An Economy in Transition and DSGE: What the Czech National Bank's New Projection Model Needs

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Abstract

Since the introduction of an inflation targeting regime in 1998 the Czech National Bank has made a considerable progress in developing formal tools for supporting its Forecasting and Policy Analysis System. This paper documents the newest version of an open economy DSGE model, which has been designed to capture some of the most important features of the Czech economy related to its convergence to economically developed European countries. The model in its current form is able to capture trends in relative prices, ensure convergence to perceived medium term expenditure shares, cope with significant undercapitalisation of the economy and take into account imperfect substitutability between old and new capital. Besides these features the model exhibits real and nominal rigidities that are fully in line with the recent advances of the New Open Economy Macroeconomics literature.

1 Introduction

The Czech National Bank has adopted inflation targeting (IT) since January 1998. To support the implementation of monetary policy the Bank has developed a forecasting and policy analysis system (FPAS) whose earlier version is described in Coats, Laxton, and Rose (2003). The analytical framework has been established around a small open

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economy quarterly projection model (QPM). The model was primarily meant to provide a quantified story-telling device; its structure therefore contains a simple monetary transmission mechanism based on forward-looking agents and a proactive central bank reacting to deviations of the inflation forecast from the target. QPM captures highly aggregated and stylized flow relationships in the Czech economy that are necessary to explain business cycle fluctuations in output, inflation, the exchange rate and the interest rate as viewed from the New Keynesian perspective. To this end, the model mechanisms primarily deal with the deviations of the main macroeconomic variables from their long-run trends (i.e. a 'gap' logic), and gaps and trends are treated, to a large extent, separately [1]. While the gap dynamics of the model can be easily linked to some underlying—rather standard—macroeconomic theories, the determination of long-run values lacks deeper supply-side or stock-flow consistency.

There were a number of good reasons for the Bank's staff to start with a relatively simple, aggregated, and calibrated model to support the implementation of IT. [2] The approximately four years of working experience with the FPAS centred around the QPM have revealed both many advantages and some limitations of the core model. The well organized forecasting process—i.e. smooth integration of short-term and expert inputs with the medium-term model mechanisms, communication between modelers and non-modelers, and that between the staff and the Board—has led to overall acceptance of and reliance on the existing FPAS. On the other hand, the staff has successively expanded their expertise in areas that are not endogenously contained in the QPM. These areas have become an integral part of the non-model side of the FPAS, and have been extensively used as extra inputs in the model simulations; they often have a deep structural nature and can hardly be addressed without a microeconomically well-founded model. Examples of them include model-consistent treatment of stocks and flows and their implications for the inflation outlook, particularly in the field of public finance, the key national accounts variables and demand components, identification and evaluation

[1] The historical lon-run trends for output, the real exchange rate, and the interest rate are determined simultaneously by a multivariate filter, and then projected to the future on a basis of expert evaluation.

[2] For instance, prior to the QPM the Bank did not rely on any simultaneous-equations model with active monetary policy and forward-looking channels, and therefore there had been no expertise in real-time using and running complex formal tools. Second, the modeling staff was initially not experienced enough to develop a fully optimizing DSGE model that could have provided more detail and macroeconomic rigor. Similarly, the non-modeling staff was not prepared to communicate on a basis of a highly formalized and sophisticated paradigm. Third, the process of inflation forecast integration (i.e. integration of the core model forecast with other short-term and expert information into a single staff projection, organizing meetings of the forecasting team with the Bank Board, etc.) was considerably smoother with a simpler model.

of the structural determinants of real appreciation, or issues relating to the envisaged ERM2 entry.

The success of the existing FPAS played an important role in the approval of a research agenda by the Board more than two years ago, directed at developing a new, dynamic stochastic general equilibrium framework. In line with growing demand for more detailed and micro-founded policy analyses at the Bank, the new model development has predominantly relied upon the recent advances in the New Open Economy Macroeconomics (NOEM) literature founded by Obstfeld and Rogoff (1995). The fully optimizing DSGE framework borrowed from the real business cycle theory and enriched with New Keynesian nominal rigidities has reached a stage of development in which it exhibits realistic quantitatives properties and predictions—even when contrasted with the performance of e.g. VAR models, as illustrated in Smets and Wouters (2003)—and may thus serve as a basis for monetary policy analyses. In addition, this class of models facilitates explicit statements about agents, markets, technologies or tastes, and provide a mapping into the economy's deep parameters to address issues embedded in the microeconomic structure. On the implementation side, there are currently several policy-making institutions (IMF's GEM, the Bank of Canada's Totem, the Bank of Finlands's Aino, the Bank of Norway's Nemo, etc.) who have put into some level of operation DSGE models that derives from the NOEM paradigm.

To motivate our final choice of the theoretical structure of the model, we turn to a set of stylized facts of the Czech economy over the last decade that we find critical or important from the point of view of monetary policy implementation; the model then needs to contain devices to replicate, or to allow for, these facts. We simplify the exposition making a distinction between the long-run trend developments and the shorter-run business cycle fluctuations present in the Czech data.

(i) Balanced growth

Because some of the cyclical properties of the model may firmly tie to the long-run economic developments, in particular when the economy undergoes transition as in the Czech case (e.g. the real interest rate issues), realistic forecasting properties require the model economy to enable the analysis along a balanced growth path rather than a stationary steady state.

(ii) Trends in relative prices

Along the transition path the Czech economy has been exhibiting significant and permanent shifts in relative prices. Most importantly, given high productivity improvements mainly in the domestic export goods sector, the corresponding trends in relative prices has shown in ongoing long-term real appreciation as measured by various definitions of the real exchange rate. We illustrate these facts in Figure A.1 by the movement in relative prices of the main expenditure deflators. As the transition in relative prices may have in general considerable effects on the inflation profile and the disinflation strategy, we should allow for it in the endogenous model mechanisms.

(iii) Medium-run developments in expenditure shares

When compared to developed economies, the expenditure shares of GDP in a transition economy usually tends to reveal a relatively high investment profile and a correspondingly lower consumption path, see Figure A.2 for comparison with Germany and France. These may be explained by the capital accumulation process along the catch-up phase on one hand, and by consumer credit rationing in the international financial market and consumer habit build-up on the other hand. Despite the fact that consumption and investment shares in some other European countries differ from those displayed in the two Europe's largest economies, it is likely that the Czech economy will ultimately converge in their direction.

(iv) Initial undercapitalization of the economy

One of the main transition issues is the process of the replacement of the obsolete capital stock inherited from the command economy with new, more productive capacities. This can be indeed addressed, from an economic point of view, as a problem of initial undercapitalization even though the old, less productive stock is rather large. The investment projects carried out over the Czech economy during the last decade (mainly FDI, see Figure A.3 for the the development of the Czech net investment position) and the expected future trends in investment activities indicate a large scale of such undercapitalization.

(v) Imperfect substutition between old and new capital

This issue directly follows from the previous paragraph. The standard macroeconomic models usually assume perfect intertemporal substitution in capital accumulation—so that the existing capacities make the same contribution to the new capital stock as the newly undertaken investment projects. While this assumption may be valid in countries where the economic development has been based on the free market forces for a long period of time, it may fail to be appropriate for economies in which the existing production capacity is, to some extent, still a result of the old command system. This is one of the reasons why we introduce a generalized capital accumulation equation, borrowed from Lucas and Prescott

(1971) and Kim (2003).

(vi) Labor market participation

The other input factor has displayed a dramatic decline in the participation rate during the transition period—especially in the case of the female participation rate. This phenomenon needs to be carefully distinguished from the large rise in unemployment rates, that occured simultaneously. The causes behind the participation rate development rest on both changes in the labor market and social system institutions, and on a gradually improving income position of households. Figure (A.4) illustrates the declining trend in employment in the profit sector which is partly explained by the drop in labor market participation. The model is capable to account for this kind of permanents shifts by time variations in the marginal utility of leisure.

(vii) Growing import intensity

Evident from Figure A.5 is an increase in the overall import intensitiy of the Czech economy. This rapid build-up of imports is attributable to (i) the ongoing investment boom with investment goods being highly import intensive, and (ii) a large increase in the new production capacities oriented predominantly on re-exporting industries.

