market services	6.56	8.32	10.25	11.61	12.80	14.13	14.69	14.70
Exports								
Agriculture	-3.62	-1.71	0.80	2.92	4.97	9.06	10.77	10.82
Manufacturing	-6.04	-3.27	0.42	3.29	6.11	10.57	12.45	12.50
Market services	-1.51	0.63	3.30	5.55	7.68	12.07	13.91	13.96
Non-market services	-2.38	-0.99	0.89	2.22	3.52	4.96	5.55	5.56
Employment								
Agriculture	-2.00	-1.20	-0.33	0.42	1.09	2.65	3.30	3.32
Manufacturing	-3.58	-2.37	-1.09	-0.12	0.73	2.16	2.75	2.77
Market services	-0.59	-0.12	0.32	0.57	0.76	0.75	0.75	0.76
Non-market services	-0.12	0.70	1.60	2.25	2.82	3.63	3.97	3.98

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels

Table 4 presents the changes in the factor markets. We can again observe the long run increase in the stock of capital and the corresponding decrease in the rental rate of capital. Note that this is the rental rate that does not include the risk premium. In the first periods, due to the removal of the risk premium, the demand for capital services goes up and the rental wage is pushed upwards. With the continuing investment, as capital becomes more abundant, the rental rate goes down and, in the long run, it is expected to remain at a level lower than in the benchmark. As capital stock goes up, the marginal product of labor increases, and so do the wages. In the long run, they are expected to go up by 7.6% in the case of low-skilled and high skilled labor and 6.8% in the case of the medium-skilled labor. Employment of all types of labor goes up, but the growth of employment of high skilled and medium skilled labor is slightly higher than in the case of low-skilled labor.

8 Sensitivity analysis

We perform a simple sensitivity test with respect to the key parameters of the model. We run the AB scenario in 7 different parameter regimes: in scenario SPILL00 we switch off the international productivity spillover feature of the model completely by setting the α^{TSP}parameter to 0. In the scenario SPILL03, we increase the parameter to 0.3 (0.15 in the base scenario). We investigate the

Table 4: Factor market. AB scenario.

Factor supply								
Sector	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
Low skilled	-1.85	-1.20	-0.52	0.00	0.44	1.19	1.50	1.51
Medium skilled	-2.21	-1.38	-0.52	0.13	0.69	1.58	1.96	1.97
High skilled	-1.28	-0.65	0.01	0.50	0.93	1.59	1.86	1.87
Capital	0.00	1.70	3.51	5.21	6.71	10.81	12.53	12.58
Factor wages								
Low skilled	1.01	2.01	3.16	4.12	5.00	6.80	7.55	7.57
Medium skilled	1.88	2.58	3.42	4.14	4.81	6.23	6.81	6.82
High skilled	1.55	2.47	3.53	4.42	5.23	6.89	7.56	7.58
Capital	2.36	2.89	4.74	4.57	4.52	0.91	-0.52	-0.56

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels

sensitivity to the choice of the parameters of the value added production function, by making the substitution between the factors of production more elastic (slightly inelastic in the base scenario). In the two subsequent scenarios, we look at the sensitivity to trade related elasticities; in SUPPLY_EL scenario we double the transformation elasticities between the domestic and foreign, and also between different foreign destinations and in IMPORT_EL, we double the import sourcing elasticities. In INTERT_EL, we increase the elasticity of intertemporal substitution to 1.1 (0.5 in the base scenario). In the last scenario (BOPCON) we run the model in a different international closure: we impose a restriction, that the current account plus net transfers have to be equal to zero each period (with no foreign savings change) with a equilibriating effect on the price of foreign exchange (real exchange rate).

