A SMALL OPEN ECONOMY WITH THE BALASSA-SAMUELSON EFFECT

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A Small Open Economy with the Balassa-Samuelson Effect*

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Abstract

The Balassa-Samuelson (B-S) effect implies that highly productive countries have higher inflation and appreciating real exchange rates because of larger productivity growth differentials between tradable and nontradable sectors relative to advanced economies. The B-S effect might pose a threat to converging European countries, which would like to adopt the Euro because of the limits imposed on inflation and nominal exchange rate movements by the Maastricht criteria. The main goal of this paper is to judge whether the B-S effect is a relevant issue for the Czech Republic to comply with selected Maastricht criteria before adopting the Euro. For this purpose, a two-sector DSGE model of a small open economy is built and estimated using Bayesian techniques. The simulations from the model suggest that the B-S effect is not an issue for the Czech Republic when meeting the inflation and nominal exchange rate criteria. The costs of early adoption of the Euro are not large in terms of additional inflation pressures, which materialize mainly after the adoption of the single currency. Also, nominal exchange rate appreciation, driven by the B-S effect, does not breach the limit imposed by the ERM II mechanism.

Keywords: Balassa-Samuelson effect, DSGE, European Monetary Union, exchange rate regimes, Maastricht convergence criteria

JEL classification: E31, E52, F41

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Abstrakt

Důsledkem Balassa-Samuelsonova (B-S) efektu je, že vysoce produktivní země mají vyšší inflaci a zhodnocení reálných směnných kurzů kvůli větším rozdílům v růstu produktivity mezi obchodovatelnými a neobchodovatelnými sektory ve srovnání s vyspělými ekonomikami. B-S efekt může představovat hrozbu pro konvergující evropské země, které chtějí zavést euro, kvůli limitům stanoveným pro inflaci a nominální kurzové pohyby maastrichtskými kritérii. Hlavním cílem této práce je posoudit, zda B-S efekt je relevantním problémem pro Českou republiku v souvislosti s dodržováním vybraných maastrichtských kritérií před přijetím eura. Pro tento účel je vybudován dvousektorový DSGE model malé otevřené ekonomiky, který je odhadnut pomocí bayesovských technik. Simulace vycházející z tohoto modelu naznačují, že B-S efekt nepředstavuje pro Českou republiku problém při plnění inflačního kritéria a kritéria na nominální směnný kurz. Náklady na brzké přijetí eura nejsou velké z hlediska dodatečných inflačních tlaků, které se projeví především po přijetí jednotné měny. Také nominální apreciace směnného kurzu způsobená B-S efektem neporušuje limit stanovený mechanismem ERM II.

1 Introduction

The Balassa-Samuelson (B-S) effect originated more than a half century ago in the works by Balassa (1964) and Samuelson (1964), and is based on differential productivity growth in tradable and nontradable production sectors. The B-S effect implies that highly productive countries have higher inflation and appreciating real exchange rates because of larger productivity growth differentials between tradable and nontradable sectors relative to advanced economies. This is particularly important for new member countries of the European Union (EU), including the Czech Republic, in which a catch-up process with advanced European countries is still ongoing.

At some point, the Czech Republic is obliged to adopt the Euro as a single currency. Prior to adopting the Euro, the so-called the Maastricht convergence criteria have to be met, which include: the inflation rate criterion, the nominal interest rate criterion, the nominal exchange rate criterion and fiscal criteria.[1] If the presence of the B-S effect is relevant for a country, occurring through higher inflation pressures and appreciation of its currency, then some criteria might not be met. This concerns mainly the inflation, interest rate and exchange rate criteria. In other words, the ongoing convergence process, measured by excessive productivity growth with respect to the rest of EU, might restrain a country from complying with the Maastricht criteria.