While the stylized facts related to the longer-term trend developments reflect the ongoing transition process in the Czech economy, and require often extra devices to be incorporated in the model structure, the business cycle features can be addressed with more standard tools found in the NOEM literature, relying upon various types of real and nominal frictions.

(i) Inflation persistence and costly disinflation

We use the Calvo (1983) mechanism augmented with backward indexation, as in Christiano, Eichenbaum, and Evans (2005), to generate endogenous inflation inertia, both in prices and nominal wages, consistent with an optimizing framework. The backward indexation is ingenious in that it introduces stickiness while maintaining steady-state monetary superneutrality and interpretation close to that of Phillips curves found in smaller and more ad-hoc models. The backward indexation makes disinflation costly; at the same time different degrees of price and wage stickiness may provide enough degrees of freedom for realistic calibration.

(ii) Exchange rate disconnect

The problem of the nominal exchange rate disconnect is described both empirically and theoretically e.g. in Baxter and Stockman (1989), Flood and Rose (1995), Obstfeld and Rogoff (2000), Devereux and Engel (2002), or Obstfeld (2002). We achieve a realistic disconnect of the excessive nominal exchange rate fluctuations from the real economy and prices by specific assumptions on the export and import price setting—International currency pricing—which resemble the usual local currency pricing but are more convenient for out multi-country framework for analytical tractability.

(iii) Real rigidities

The empirically observed hump-shaped and delayed reactions of real consumption and investment to both temporary and permanent shocks are generated by two nowadays standard mechanisms: external habit in consumption as originally introduced by Abel (1990), and the time-to-build constraint on capital accumulation proposed by Kydland and Prescott (1982). The importance of habit formation in monetary-policy models was emphasized by Fuhrer (2000).

2 Structure of the Model and Features of Convenience

The World economy consists of a continuum of small countries indexed on the interval $[0, 1]$; we call one of those Home. All countries are identical; they produce their own variety of final goods that are then either consumed/invested domestically, or sold abroad as intermediate input to foreign production. Each economy has its own currency, however, International currency exists and is used in the international markets.

Home final goods are produced from two inputs, the imported intermediate goods purchased from importers, and the Home intermediate goods, produced by intermediate producers. The Home intermediate producers employ two domestic input factors, capital and labor. Home households consume domestically produced consumption goods and supply labor and accumulated capital. In addition they may hold Home currency bonds, and cash money. The International currency bonds trading is delegated to foreign exchange dealers.

The nominal wages as well as the export, import, and intermediate goods prices are sticky. To this end we introduce demand for variety and monopolistic competition in the respective markets. Nevertheless, as the price stickiness is the only purpose of these extra assumptions we use the same elasticity of substitution for all these four varieties, and denote it by ϵ. Moreover, to simplify the steady-state national accounting and the steady-state calibration the monopoly distortions and markups are eliminated by government subsidies provided at a fixed rate $\zeta = \epsilon/(\epsilon - 1) - 1$.

Furthermore, we strictly maintain the partition of parameters (steady-state versus transitory) which is especially noticeable in our definitions of preferences and technologies: Those parameters that describe mechanisms introduced exclusively to generate a realistic business-cycle profile, such as habit (χ) or imperfect substitution between old and new capital (η), have no affect on the steady state properties of the model economy at all.

Finally, in our notation, the lowercase letters denote (i) quantities demanded and (ii) individual prices of differentiated goods. On the other hand, the uppercase letters denote (i) quantities supplied, (ii) sector- or economy-wide price indexes, and (iii) competitive prices. Caligraphic letters are reserved for functions whereas lowercase Greek letters for parameters.

3 Households

The economy is populated by a continuum of households indexed on the interval $[0, 1]$. Each household is a consumer of a variety of consumption goods, a monopoly supplier of a differentiated labor service, and a competitive supplier of capital services; the investment in the capital stock needs time to build as in Kydland and Prescott (1982). The households can domestically trade in Home-currency non-contingent bonds and cash money; all Home trading in International-currency bonds is delegated to forex dealers who act in households' interests, see Devereux and Engel (2002). Households then receive a net payment from dealers, negative or positive.

Furthermore, when setting their wage rates the households face a random duration of the contracts as originally introduced by Calvo (1983) and modified herein in the direction proposed by Christiano, Eichenbaum, and Evans (2005). In each period, a constant fraction $1 - \xi_w$ of households receive a signal to re-optimize their wage contracts; the remaining proportion ξ_w of households must maintain the previous period's wage rate updated at the previous period's market-wide rate of nominal wage inflation. The signal receivers are chosen randomly, with each household having an equal probability $1 - \xi_w$ of being drawn. Under these circumstances, the risk of not receiving the signal is idiosyncratic: the households would end up heterogenous not only in their current wage rates and labor effort but also in consumption and wealth. As a consequency the analytical tractability of the model would dramatically decline. However, given the fact that individual but no aggregate uncertainty exists in the labor market there is scope for insurance. We therefore suppose that there is a competitive market with insurance companies that offer one-period insurance against the wage-setting risk. At date t each household may purchase any positive or negative amount v_t of insurance at the price P^v_t/i_t where i_t is the riskless nominal gross rate. Consecutively, if the household fails to receive the re-optimization signal at date $t+1$, the company makes or collects the payment v_t. Put formally, the s-th household's budget constraint at date t reads

$$i_{t-1}b_{t-1}(s) + m_{t-1}(s) + P_t^K u_t K_{t-1}(s) + \Phi_t(s) + \Psi_t(s) + \tau_t(s) = \\ b_t(s) + m_t(s) + P_t^C c_t(s) + P_t^J \sum\nolimits_{k=0}^{T} j_{t-k}(s)/(T+1), \quad (1)$$

where b_t and m_t, are respectively holdings of Home currency bonds and cash money, $u_t K_{t-1}$ is the volume of capital services sold to the intermediate producers at date t, compounded of the capital (or production capacity) K_{t-1} utilized at a rate u_t, Φ_t is the net labor income defined below, $\Psi_t = \Psi_t^Y + \Psi_t^N + \Psi_t^X$ and τ_t are positive or negative lump-sum payments made by firms (profits or losses) and the government (transfers or taxes), respectively, c_t is real consumption and j_t denotes an investment plan initiated at time t and resulting in an increase in available production capacity after $T+1$ periods.[3]

The net labor income includes compensation for labor effort plus the net payment made with the insurance companies, i.e.

$$\Phi_t(s) = (1+\zeta)\, w_t(s) L_t(s) - P_t^V(s) v_t(s) + \begin{cases} 0, & \text{if signal received,} \\ v_{t-1}(s), & \text{if signal not received,} \end{cases} \quad (2)$$

where $w_t(s)$ is the nominal wage rate, $L_t(s)$ the labor effort exercised, and ζ is the rate at which the government subsidizes the households to eliminate the monopolistic distortion due to imperfect substitution in the labor market, and hence to drive the steady-state wage markup to zero; recall that $\zeta = \epsilon/(\epsilon-1) - 1$, where ϵ is the respective elasticity of subtitution.

Our insurance market is indeed analogous to the life insurance used by Yaari (1965). An alternative assumption found in the sticky price literature is the existence of state contingent bonds that provide exactly the same kind of insurance against the wage-setting risk, see e.g. Woodford (1996) or Erceg, Henderson, and Levin (2000).

Provided the households are risk averse and face actuarially fair prices of the insurance (in that P_t^v equals the probability ξ_w which requirement is justified by perfect competition in the insurance market where profits are driven to zero), they will always decide to completely pool the wage-setting risk. As a consequence, randomness of re-optimization signals will not affect the shadow value of their wealth.[4] Moreover, if prefences and initial wealth are identical across households, then all of them will choose identical consumption and asset holdings plans whereas heterogeneity will only prevail

[3] Each project requires real investment equally distributed over the time-to-build period.