In the first step, we analyze the sensitivity of the gross domestic product (table 5) with respect to different parameter changes. The largest deviation downwards is expected in the case of the BOPCON scenario, where the long run gain in GDP is only 6%. This clearly indicates the gains from the ability to borrow - the economy is able to reach a higher level of GDP in the long run. Switching off the international spillover portion of the model changes the simulated gain to 6.9%, while doubling it increases the simulated GDP gain to 8%. The most important change in upwards is when one increases the factor substitution elasticity beyond one. In that case, the simulated GDP gain amounts to 9%. Other changes in elasticity do not affect the results by more than 1pp.

The private consumption variable (table 6) seem to be quite resistant to parameter changes with one exception, the SPILL00 and SPILL03 scenarios. The international productivity spillover directly affects the productivity of labor and therefore the endowment of labor that the consumer can either supply or consume in the form of leisure. Therefore doubling the parameter increases the long run gain in consumption by 0.5pp. In the BOPCON scenario, we can observe the long run increase in

Table 5: Sensitivity analysis: GDP

Scenario	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
BASE	-0.50	0.88	2.43	3.64	4.73	6.66	7.45	7.48
SPILL00	-0.66	0.59	1.98	3.11	4.12	6.05	6.89	6.91
SPILL03	-0.32	1.21	2.90	4.19	5.35	7.26	8.02	8.04
PROD_EL	-0.44	1.10	2.79	4.12	5.33	7.72	8.95	9.00
SUPPLY_EL	-1.21	0.36	2.16	3.59	4.89	7.15	8.07	8.10
IMPORT_EL	-0.36	1.13	2.77	4.06	5.22	7.14	7.81	7.82
INTERT_EL	-0.83	0.61	2.21	3.48	4.62	6.67	7.55	7.58
BOPCON	1.80	2.49	3.28	3.85	4.40	5.27	5.97	6.05

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels.

Table 6: Sensitivity analysis: Private consumption

Scenario	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
BASE	2.25	2.39	2.59	2.79	2.98	3.51	3.73	3.73
SPILL00	1.84	1.96	2.14	2.33	2.51	3.01	3.23	3.24
SPILL03	2.67	2.82	3.03	3.25	3.46	4.01	4.22	4.23
PROD_EL	2.15	2.30	2.51	2.72	2.92	3.52	3.82	3.83
SUPPLY_EL	2.72	2.81	2.95	3.10	3.24	3.68	3.85	3.86
IMPORT_EL	2.63	2.78	2.99	3.19	3.38	3.83	3.98	3.99
INTERT_EL	2.59	2.61	2.72	2.85	3.00	3.48	3.68	3.68
BOPCON	-0.22	0.07	0.51	0.96	1.44	2.98	4.25	4.41

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels.

consumption of 4.4%, but consumption goes up at much slower pace. At the same time, given the lower capital stock, the marginal productivity of labor is lower. Therefore, the overall level of welfare is lower in the BOPCON scenario.

Similarly, investment (table 7) path is relatively stable, given the various choices of model parameters, the deviations from the base scenario usually do not exceed 1pp. with an exception of the scenario where the elasticity of factor substitution is over 1. Similarly, the growth of investment is considerably slower in the BOPCON scenario.

Tables 8, 9 and 10 in the appendix show the sensitivity analysis results for imports, exports and capital stock. Overall, it seems that the model performs quite well and the results are relatively stable. Reactions of the macroeconomic variables within the +/- 1-2pp. bounds seem reasonable, especially that the imposed changes in parameters were substantial. It is also seems reasonable to assume that results from presented simulations are subject to parameter uncertainty and that such bounds are admissible when thinking of the model accuracy.

Table 7: Sensitivity analysis: Investment

Scenario	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
BASE	16.54	19.23	20.05	19.83	18.82	14.49	12.63	12.58
SPILL00	15.47	18.07	18.85	18.69	17.75	13.82	12.05	11.99
SPILL03	17.68	20.44	21.27	20.99	19.89	15.15	13.21	13.16
PROD_EL	20.61	23.64	24.76	24.75	23.88	19.42	17.01	16.90
SUPPLY_EL	17.70	20.84	21.61	21.33	19.99	15.42	13.45	13.40
IMPORT_EL	17.94	20.77	21.70	21.39	20.29	14.97	13.06	13.02
INTERT_EL	15.68	18.71	19.80	19.77	18.88	14.63	12.72	12.67
BOPCON	7.98	9.94	11.82	12.79	13.59	12.49	11.49	11.36

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels.