The mainstream literature has predominately focused on the magnitude, causes and consequences of the B-S effect within non-optimizing frameworks[2]. There are some exceptions that build dynamic stochastic general equilibrium (DSGE) models for European accession countries, which do address the implications of the B-S effect on the ability of converging countries to satisfy the Maastricht criteria. For instance, Ravenna and Natalucci (2008) construct a two-sector DSGE model for the Czech Republic, and conclude that in the presence of the B-S effect there is no monetary policy that would allow for the fulfillment of both nominal exchange rate criterion and the inflation rate criterion. Masten (2008) builds a simpler two-sector DSGE model calibrated for the Czech Republic, and found that the B-S effect is not a threat to fulfilling the inflation rate criterion when monetary policy is committed to an inflation objective. The evidence seems to be mixed, at least for the Czech

[1] Specifically, the annual inflation rate must not exceed the average of the three countries in the Euro Area with the lowest inflation by more than 1.5 percentage points. The average long-term interest rate must not exceed the long-term interest rates in the three countries in the Euro Area with the lowest inflation by more than 2 percentage points. The country has to participate in the European Exchange Rate Mechanism (ERM II) for at least two years, which requires limited movements of the exchange rate against the Euro (+/-15%), without devaluating its currency. Fiscal criteria restrict general government debt and deficit below 60% and 3% of GDP respectively.

[2] See for example Mihaljek and Klau (2004), Égert, Halpern, and MacDonald (2006) and related references therein.

Republic, and therefore this paper contributes to this debate, judging the ability to meet the Maastricht criteria with Euro adoption. Another value added of this paper is that it simulates a transition from a flexible to a fixed exchange rate regime on the background of the B-S effect.

Furthermore, the following questions are tackled in this paper: What is an appropriate time for a converging country to enter the Euro Area (EA)? Should it wait until the B-S effect fades out over time and join the EA afterwards? Is early adoption of the Euro wrong? If a country decides to enter the EA early, what are the inflation costs due to the ongoing transition process? What is the extent of exchange rate appreciation that is induced by the productivity growth differential between the Czech Republic and the EA?

In order to answer these questions, I build a two-sector DSGE model of a small open economy, which is estimated for the Czech Republic. The model draws mainly from Ravenna and Natalucci (2008), but in order to be more realistic it is extended by several dimensions, including the following: i) the model is estimated on Czech data using Bayesian techniques, ii) wages are set in staggered contracts, iii) habits in consumption are allowed, iv) productivity growth can be permanent, and v) the inflation target can be non-zero.

The simulations from the model show that the B-S effect is not a relevant issue for the Czech Republic in meeting the Maastricht convergence criteria before adopting the Euro. The costs of early adoption of the Euro are not so large in terms of additional inflation pressures, which materialize after adoption of the single currency. To be more specific, early transition is associated with initially higher inflation, rising by some 0.4 percentage points in the first year after adoption of the Euro. Also, nominal exchange rate appreciation, driven by the B-S effect, does not breach the limit imposed by the ERM II mechanism.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature concerning the B-S effect, Section 3 presents the model, used data, its calibration and estimation, Section 4 provides the results of the simulations from the model and their robustness. The last section summarizes findings and outlines possible directions for future research.

2 Relevant Literature with the B-S Effect

There is a growing number of papers that empirically investigate the extent of the B-S effect for Central and Eastern Europe (CEE) countries. Older studies based on data from 1990s estimated sizeable contributions of the B-S effect on inflation rates for CEE countries, whereas recent literature found the impact of the B-S effect on inflation differentials between the new EU member countries and the EA in the range of 0 to 2 percentage points annually (Égert 2011; Konopczak 2013; Mihaljek and Klau 2008; Miletic 2012).[3] A couple of reasons might explain why the impact of the B-S effect on inflation differential is found to be relatively small. The large share of food items and the low share of nontradables in the consumer price index (CPI) may attenuate the extent of the B-S effect (Égert, Drine, Lommatzsch, and Rault 2003). Further, a large proportion of administrated and regulated prices in CPI can account for an important share of excess inflation (Cihak and Holub 2003). The small extent of the B-S effect can be also attributable to the fact that purchasing power parity (PPP) might not hold for tradable goods, since many prices of tradable goods involve some nontradable components, such as the rents, distribution services, advertising, etc.