[4] Herein the shadow value of wealth is represented by the Lagrange multipliers associated with nominal bonds and physical capital.

in their wage rates earned and labor effort exercised. This assumption allows us to solve the households' optimization problem separaterly for representative consumption and asset holdings on one hand, and for distribution of the individual wage rates and labor supply on the other hand.

Representative Consumption and Asset Holdings

Throughout this subsection we drop indexation of quantities related to a particular household since we deal with representative decisions made identically by all households. The household seeks to maximize a lifetime objective

$$\mathrm{E}_t \sum_{k=0}^{\infty} \beta^k \Big[\mathcal{U}(c_{t+k} - \chi\, h_{t+k},\ m_{t+k}/P^C_{t+k}) + \mathcal{V}(1 - L_{t+k}) \Big] \tag{3}$$

where the utility derives from consumption adjusted for external habit, real money holdings, and leisure. We assume the following instantaneous utility functions

$$\mathcal{U} \equiv (1-\chi)\log(c_t - \chi h_t) + \log(m_t/P^C_t), \quad \mathcal{V} \equiv \kappa_t\,(1 - L_t), \tag{4}$$

where $\chi \in [0, 1)$ reflects the importance of habit in consumption, and $\kappa_t > 0$ controls the households' labor participation. [5] The linearity of the utility from leisure (or, in other words, constant marginal disutility of labor and hence an infinitely elastic labor supply curve) arises here because of the imposed indivisibility of labor as in Hansen (1985).

The process of capital accumulation follows a law of motion with $T + 1$ periods to build where we allow for a general—though constant—elasticity of substitution between the existing capital in place and the newly installed one, as proposed by Lucas and Prescott (1971) and generalized by Kim (2003),

$$K_t = \mathcal{K}(K^\star_{t-1}, j^\star_{t-T}), \tag{5}$$

where $\mathcal{K}$ is a CES function of the previously installed capital, $K^\star_{t-1}$, and the currently finished investment plan, $j^\star_{t-T}$, with both measured in effective units as defined below. We find at least three motivations for the more general accumulation equation: (i) K_t may now have a more general interpretation of overal production capacity rather than physical capital alone, (ii) it provides a device similar to the more usual intertemporal capital adjustment costs, and (iii) in the context of a transition economy the equation

[5] As claimed in Introduction, time-varying labor participation is one of the ingredients needed for addressing the transition issues.

may well describe a process of replacement of the old capacity (inherited from the command economy) with the new, more productive one. The capital accumulation function has the form

$$\mathcal{K} \equiv \left[\nu \left(\alpha K^\star_{t-1} \right)^{\frac{\eta-1}{\eta}} + (1-\nu) \left(\frac{j^\star_{t-T}}{1-\nu} \right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{6}$$

where $\eta > 1$ is the elasticity of substitution, α is the steady-state growth rate of the economy, and a^K_t is a shock to the capital accumulation. The specific form is indeed an extension to Kim (2003) for a balanced-growth economy. The effective units of capital and investment are defined as

$$K^\star_{t-1} = {u_t}^{1-\upsilon}\, K_{t-1}, \qquad j^\star_t = a^K_t\, j_t, \tag{7}$$

where $u_t > 1$ is the capital utilization rate decided on by the households, $\upsilon > 1$ is the elasticity of capital depreciation with respect to utilization, and α^K_t is an exogenous economy-wide new-capital-specific technological process. We assume both $u_t = 1$ and $\alpha^K_t = 1$ in steady state.

When setting $\nu = (1-\delta)/\alpha$ the seemingly complicated structure of (6) allows us to achieve two convenient features of the model: first, for any admissible elasticity of subsitution η we obtain an identical steady-state investment-to-capital ratio, namely $j_{t-T}/K_t = (\alpha - 1 + \delta)/\alpha$; second, for $\eta = \infty$ we obtain the standard identity $K_t = (1-\delta)K^\star_{t-1} + j^\star_{t-T}$.

The first-order conditions necessary maximize (3) subject to (1) and (5) taking the net labor income as given are listed in Appendix A.1, equations (A.1)–(A.5).

Finally, the external consumption habit evolves as a stochastic autoregression depending on the past economy-wide per-capita consumption,

$$\log h_t = \rho_H \, \log h_{t-1} + (1-\rho_H) \, \log(\alpha\, c_{t-1}) + e^H_t \tag{8}$$

so that it is not internalized when households optimize. Note that $h_t = c_t$ in steady state which makes the long-run elasticity of intertemporal substitution independent of χ.

Staggered Wage Setting

To describe the aggregate wage dynamics we need to derive the wage rate set by those households who receive the re-optimization signal; the non-receivers simply follow the specified rule,

$$w_t(s) = w_t(s) \cdot W_{t-1}/W_{t-2},$$

where the market-wide index, W_t, is introduced later in this section.

First note that because no other idiosyncratic uncertainty exists for households in the model all time t signal receivers will choose the same rate regardless of their own history. For this reason we again drop the index s and denote by $w_{t+k|t}$ the wage rate valid at time $t+k$ that was optimized at time t last and updated since then, and by $L_{t+k|t}$ the corresponding labor effort supplied at time $t+k$ by a household who received the signal k periods ago last.[6]

The wage setter optimizes (4) over all future states of nature in which she consecutively fails to receive the re-optimization signal and must keep updating today's decided wage rate. This effectively means to maximize

$$\mathrm{E}_t \sum_{k=0}^{\infty} (\xi_W \beta)^k \Big[\mathcal{V}(1 - L_{t+k|t}) + \lambda_{t+k} \, (1+\zeta) \, w_{t+k|t} L_{t+k|t} \Big], \tag{9}$$

taking λ_{t+k} as given, subject to the demand function for her own labor service (derived later in the section, see 20), and the wage-indexation scheme converted to the relative wage terms,

$$L_{t+k|t} \leq \ell_{t+k|t} = \left(w_{t+k|t}/W_{t+k} \right)^{-\epsilon} \ell_{t+k}, \tag{10}$$

$$\frac{w_{t+k|t}}{W_{t+k}} = \frac{w_{t|t}}{W_t} \cdot \frac{W_{t+k-1}/W_{t-1}}{W_{t+k}/W_t} = \frac{w_{t|t}}{W_t} \cdot \Omega_t/\Omega_{t+k}, \tag{11}$$

where $\Omega_t = W_t/W_{t-1}$ denotes the market-wide gross rate of wage inflation.

The first-order conditions are listed in Appendix A.2. Note that for ease of the model aggregation the condition (A.6) is expressed in market-wide terms. Finally, in Section 5 we derive the law of motion for the market-wide wage rate and its inflation, and quantify the effect of the wage and labor effort dispersion that prevails in the economy off steady state due to the sticky wage setting.

Foreign Exchange Dealers

Forex dealers, who are delegated to buy or sell International currency bonds, are short-lived: they only exist two consecutive periods. At date t they collect payments from households and invest the amount in the international financial market; at date $t+1$ they transfer all cash flows back to households and die. The representative dealer chooses the stock of International currency bonds, $\widetilde{B}_t$, to maximize the expected net cash flow

[6] Hence, the choice variables of our interest are $w_{t|t}$, the currently optimized wage rate, and $L_{t|t}$, the optimizer's labor supply.

evaluated at the households' shadow value of wealth, facing a quadratic cost of protfolio adjustment [7] ,

$$a_t^s\,\mathrm{E}_t\left(\beta\lambda_{t+1}\cdot S_{t+1}\widetilde{B}_t\,\widetilde{\imath}_t\right)-\lambda_t\cdot S_t\widetilde{B}_t\left(1+\tfrac{1}{2}\phi_b\,a_t\widetilde{B}_t\right).$$

where a_t^s captures both the expectational errors and the ex-ante risk premium; the former can be serially correlated because of the dealers' short-livedness. The net cash flow maximizing first-order condition is

$$a_t^s\,\mathrm{E}_t\frac{\beta\lambda_{t+1}}{\lambda}\cdot\frac{S_{t+1}v_t}{S_t}\,\widetilde{\imath}_t=1+\phi_b\,a_t\widetilde{B}_t,\tag{12}$$

which is the model's uncovered interest parity.