9 Conclusions

We model monetary integration effects through savings in the trade related costs and through falling investment risk premia. Our simulations suggest that the long run GDP gain from the euro accession amounts to 7.5% of GDP of which 90% occurs in the first 10 years. The gains from elimination of risk premia is slightly higher than those from trade creation.

The main factor behind growth is investment that leads to 12.6% of extra capital accumulated in the long run. Both scenarios are trade enhancing, directly - through lowering of trade costs and indirectly through booming investment demand. Increasing import competition affects domestic output in the initial period under consideration, but since import demand is mainly investment driven, this leads to a rapid expansion of the capital stock and production cost savings which subsequently lead to domestic output and export expansion. Exports go up to reach a level higher by almost 13% than the benchmark scenario and in the long run the current account is expected to reach a surplus.

The welfare gains amount to roughly 2% of the value of GDP each year. The poor households gain slightly more than the non-poor households due to the fact that the loose relatively less risk premium revenues. Consumption is expected to go up by 3.7% in the long run. The production structure of the economy shifts towards market services and the production becomes more capital intensive. Employment effects are significant, however not as pronounced as the output expansion, due to the shift of the economy to more intensive capital use.

We perform a sensitivity analysis that checks how the results are affected by the choice of key parameters of the model. The performed simulation suggest that the model behavior is reasonably resistant to parameter changes and the range that reasonable variation in parameters leads to a variation in key macroeconomic variables by roughly 1pp.

When looking at these results one has to bear in mind that this paper looks only at selected effects that the monetary integration may have. It does completely abstract from monetary issues, such as sub-optimality of common monetary policy, dis-alignment of business cycles and costs of fiscal tightening to meet the Maastricht criteria and subsequently to satisfy the Stability and Growth Pact requirements. Due to the model set up, our simulations do not take into account the effects of the monetary integration on the level of inflation, both through the monetary policy conduct and through the well know through anecdotic evidence "rounding up" problem. The model does not analyze the question of the appriopriate level of the fixed nominal exchange rate. All these problems require separate analyses and a full cost-benefit analysis should be performed to draw conclusions for the political decision making process.

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A Model equations

A.1 Zero profit conditions

Value added:

$$pva_{i,t} = \left[\alpha^{VA}_{K,i}((1+tfac_{K,i,t}+rp_t)rk_t)^{1-\sigma^{VA}_i} + \sum_{m\in FACL}\alpha^{VA}_{m,i}((1+tfac_{m,i,t})w_{m,t})^{1-\sigma^{VA}_i}\right]^{\frac{1}{1-\sigma^{VA}_i}}, \qquad i\in SEC,\, t\in T, \tag{46}$$

Final output:

$$(1-tsec_{i,t}+subs_{i,t})pxd_{i,t} = \alpha^{XD}_{VA,i,t}pva_{i,t} + \sum_{j\in SEC}\alpha^{VA}_{j,i,t}px_{j,t}, \qquad i,j\in SEC,\, t\in T, \tag{47}$$

Supply:

$$pxd_{i,t} = [\gamma^{XD}_i pe_{i,t}^{1+\eta^{XD}_i} + (1-\gamma^{XD}_i)pxdd_{i,t}^{1+\eta^{XD}_i}]^{\frac{1}{1+\eta^{XD}_i}}, \qquad i\in SEC,\, t\in T, \tag{48}$$

Export supply:

$$pe_{i,t} = [\sum_{f\in INSTF}\gamma^{E}_{i,f}(ax_{i,f,t}pfx_{f,t})^{1+\eta^{E}_i}]^{\frac{1}{1+\eta^{E}_i}}, \qquad i\in SEC,\, t\in T, \tag{49}$$