The discussion in the literature focuses somewhat less on the implications of the B-S effect in the DSGE-type models. Two relevant contributions were mentioned in the introduction (Ravenna and Natalucci 2008; Masten 2008), which address the consequences of the B-S effect on the ability of the Czech Republic to meet the Maastricht criteria. Masten (2008) criticizes Ravenna and Natalucci (2008) for an inappropriate simulation of the B-S effect, where a stationary productivity process in the tradable sector is set so as to deliver the desired increasing productivity path, and argues that one should simulate the B-S effect with permanent nonstationary productivity shocks. He proceeds in this manner in his paper; nonetheless, the main concern about the model in Masten (2008) is the assumption of exogenous externality in production costs. This feature turned out to be crucial to mimic theoretical predictions of the B-S effect, but it lacks any microeconomic foundations. A closer view of the models used in these two papers, also compared against the one developed in this paper, is provided in Table 3 in the Appendix.

Further, Devereux (2003) develops a DSGE of a small open economy to examine the adjustment process following EU accession in the presence of capital inflow and productivity shocks. He identifies the following transition problems after adopting the Euro: large foreign borrowing, high wage inflation, excessive growth on the stock market and in the nontradable sector. However, these inefficiencies can be overcome by the application of alternative monetary policies; particularly, the policy of flexible inflation targeting with weight on exchange rate stability seems the best. Laxton and Pesenti (2003) build a DSGE model of large complexity to assess the effectiveness of the alternative Taylor rules in stabilizing variability in output and inflation. Their model is calibrated for the Czech Republic, and the authors found that inflation-forecast-based rules perform better than conventional Taylor rules.

[3]One explanation can stem from the fact that the productivity differential has stalled during the more recent period. For instance, see Figure 8 in the Appendix for the productivity differential between the Czech Republic and the Euro Area.

Lipinska (2008) in her DSGE model, calibrated for the Czech Republic, analyzes what convergence criteria are not satisfied when monetary policy is conducted optimally. The author found that optimal monetary policy violates the inflation rate criterion and the nominal interest rate criterion. Moreover, she compares the welfare costs when optimal monetary policy is unconstrained with the case when monetary policy is constrained by the Maastricht convergence criteria. The results indicate that constrained monetary policy accounts for additional welfare costs to the amount of 30% of the deadweight loss associated with the optimal unconstrained monetary policy.