4 Production

There are two varieties of intermediate goods produced in the economy: the Home intermediate goods and the import intermediate goods. The former variety is produced by a continuum of Home intermediate firms indexed on the interval $[0,\,1]$; the latter is produced by a continuum of Home residing importers indexed again on $[0,\,1]$. The intermediate goods are used by the final goods producers to assemble four types of goods: consumption, government consumption, investment, and export.

Intermediate Producers

There is a continuum of intermediate producers in Home indexed on the interval $[0,1]$ who combine capital services, k_t, and labor services, ℓ_t, rented or hired from households in competitive markets, to produce a variety of intermediate goods. These goods are then demanded by the final goods producers. The intermediate producers are homogenous in the technology they use, including a labor-augmenting technological process, and in the factor prices they face. Assuming a CRS-CES technology we may reduce the notational burden by expressing directly the sector-wide level of output as a function of the sector-wide quantities of the two input factors employed,

$$\int_0^1 Y_t(s)\,\mathrm{d}s=Y_t=\mathcal{F}(k_t,\ell_t),\tag{13}$$

[7] The portfolio adjustmen cost is one of the convenient ways to achieve a unique stationary distribution of the households' wealth and consumption plans in steady state in small open economy models, see Schmitt-Grohe and Uribe (2003).

where we assume unit elasticity of substitution between the two input factors,

$$\mathcal{F} \equiv {k_t}^{1-\gamma} \, (a_t \, \ell_t)^\gamma, \tag{14}$$

with a_t denoting the sector-specific technological process. Readily, each producer's cost minimization leads to the following sector-wide relative factor demand

$$k_t/\ell_t = (1-\gamma)/\gamma \cdot W_t/P_t^K, \tag{15}$$

where P_t^K denotes the rental price of capital services whereas W_t is the marginal cost of obtaining one more unit of labor services, and is introduced later in this subsection. Furthermore, the nominal marginal, and at the same time also average, cost is identical for all producers and independent of the level of their production,

$$\Theta_t^Y(s) = \Theta_t^Y = {P_t^K}^{1-\gamma} \, {W_t}^\gamma / [\gamma^\gamma (1-\gamma)^{1-\gamma}]. \tag{16}$$

As in the case of households each producer's output is subsidized by the government at a fixed rate $1+\zeta$ to eliminate the monopolistic distortion; for future reference we write the instantaneous sector-wide net cash-flow as

$$\Psi_t^Y = (1+\zeta) \int_0^1 p_t^Y(s) Y_t(s) \, \mathrm{d}s - P_t^K \, k_t - W_t \, \ell_t. \tag{17}$$

Each producer chooses her output, $Y_t(s)$, and price, $p_t^Y(s)$, to maximize the net cash-flow over an infinite horizon evaluated at the households' present shadow value of wealth, $\beta^k \lambda_{t+k}$, subject to two restrictions: (i) the demand function for her own output derived in (32),

$$Y_t(s) \leq y_t(s) = [p_t^Y(s)/P_t^Y]^{-\epsilon} \, y_t, \tag{18}$$

and (ii) the sticky-price constraint. Without the latter limitation, e.g. if the producer were allowed to optimize freely at each date, she would simply maintain the price equal to her nominal marginal cost, $p_t^Y(s) = \Theta_t^Y(s)$ or $P_t^Y = \Theta_t^Y$ (recall that markups arising from the monopoly power are offset by the subsidy), and produce output to satisfy the correspoding demand. This, however, only holds in steady state, and we instead assume the intermediate price setting is staggered in a similar way as the nominal wage. A fixed fraction $1-\xi_Y$ of producers is randomly drawn each period and allowed to re-optimize. The remaining proportion of ξ_Y can only adjust their previous period's prices for the previous period's sector-wide rate of inflation, $\Pi_{t-1}^Y = P_{t-1}^Y/P_{t-2}^Y$. The sticky-price problem is described in a separate subsection along with other sectors.

Finally, the labor input in the production function, ℓ_t, is composed as a CES index of the variety of differentiated labor services supplied by the households, [8]

$$\ell_t = \left[\int_0^1 \ell_t(z)^{\frac{\epsilon-1}{\epsilon}} \mathrm{d}s\right]^{\frac{\epsilon}{\epsilon-1}}. \tag{19}$$

The standard expenditure-minimization conditions then determine the demand for the individual labor services,

$$\ell_t(z) = \left[w_t(z)/W_t\right]^{-\epsilon} \ell_t, \tag{20}$$

where the minimum-expenditure wage index is defined as

$$W_t = \left[\int_0^1 w_t(z)^{1-\epsilon} \, \mathrm{d}s\right]^{\frac{1}{1-\epsilon}}, \tag{21}$$

and, obviously, coincides with those used in (15) and (16).

Importers

There is a continuum of importers indexed on the interval $[0, 1]$ who purchase export goods abroad and produce a variety of differentiated imported intermediate goods using a CES production technology. Moreover, the imports from individual countries themselves are assumed to be CES bundles defined over the variety of that country's national exporters. That is, each national exporter compete with other national exporters, but not with any foreign one, whereas the aggregate national export as a whole competes with other countries' aggregate exports; neither individual nor national exports are directly confronted with the intermediate goods produced domestically. The multi-stage import structure provides enough flexibility to calibrate the expenditure switching in response to the nominal exchange rate fluctuations. There are three distinct elasticities of substitution on the import side: one between any pair of goods produced by exporters from the same country introduced beacuse of the sticky-price assumption; another between any two composite imports at the national lavel introduced to redirect demands internationally; and yet another between the import goods and Home value added.

We again express the sector-wide production function which takes the inputs from all

[8] Note that $\ell_t(z)$ denotes the sector-wide demand for the s-the labor service, and not the demand by the s-th producer.

countries,

$$\int_0^1 N_t(s)\,\mathrm{d}s = N_t = a_t^N \left[\int_0^1 q_t(z)^{\frac{\theta-1}{\theta}}\mathrm{d}z\right]^{\frac{\theta}{\theta-1}}, \tag{22}$$

where $\theta > 1$ is the elasticity of substitution between any pair of countries, and each $q_t(z)$ itself is a CES index of goods supplied by the z-th country's individual producers, and a_t^N a import-specific technological process. We again assume that the production is subsidized by the governemtn at a fixed rate ζ to eliminate the monopolistic distortion which fact alters the instantaneous sector-wide net cash-flow,

$$\Psi_t^N = (1+\zeta)\int_0^1 p_t^N(s)\,N_t(s)\,\mathrm{d}s - S_t\left[\int_0^1 \widetilde{p}_t^Q(z)^{1-\theta}\,\mathrm{d}z\right]^{\frac{1}{1-\theta}}. \tag{23}$$

where $\widetilde{p}_t^Q(s)$ are the import price indexes related to the imports from individual countries and quoted in International currency. The sector-wide nominal marginal, and at the same time also average, cost faced by all importers is clearly

$$\Theta_t^N(s) = \Theta_t^N = S_t\left[\int_0^1 \widetilde{p}_t^Q(z)^{1-\theta}\,\mathrm{d}z\right]^{\frac{1}{1-\theta}} / \,a_t^N = S_t\,\widetilde{P}^Q/\,a_t^N. \tag{24}$$

Moreover, the cost minimization performed by and aggregated over all importers then gives [9]

$$q_t(z) = \left[\frac{\widetilde{p}_t^Q(z)\,S_t}{a_t^N\,\Theta_t^N}\right]^{-\theta} N_t/\,a_t^N. \tag{25}$$

The problem solved by an importer is fully analogous to that of an intermediate firm: by choosing the output, $N_t(s)$, and price, $\widetilde{p}_t^Q(s)$ she maximizes the net cash-flow over an infinite horizon subject to the demand for her own production,

$$N_t(s) \leq n_t(s) = [p_t^N(s)/P_t^N]^{-\epsilon}\,n_t, \tag{26}$$

[9] The system of Home demand curves for the production of individual firms indexed by $s \in [0,1]$ residing in the z-th country is trivial,

$$q_t(s,z) = \left[\frac{\widetilde{p}_t^Q(s,z)}{\widetilde{p}_t^Q(z)}\right]^{-\epsilon} q_t(z),$$

where ϵ differs from θ. This fact is later used to impose the world-wide demand for a Home exporter's output: the prices $\widetilde{p}_t^Q(s,z)$ and $\widetilde{p}_t^Q(z)$ are then obviously replaced with respectively $\widetilde{p}_t^X(s)$ and $\widetilde{p}_t^X$, and the quantitites $q_t(s,z)$ and $q_t(z)$ with respectively $x_t(s)$ and x_t.

and the sticky-price constraint.