Gross investment:

$$pj_t = \prod_{i \in SEC} px_{i,t}^{\alpha_i^J}, \qquad t \in T. \tag{50}$$

Investment:

$$pk_{t+1} = pj_t(1 + \phi \frac{I_t}{K_t}), \qquad t \in T. \tag{51}$$

Capital formation:

$$pk_t = pk_{t+1}(1 - \delta) + rk_t + \frac{\phi}{2} \frac{I_t^2}{K_t^2} pj_t, \qquad t \in T. \tag{52}$$

Composite Armington good:

$$px_{i,t} = [\alpha_i^X pim_{i,t}^{1-\sigma_i^X} + (1 - \alpha_i^X) pxdd_{i,t}^{1-\sigma_i^X}]^{\frac{1}{1-\sigma_i^X}}, \qquad i \in SEC, t \in T, \tag{53}$$

Import sourcing:

$$pim_{i,t} = [\sum_{f \in INSTF} \alpha_{i,f}^{IM} ((1 + tariff_{i,f,t}) \frac{pfx_{f,t}}{am_{i,f,t}})^{1-\sigma_i^{IM}}]^{\frac{1}{1-\sigma_i^{IM}}}, \qquad i \in SEC, t \in T. \tag{54}$$

Government consumption price index:

$$pwg_t = \prod_{i \in SEC} px_{i,t}^{\alpha_i^G}, \qquad t \in T \tag{55}$$

Intertemporal consumer price index:

$$pu_h = \left(\sum (\frac{1}{1+r})_{t \in T}^t (pw_{h,t})^{1-\sigma_h^U} \right)^{\frac{1}{1-\sigma_h^U}}, \qquad h \in INSTH. \tag{56}$$

Price index of consumer period utility:

$$pw_{h,t} = \left(\alpha_h^W pww_{h,t}^{1-\sigma_h^W} + (1 - \alpha_h^W) pwl_{h,t}^{1-\sigma_h^W} \right)^{\frac{1}{1-\sigma_h^W}}, \qquad h \in INSTH, t \in T. \tag{57}$$

Consumer price index:

$$pww_{h,t} = \left(\sum_{i \in SEC} \alpha_{i,h}^{WW} C_{i,h,t}^{1-\sigma_h^{WW}} \right)^{\frac{1}{1-\sigma_h^{WW}}}, \qquad h \in INSTH, t \in T. \tag{58}$$

Consumer leisure price index:

$$pwl_{h,t} = \left(\sum_{l \in FACL} \alpha_{l,h}^{WL} LEIS_{l,h,t}^{1-\sigma_h^{WL}} \right)^{\frac{1}{1-\sigma_h^{WL}}}, \qquad h \in INSTH, \, t \in T. \tag{59}$$

A.2 Market clearing conditions

Value added:

$$VA_{i,t} = \alpha_{VA,i}^{XD} XD_{i,t}, \qquad i \in SEC, \, t \in T., \tag{60}$$

Gross investment:

$$J_t = I_t(1 + \phi \frac{I_t}{2K_t}), \qquad t \in T. \tag{61}$$

Period government consumption aggregate:

$$WG_t / GDP_t = \alpha_t^{WG}, \qquad t \in T. \tag{62}$$

Government consumption:

$$WG_t pwg_t = MG_t, \qquad t \in T. \tag{63}$$

Consumer lifetime utility:

$$M_h = U_h pu_h, \qquad h \in INSTH. \tag{64}$$

Consumer period sub-utility:

$$W_{h,t} = U_h (\frac{1}{1+r})^t \left(\frac{pu_h}{pw_{h,t}} \right)^{\sigma_h^U}, \qquad h \in INSTH, \, t \in T. \tag{65}$$

Consumer sub-utility derived from goods:

$$WW_{h,t} = \alpha_h^W W_{h,t} \left(\frac{pw_{h,t}}{pww_{h,t}} \right)^{\sigma_h^W}, \qquad h \in INSTH, \, t \in T. \tag{66}$$

Consumer sub-utility derived from leisure:

$$WL_{h,t} = \alpha_h^W W_{h,t} \left(\frac{pw_{h,t}}{pwl_{h,t}} \right)^{\sigma_h^W}, \qquad h \in INSTH, \, t \in T. \tag{67}$$

Factor supply:

$$FACSUP_{l,h,t} = ENDOW_{l,h,t}(1+tsp_t+tp_{l,t})-\alpha^{WL}_{l,h} WL_{h,t}\left(\frac{pwl_{h,t}}{w_{l,t}}\right)^{\sigma^{WW}_h}, l \in FACL,\, h \in INSTH,\, t \in T. \tag{68}$$

Market clearing for labor:

$$\sum_{h\in INSTH} FACSUP_{h,l,t} = \sum_{i\in SEC}\left[\alpha^{VA}_{K,i,t} VA_{i,t}\left(\frac{pva_{i,t}}{w_{l,t}(1+tfac_{l,i,t})}\right)^{\sigma^{VA}_i}\right], l \in FACL,\, t \in T. \tag{69}$$

Market clearing for domestic output:

$$\alpha^X_i X_{i,t}\left(\frac{px_{i,t}}{pxdd_{i,t}}\right)^{\sigma^X_i} = (1-\gamma^{XD}_i)XD\left(\frac{pxdd_{i,t}}{pxd_{i,t}}\right)^{\eta^{XD}_i}. \tag{70}$$

Market clearing for the Armington good:

$$\begin{array}{rcll} X_{i,t} & = & \sum_{h\in INSTH}\left(\alpha^{WW}_{i,h} WW_{h,t}\left(\frac{pww_{h,t}}{px_{i,t}}\right)^{\sigma^{WW}_h}\right) & \text{household demand} \\ & + & \alpha^G_i WG_t \frac{pwg_t}{px_{i,t}} & \text{government demand} \\ & + & \sum_{j\in SEC}\left(\alpha^{XD}_{i,j,t} XD_{j,t}\right) & \text{intermediate demand} \\ & + & \alpha^J_i J_t \frac{pj_t}{px_{i,t}} & \text{investment demand} \end{array} \tag{71}$$

International balance:

$$\begin{array}{lcl} & \sum_{t\in T}\sum_{i\in SEC}\left(\alpha^X_i \alpha^{IM}_{i,f} X_{i,t}\left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma^X_i}\left(\frac{am_{i,f,t}pim_{i,t}}{pfx_{f,t}(1+tariff_{i,f,t})}\right)^{\sigma^{IM}_i}\right) & \text{imports} \\ + & \sum_{t\in T}\sum_{k\in INST} TRANS_{k,f,t} & \text{outgoing transfers} \\ & = & \\ & \sum_{t\in T}\sum_{k\in INST} TRANS_{f,k,t} & \text{exports} \\ + & \sum_{t\in T}\sum_{i\in SEC}\left(\gamma^E_{i,f}\gamma^{XD}_i XD\left(\frac{pe_{i,t}}{pxd_{i,t}}\right)^{\eta^{XD}_i}\left(\frac{ax_{i,f,t}pfx_{f,t}}{pe_{i,t}}\right)^{\eta^E_i}\right) & \text{incoming transfers} \end{array} \tag{72}$$

A.3 Income definitions

Government income:

$$
\begin{array}{rcll}
MG_t & = & \sum_{i\in SEC}((tsec_{i,t}-subs_{i,t})XD_{i,t}pxd_{i,t}) & \text{output tax and subsidies} \\
& + & \sum_{i\in SEC}(tfac_{K,t}K^D_{i,t}rk_t+\sum_{l\in FACL}tfac_{l,t}L^D_{l,i,t}w_{l,t}) & \text{factor taxes} \\
& + & \sum_{h\in INSTH}INCTAX_{h,t} & \text{income taxes} \\
& + & \sum_{i\in SEC}\sum_{f\in INSTF}(tariff_{i,f,t}IM_{i,f,t}pfx_{f,t}) & \text{import tariffs} \\
& + & \sum_{k\in INST}(TRANS_{k,G,t}-TRANS_{G,INST,t}) & \text{transfers} \\
& + & GDEF_t & \text{government deficit}
\end{array} \tag{73}
$$