Final Goods Producers

There are four types of final goods producers: exporters, and consumption, government, and investment goods firms; to assemble their output they use the two intermediate goods with various intensity. For the reasons laid out in Introduction we assume the following: (i) the elasticity of substitution between imports and Home intermediate goods is zero, i.e. a Leontieff function applies, (ii) the investment goods are fully import intensive, the govetnment goods have zero import intensity, and the export and consumption goods' import intensity is the same and lying between 0 and 1, (iii) the exporters' prices are sticky in International currency, therefore we need to introduce monopolistic competition among them, the other producers operate in competitive markets without any control over their prices.

Accordingly, we may write the sector-wide production functions as

$$\int_0^1 X_t(s)\,\mathrm{d}s = X_t = a_t^X \min\Big\{n_t^X/\omega\,,\ y_t^X/(1-\omega)\Big\}, \tag{27a}$$

$$C_t = a_t^C \min\Big\{n_t^C/\omega\,,\ y_t^C/(1-\omega)\Big\}, \tag{27b}$$

$$J_t = a_t^J\, n_t^J, \tag{27c}$$

$$G_t = a_t^G\, y_t^G, \tag{27d}$$

where $a_t^{\{X,\,C,\,J,\,G\}}$ are sector-specific technological processes, $n_t^{\{X,\,C,\,J\}}$ and $y_t^{\{X,\,C,\,G\}}$ are the sector-wide demands for the respective intermediate goods, and $\omega \in (0,\,1)$ is the import intensity of export and consumption.

The cost minimization in the export and consumption sectors leads to the following demands for the intermediate inputs,

$$n_t^X = \omega\, X_t/a_t^X, \tag{28a}$$

$$n_t^C = \omega\, C_t/a_t^C, \tag{28b}$$

and

$$y_t^X = (1-\omega)\, X_t/a_t^X, \tag{29a}$$

$$y_t^C = (1-\omega)\, C_t/a_t^C, \tag{29b}$$

wherease the other sectors' input demands are rather trivial. The sector-wide nominal marginal and average costs are

$$\Theta_t^X(s) = \Theta_t^X = \left[\omega P_t^N + (1-\omega)P_t^Y\right]/a_t^X, \tag{30a}$$

$$\Theta_t^C = \left[\omega P_t^N + (1-\omega)P_t^Y\right]/a_t^C, \tag{30b}$$

$$\Theta_t^J = P_t^N/a_t^J, \tag{30c}$$

$$\Theta_t^G = P_t^Y/a_t^G. \tag{30d}$$

In the three competitive sectors the prices will be driven to the nominal marginal costs at each date, i.e. $P_t^C = \Theta_t^C$. $P_t^J = \Theta_t^J$, $P_t^G = \Theta_t^G$. On the other hand the exporters face their world-wide demand curves,

$$X_t(s) \leq x_t(s) = \left[\widetilde{p}_t^X(s)/\widetilde{P}_t^X\right]^{-\epsilon} x_t, \tag{31}$$

and set their prices sticky in International currency; the export price dynamics are described below.

Finally assuming that the production function inputs in (27a)–(27d) are themselves CES indexes over the variety of the respective intermediate goods, and making use of the fact that their prices are the same for anybody, we may from the cost minimization impose the economy-wide demand for the s-the good,

$$y_t(s) = y_t^C(s) + y_t^J(s) + y_t^G(s) = \left[p_t^Y(s)/P_t^Y\right]^{-\epsilon} y_t, \tag{32}$$

where

$$y_t = y_t^C + y_t^J + y_t^C = \left[\int_0^1 y_t(s)^{\frac{\epsilon-1}{\epsilon}} \mathrm{d}s\right]^{\frac{\epsilon}{\epsilon-1}}, \tag{33}$$

$$P_t^Y = \left[\int_0^1 p_t^Y(s)^{1-\epsilon} \mathrm{d}s\right]^{\frac{1}{1-\epsilon}}. \tag{34}$$

Fully symmetric expressions hold for the import intermediate goods.

Staggered Price Setting

In this subsection we derive the optimal prices set by signal receivers in the intermediate, import, and export goods sectors. The three problems are indeed close parallels so that we only describe in full the behavior of Home intermediate producers. Some differences nevertheless arise as the exporters set their prices in International currency but face the nominal marginal costs sticky in Home currency while the reverse holds for the importers. [10]

As in the case of wage-setting households, all the time t optimizing intermediate producers choose the same price, and hence we drop the index s. Next we denote by $P^Y_{t+k|t}$ the price valid at time $t+k$ that was optimized at time t last and updated since then; correspondingly we denote by $Y_{t+k|t}$ the output supplied at time $t+k$ by a producer who received the signal k periods ago last.

The producer optimizes her profit function over all future states of nature in which she consecutively fails to receive the re-optimization signal and must keep updating today's decided price,

$$\mathrm{E}_t \sum_{k=0}^{\infty} {\xi_Y}^k \, \iota_{t,t+k} \, Y_{t+k|t} \left[(1+\zeta) \, p^Y_{t+k|t} - \Theta^Y_t \right], \tag{35}$$

subject to the demand function for her own production and the price-indexation scheme converted to the relative price terms,

$$Y_{t+k|t} \leq y_{t+k|t} = (p^Y_{t+k|t}/P^Y_{t+k})^{-\epsilon} y_{t+k}, \tag{36}$$

$$\frac{p^Y_{t+k|t}}{P^Y_{t+k}} = \frac{p^Y_{t|t}}{P^Y_t} \cdot \frac{P^Y_{t+k-1}/P^Y_{t-1}}{P^Y_{t+k}/P^Y_t} = \frac{p^Y_{t|t}}{P^Y_t} \cdot \Pi^Y_t / \Pi^Y_{t+k}, \tag{37}$$

where the sector-wide nominal marginal cost, Θ^Y_t, has been defined earlier, and the the disount factor is based on the present shadow value of wealth, $\iota_{t,t+k} = \lambda_t / (\beta^k \lambda_{t+k})$. The optimal relative price first-order conditions for all sectors are listed in Appendix A.3.

The law of motions for the sector-wide price index or its inflation can be directly derived from the definition (34) taking into account the time- and state-independence of signal receivers' distribution in the population. Specifically for the gross rate of inflation,

$$\Pi^Y_t = \left[\xi_Y {\Pi^Y_{t-1}}^{1-\epsilon} + (1-\xi_Y) \left(\frac{p^Y_{t|t}}{P^Y_t} \, \Pi^Y_t \right)^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}. \tag{38}$$

Government

The government's fiscal policy ensures intertemporal balance through nominal lump-sum trasfers or taxes, τ_t. Income consists of seignorage on money while expoenditure

[10] But both of them maximize the Home currency profit.

consists of goods purchased, $P_t^G g_t$, and subsidies to eliminate the monopolictic distortions in the labor market and the intermediate, export, and import goods markets. Furthermore we assume that the government does not intervene in the foreign exchange market, and the exchange rate floats freely. These assumptions describe the following intertemporal budget constraint,

$$M_t = M_{t-1} + \tau_t + P_t^G g_t + \zeta \int_0^1 \Big[w_t(s) L_t(s) + p_t^N(s) N_t(s) + p_t^Y(s) Y_t(s) + S_t \tilde{p}_t^X(s) X_t(s) \Big] \mathrm{d}s \quad (39)$$

Monetary policy acts proactively to achieve a target specified in consumer inflation. We adopt the following inflation-forecast rule,

$$\log i_t = \rho_I \log i_{t-1} + (1-\rho_I) \left(\log \bar{\imath}_t + \psi \log \widehat{\Pi}_t \right) + e_t^I \quad (40)$$

in which policy reacts to an infinite discounted sum of today's and future deviations of consumer inflation, Π_t^C, from the target, Π_t^*,

$$\log \widehat{\Pi}_t = (1-\Delta) \sum_{k=0}^{\infty} \Delta^k \left(\log \Pi_{t+k}^C - \log \Pi_{t+k}^* \right). \quad (41)$$

The rule (40) is flexible in the sense that by changing the parameter $\Delta \in (0,1)$ we can smoothly adjust the average forecast horizon which is monitored by the policy-maker: the steady-state average horizon can be shown equal to $\Delta/(1-\Delta)$. Furthermore, the policy-maker has the option to engage in the interest rate smoothing whenever $\rho_I > 0$.

The policy neutral rate, $\bar{\imath}$, used as a basis in the rule, is defined as a nominal rate consistent with the steady-state real rate of interest (which is determined by α/β) if expecations were anchored to the target,

$$\log \bar{\imath}_t = \log(\alpha/\beta) + \log \Pi_{t+1}^*. \quad (42)$$

The target itself can vary over time in general, however it is assumed to converge ultimately to a pre-specified long-run rate of inflation denoted by Π ("ultimate price stability"); this is to allow for disinflation episodes.

Tewchnological Processes

The main technological process in the model that stimulates the economy's growth is the labor-augmenting progress a_t in (14). We assume for convenience that it follows a time-trend-stationary process,

$$a_t = \rho_A (a_{t-1} + \alpha) + (1-\rho_A) \alpha t + e_t^A. \quad (43)$$

where α is the steady-state real growth rate of the economy, and e_t^A is an i.i.d. productivity shock. Note that possible Home economy's underdevelopedness is then simply dealt with as an initial deviation $a_t - \alpha t$.

The other technological processes, including that in househols' capital accumumlation, i.e. $a_t^{\{K,N,X,C,J,G\}}$, are stationary first-order autoregressions with known autocorrelations; this guarantees that the relative prices and the investment-to-capital ratio are stable in steady state.[11] Moreover, for easy of computation of the steady state, the uncoditional expectations of the technological processes are set to 1. However, as claimed in Introduction, the latter set of technological processes is critical to address some of the convergence issues in an economy in transition, in particular those related to the relative prices including various measures of the real exchange rate.[12] We in fact assume large and persistent deviations of a_t's from their unconditional means along such transition.

5 Equilibrium and Aggregation of the Model

[To be included]

6 Calibration and Sample Simulations

In Figures A.6 to A.9 we report four types of permanent shocks that have some relevance in the recent Czech history.

[To be finished]

[11] This is, however, not true for some of our shock simulation exercises where we investigate the effects of a permanent change in these technological process, see Section 6.

[12] The potential of a fast export-specific technological progress in generating effects similar to the traditional Balassa-Samuelson ones from the tradable-nontradable structure is analyzed e.g. in Gregorio and Wolf (1994).

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A Some First-Order Conditions

A.1 Representative Consumption and Asset Holding

The first-order conditions necessary for maximization of (3) subject to (1) and (5) with respect to c_t, m_t, b_t, j_t, K_t, and u_t are respectively

$$\mathcal{U}_{1,t} = \lambda_t P_t^C, \tag{A.1}$$

$$\mathcal{U}_{3,t}/\mathcal{U}_{1,t} = 1 - 1/i_t, \tag{A.2}$$

$$1/i_t = \beta/\lambda_t \cdot \mathrm{E}_t \lambda_{t+1}, \tag{A.3}$$

$$1/\lambda_t \cdot \mathrm{E}_T \sum_{k=0}^{T} \beta^k \lambda_{t+k} P_{t+k}^J = (T+1)\, \mathcal{K}_{2,t+T}\, a_t^J\, \mu_t, \tag{A.4}$$

$$\mu_t = \beta/\lambda_t \cdot \mathrm{E}_t \left[P_{t+1}^K + \mu_{t+1} \mathcal{K}_{1,t+1}\, {u_{t+1}}^{1-v} \right], \tag{A.5}$$

where e.g. $\mathcal{U}_{k,t}$ is the derivative of $\mathcal{U}$ w.r.t. the k-th argument evaluated at time t, and λ_t and μ_t are the Lagrange multipliers associated with respectively the budget constraint and the capital accumulation equation.

A.2 Staggered Wage Setting

The first order condition necessary for maximization of (9) subject to (10) and (11) with respect to w_t^* and L_t^* is

$$\frac{w_{t|t}}{W_t} = \frac{\mathrm{E}_t \sum_{k=0}^{\infty} (\xi_W \beta)^k\, \ell_{t+k}\, \mathcal{V}_{1,t+k} \left(\frac{\Omega_t}{\Omega_{t+k}}\right)^{-\epsilon}}{\mathrm{E}_t \sum_{k=0}^{\infty} (\xi_W \beta)^k\, \ell_{t+k}\, \mathcal{U}_{1,t+k}\, \frac{W_{t+k}}{P_{t+k}^C} \left(\frac{\Omega_t}{\Omega_{t+k}}\right)^{1-\epsilon}} \tag{A.6}$$

A.3 Staggered Price Setting

The first-order condition necessary for maximization of (35) subject to (36) and (37) is

$$\frac{p_t^{Y*}}{P_t^Y} = \frac{\mathrm{E}_t \sum_{k=0}^{\infty} {\xi_Y}^k \rho_{t+k|t}^Y Y_{t+k} \frac{\Theta_{t+k}^Y}{P_{t+k}^Y} \left(\Pi_t^Y / \Pi_{t+k}^Y\right)^{-\epsilon}}{\mathrm{E}_t \sum_{k=0}^{\infty} {\xi_Y}^k \rho_{t+k|t}^Y Y_{t+k} \left(\Pi_t^Y / \Pi_{t+k}^Y\right)^{1-\epsilon}}, \tag{A.7}$$

and analogously for the import and export sectors

$$\frac{p_t^{N*}}{P_t^N} = \frac{\mathrm{E}_t \sum_{k=0}^{\infty} {\xi_N}^k \rho_{t+k|t}^N N_{t+k} \frac{\Theta_{t+k}^N}{P_{t+k}^N} \left(\Pi_t^N / \Pi_{t+k-1}^N\right)^{\epsilon}}{\mathrm{E}_t \sum_{k=0}^{\infty} {\xi_N}^k \rho_{t+k|t}^N N_{t+k} \left(\Pi_t^N / \Pi_{t+k-1}^N\right)^{1-\epsilon}}, \tag{A.8}$$

$$\frac{\widetilde{p}_t^{X*}}{\widetilde{P}_t^X} = \frac{\mathrm{E}_t \sum_{k=0}^{\infty} {\xi_X}^k \rho_{t+k|t}^X X_{t+k} \frac{\Theta_{t+k}}{\widetilde{P}_{t+k}^X S_{t+k}} (\widetilde{\Pi}_t^X / \widetilde{\Pi}_{t+k-1}^X)^{-\epsilon}}{\mathrm{E}_t \sum_{k=0}^{\infty} {\xi_X}^k \rho_{t+k|t}^X X_{t+k} (\widetilde{\Pi}_t^X / \widetilde{\Pi}_{t+k-1}^X)^{1-\epsilon}}. \tag{A.9}$$

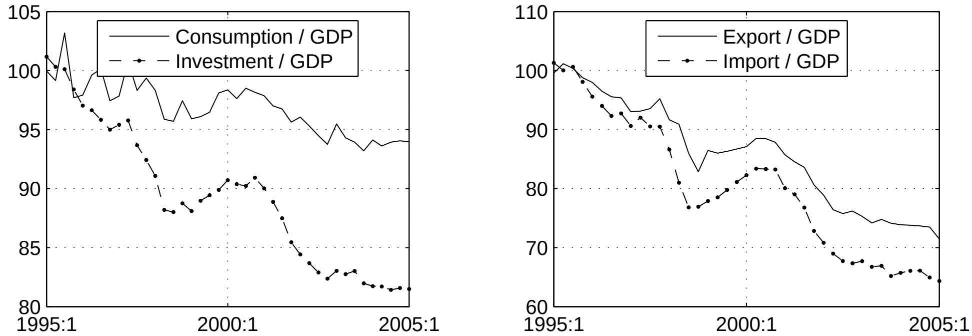

Fig. A.1. Shifts in relative prices (deflators of demand components).