Household lifetime income:

$$
\begin{aligned}
M_h =& pk_0K_{h,0}-pk_TK_{h,T} \\
&+\sum_{t=0}^{T}(\sum_{l\in FACL}w_{l,t}L^E_{h,t}+rp_trk_tK_{h,t} \\
&+\sum_{k\in INST}TRANS_{h,k,t}-\sum_{k\in INST}TRANS_{k,h,t}-INCTAX_{h,t}-GDEF_t).\, h\in INSTH
\end{aligned} \tag{74}
$$

Household capital shares:

$$
K_{h,t}=\alpha^K_hK_t \tag{75}
$$

Income tax determination:

$$
\begin{aligned}
INCTAX_{h,t} =& inctax_{h,t}((1+rp_t)rk_tK_{h,t}+\sum_{l\in FACL}w_{l,t}L^E_{h,t} \\
&+\sum_{k\in INST}TRANS_{h,k,t}-\sum_{k\in INST}TRANS_{k,h,t}),\ h\in INSTH,\ t\in T,
\end{aligned} \tag{76}
$$

Determination of transfers:

$$
TRANS_{k,h,t}=\alpha^{TRANS}_{k,h,t}GDP_t, \qquad k,h\in INST, t\in T. \tag{77}
$$

A.4 Other definitions

Definition of GDP:

$$
\begin{aligned}
GDP_t &= \textstyle\sum_{h\in INSTH}\left(\alpha^{WW}_{i,h} WW_{h,t}\left(\frac{pww_{h,t}}{px_{i,t}}\right)^{\sigma^{WW}_h}\right) && \text{private consumption}\\
&+ \textstyle\sum_{i\in SEC}\alpha^J_i J_t \frac{pj_t}{px_{i,t}} && \text{investment demand}\\
&+ \textstyle\sum_{i\in SEC}\alpha^G_i WG_t \frac{pwg_t}{px_{i,t}} && \text{government demand}\\
&+ \textstyle\sum_{f\in INSTF}\sum_{i\in SEC}\left(\gamma^E_{i,f}\gamma^{XD}_i XD\left(\frac{pe_{i,t}}{pxd_{i,t}}\right)^{\eta^{XD}_i}\left(\frac{ax_{i,f,t}pfx_{f,t}}{pe_{i,t}}\right)^{\eta^E_i}\right) && \text{exports}\\
&- \textstyle\sum_{f\in INSTF}\sum_{i\in SEC}\left(\alpha^X_i\alpha^{IM}_{i,f}X_{i,t}\left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma^X_i}\left(\frac{am_{i,f,t}pim_{i,t}}{pfx_{f,t}(1+tariff_{i,f,t})}\right)^{\sigma^{IM}_i}\right) && \text{imports}
\end{aligned}
\tag{78}
$$

Definition of nominal GDP:

$$
\begin{aligned}
NGDP_T &= \textstyle\sum_{i\in SEC} VA_{i,t}pva_{i,t} && \text{value added}\\
&+ \textstyle\sum_{i\in SEC}(tsec_{i,t}-subs_{i,t})pxd_{i,t}XD_{i,t} && \text{output taxes}\\
&+ \textstyle\sum_{f\in INSTF}\sum_{i\in SEC} tariff_{i,f,t}pfx_{f,t}\left(\alpha^X_i\alpha^{IM}_{i,f}X_{i,t}\left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma^X_i}\left(\frac{am_{i,f,t}pim_{i,t}}{pfx_{f,t}(1+tariff_{i,f,t})}\right)^{\sigma^{IM}_i}\right) && \text{import tariffs}
\end{aligned}
\tag{79}
$$