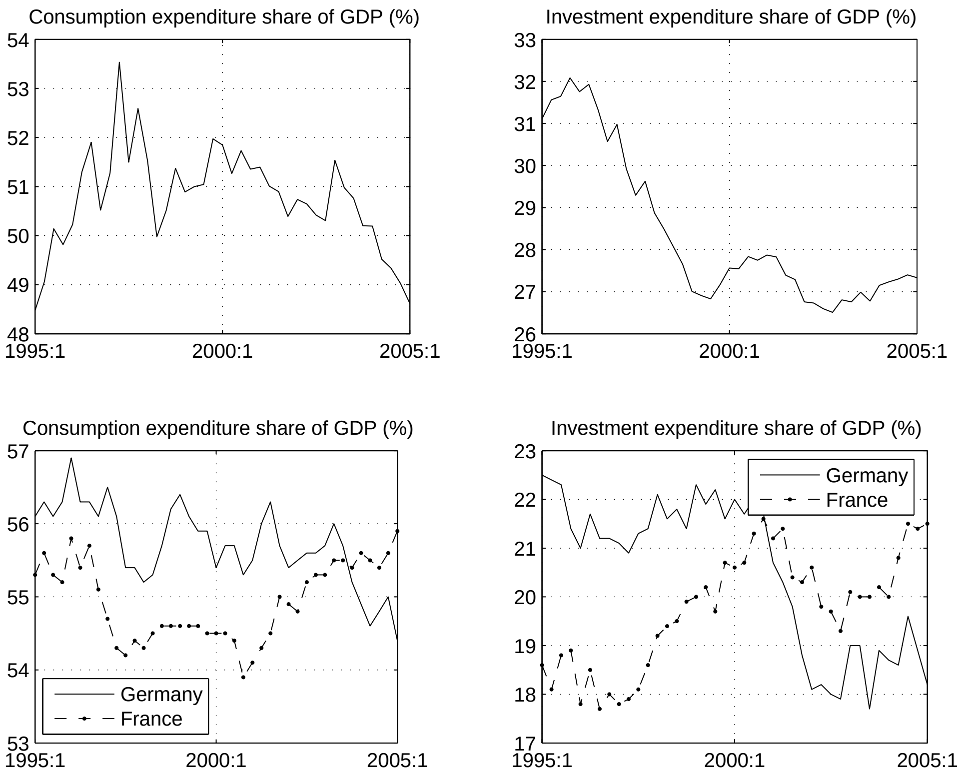

Fig. A.2. Consumption and investment expediture shares of GDP.

Fig. A.3. Net investment position to GDP ratio (%, annualized).

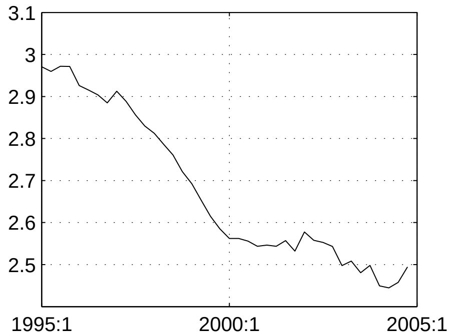

Fig. A.4. Employment in profit sector.

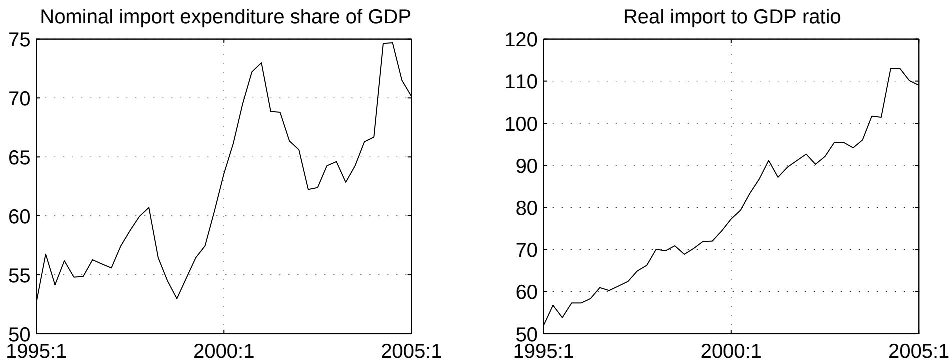

Fig. A.5. Imports and GDP.

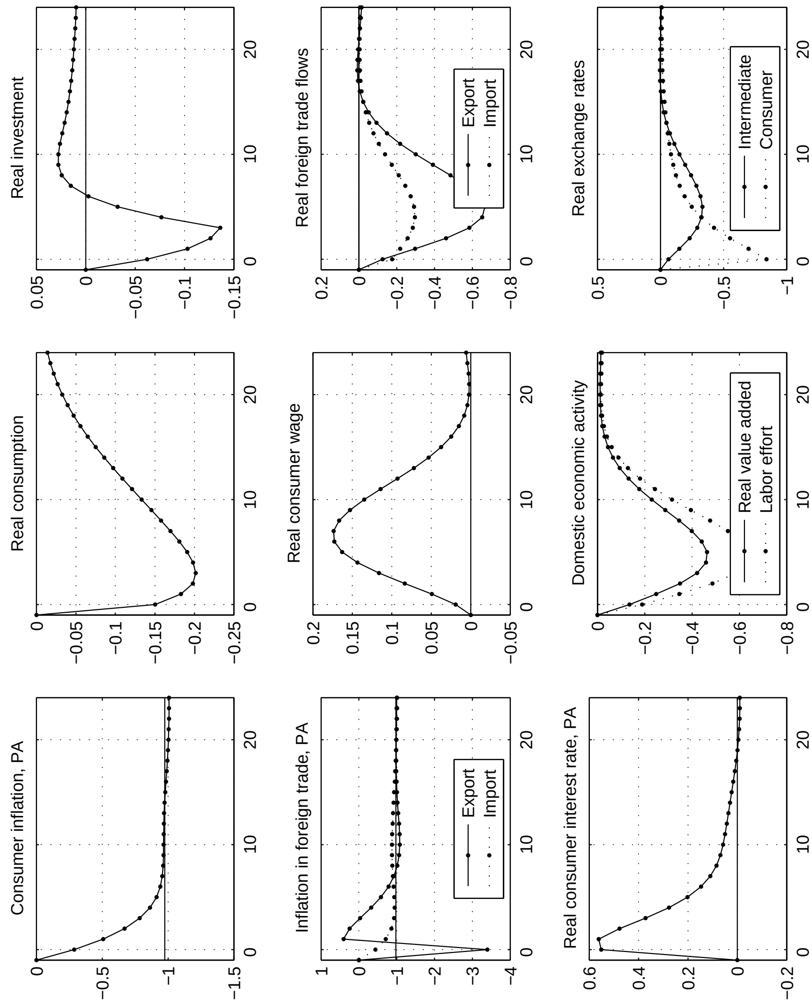

Fig. A.6. Unanticipated fully credible immediate disinflation.

Reported are pct deviations from the steady state prevailing prior to the shock. Time scale is in quarters, the shock period is 0. Interest rates and rates of growth are annualized.

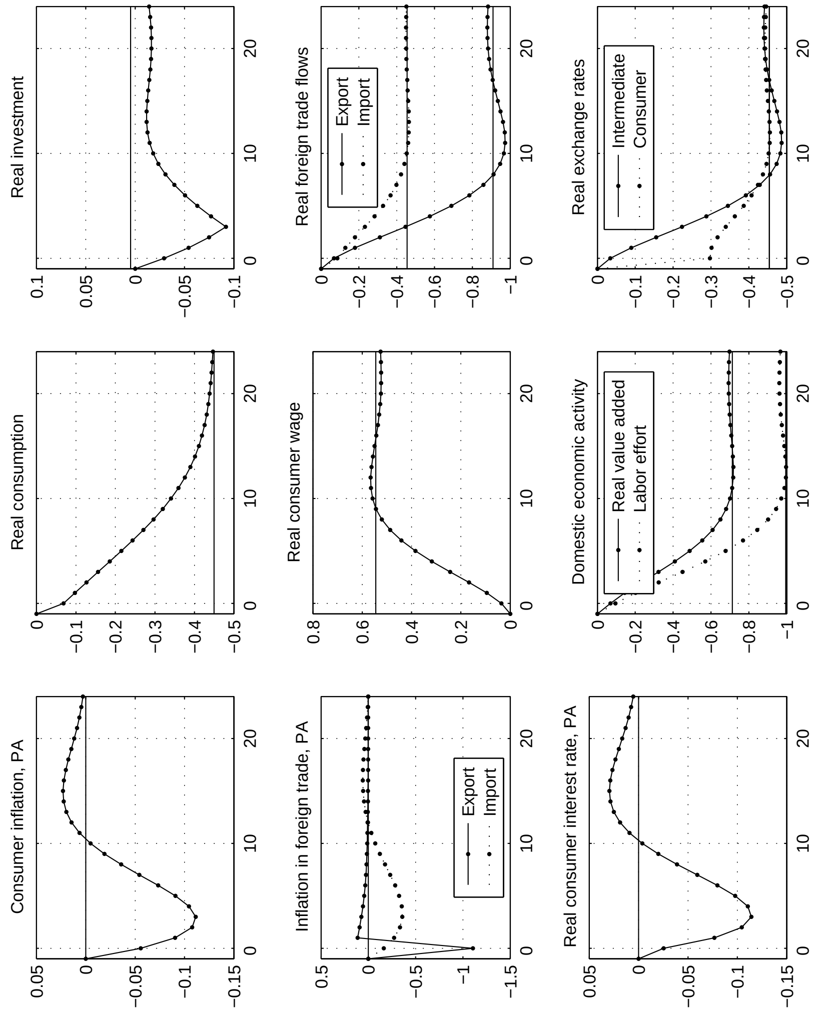

Fig. A.7. Labor participation shock.

Reported are pct deviations from the steady state prevailing prior to the shock. Time scale is in quarters, the shock period is 0. Interest rates and rates of growth are annualized.

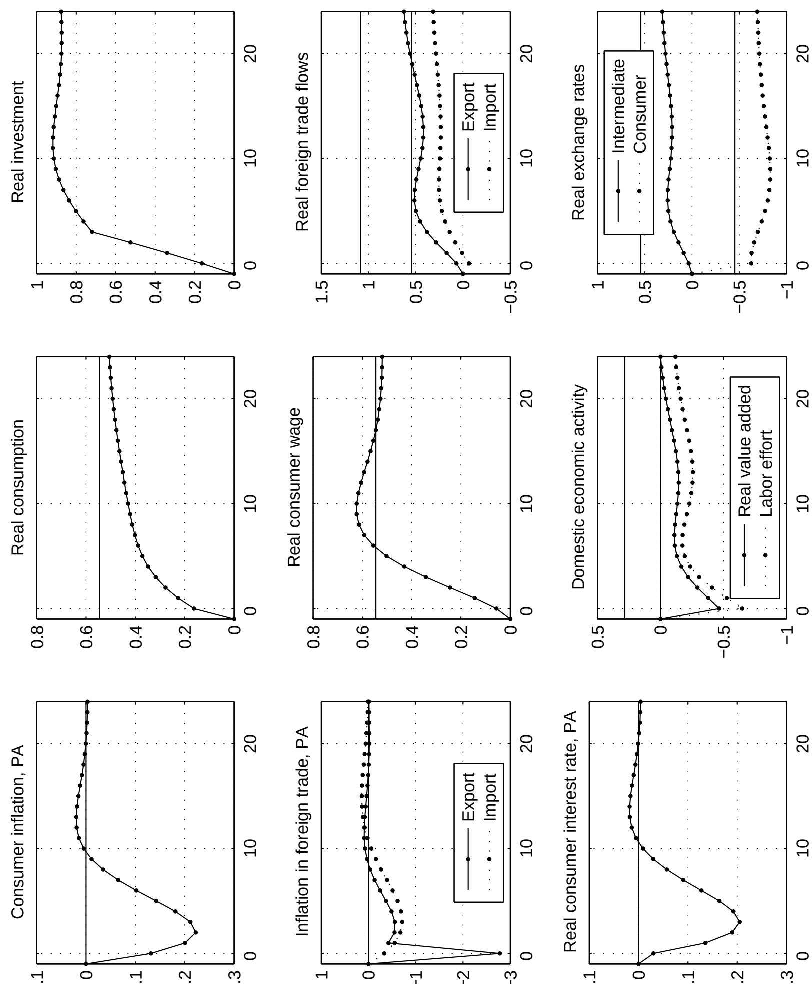

Fig. A.8. 'Permanent export-sector positive technological shock.

Reported are pct deviations from the steady state prevailing prior to the shock. Time scale is in quarters, the shock period is 0. Interest rates and rates of growth are annualized.

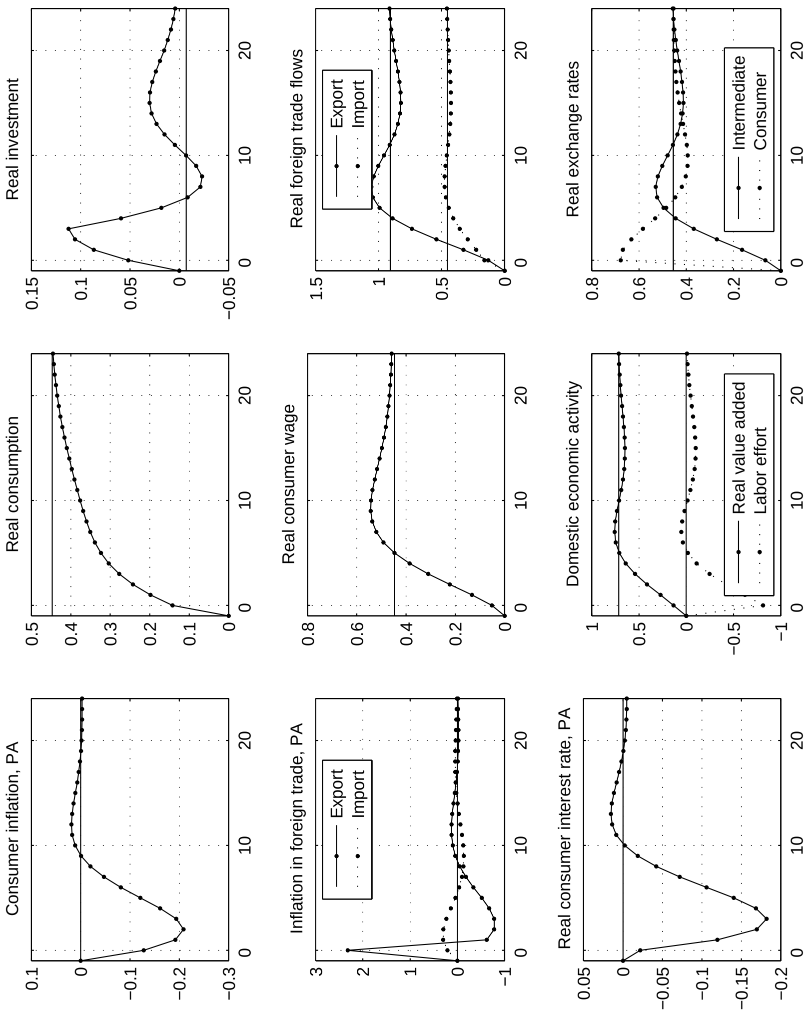

Fig. A.9. Permanent shift in Home labor-augmenting technological time trend.

Reported are pct deviations from the steady state prevailing prior to the shock. Time scale is in quarters, the shock period is 0. Interest rates and rates of growth are annualized.