Determination of technology spillovers:

$$
\begin{aligned}
tsp_{i,t} = \alpha^{TSP}/tsp_0(&\sum_{f\in INSTF}\sum_{i\in SEC}\left(\gamma^E_{i,f}\gamma^{XD}_i XD\left(\frac{pe_{i,t}}{pxd_{i,t}}\right)^{\eta^{XD}_i}\left(\frac{ax_{i,f,t}pfx_{f,t}}{pe_{i,t}}\right)^{\eta^E_i}\right)\\
&+\sum_{f\in INSTF}\sum_{i\in SEC}\left(\alpha^X_i\alpha^{IM}_{i,f}X_{i,t}\left(\frac{px_{i,t}}{pim_{i,t}}\right)^{\sigma^X_i}\left(\frac{am_{i,f,t}pim_{i,t}}{pfx_{f,t}(1+tariff_{i,f,t})}\right)^{\sigma^{IM}_i}\right))/GDP_t,
\end{aligned}
\tag{80}
$$

A.5 Terminal conditions

$$
\frac{J_T}{J_{T-1}} = \frac{K_T}{K_{T-1}}.
$$

B Additional tables

Table 8: Sensitivity analysis: Imports

Scenario	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
BASE	9.13	10.28	10.98	11.17	11.13	9.78	9.22	9.21
SPILL00	8.42	9.56	10.26	10.47	10.45	9.22	8.69	8.67
SPILL03	9.86	11.02	11.72	11.88	11.81	10.33	9.75	9.74
PROD_EL	10.48	11.73	12.50	12.74	12.72	11.28	10.55	10.52
SUPPLY_EL	8.58	10.17	11.37	11.95	12.25	11.50	11.19	11.18
IMPORT_EL	12.50	13.78	14.58	14.64	14.48	12.06	11.22	11.20
INTERT_EL	9.18	10.35	11.05	11.23	11.18	9.80	9.20	9.19
BOPCON	3.71	4.89	6.34	7.27	8.17	8.88	9.44	9.51

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels.

Table 9: Sensitivity analysis: Exports

Scenario	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
BASE	-4.64	-2.08	1.28	3.96	6.55	10.97	12.83	12.88
SPILL00	-4.42	-2.12	0.97	3.47	5.90	10.27	12.18	12.24
SPILL03	-4.81	-1.99	1.63	4.48	7.22	11.67	13.46	13.51
PROD_EL	-5.17	-2.38	1.19	4.07	6.87	12.21	15.02	15.14
SUPPLY_EL	-8.15	-4.93	-0.36	3.31	6.98	13.00	15.52	15.59
IMPORT_EL	-2.32	0.47	4.07	6.86	9.54	13.54	14.96	14.98
INTERT_EL	-5.39	-2.71	0.79	3.59	6.31	11.00	13.05	13.11
BOPCON	3.73	4.92	6.38	7.31	8.22	8.93	9.49	9.56

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels.

Table 10: Sensitivity analysis: Capital stock

Scenario	1. yr	2. yr	3. yr	4. yr	5. yr	10. yr	25. yr	50. yr
BASE	0.00	1.70	3.51	5.21	6.71	10.81	12.53	12.58
SPILL00	0.00	1.59	3.29	4.89	6.31	10.22	11.94	11.99
SPILL03	0.00	1.82	3.73	5.54	7.13	11.40	13.12	13.16
PROD_EL	0.00	2.12	4.33	6.44	8.32	13.86	16.77	16.90
SUPPLY_EL	0.00	1.82	3.78	5.61	7.23	11.55	13.35	13.40
IMPORT_EL	0.00	1.85	3.79	5.63	7.26	11.49	13.00	13.02
INTERT_EL	0.00	1.61	3.37	5.06	6.58	10.78	12.61	12.67
BOPCON	0.00	0.82	1.76	2.79	3.82	7.69	10.94	11.35

Source: Own model simulations.

Note: changes in percent deviations of benchmark variable levels.