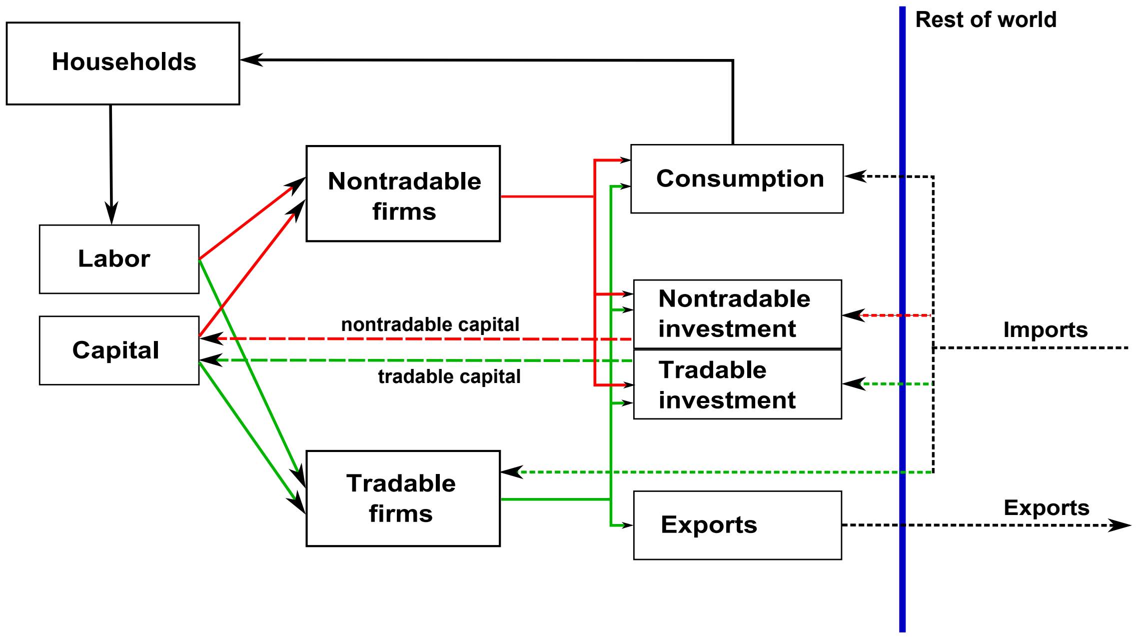
Ghironi and Melitz (2005) provide an endogenous microfounded explanation for the B-S effect in response to productivity shocks. In their two-country DSGE model the firms differ in productivity, and face sunk entry cost and export costs. This suggests that only sufficiently productive firms enter the foreign market, and thus some of the goods will remain nontraded. This is the feature of endogenous nontradedness, which evolves over time in relation to productivity growth. The outcome of the model is consistent with the B-S effect, that is, more productive countries are associated with higher average prices and with appreciating real exchange rates.

Sadeq (2008) in his DSGE model compared estimated structural shocks and impulse responses to permanent tradable productivity shocks across five accession countries. In the case of the Czech Republic, he identified a risk premium shock to be volatile, but impulse responses to tradable shocks were less volatile compared to other countries in the sample. Rabanal (2009) estimated a DSGE model of a currency union to explain the sources of inflation differentials between the EA and Spain, and concluded that the B–S effect does not seem to be an important driver of the inflation differential.

3 Structural DSGE Model

The model is based on Ravenna and Natalucci (2008), enriched with several extensions. The small open economy is populated by monopolistically competitive households, which provides differentiated labor services to an employment agency. The employment agency distributes labor services to the firms in the nontradable and tradable sectors, according to their demand. Labor is perfectly mobile across two sectors, and the wages are set in staggered contracts. The firms in the nontradable sector are monopolistically competitive, and adjust their prices in the manner of Calvo (1983), whereas the firms in the tradable sector are perfectly competitive. Renting capital, the firms face adjustment costs. The investment goods are composed from tradable, nontradable and foreign inputs. Tradable firms are allowed to use foreign inputs in their production. Notice that foreign goods im-

Figure 1: The Scheme of the Model



plicitly enter nontradable production as well through capital accumulation. The labor-augmenting productivity for tradable and nontradable firms can differ, which enables the simulation of the B-S effect.

The value added of this model compared to Ravenna and Natalucci (2008) is that it includes several more realistic features: i) the model is estimated on Czech data using Bayesian techniques, ii) wages are set in staggered contracts, iii) habits in consumption are allowed, iv) productivity growth can be permanent (balanced growth path model), and v) the inflation target can be non-zero. The features of the model are shown in Figure 1, where the green parts depict the flows in the tradable sector, and the red parts represent the flows in the nontradable sector.

3.1 Households

The economy is populated by a continuum of monopolistically competitive households, indexed by $i \in [0,1]$. Each household supplies a differentiated labor service to the firms, and maximizes its lifetime utility function given by:

$$U(i) = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ D_t \log \left[C_t(i) - \chi_c C_{t-1}(i) \right] - l \frac{[L_t^s(i)]^{1+\eta_L}}{1+\eta_L} \right\}, \tag{1}$$

where β is a discount factor, χ_c is a consumption habit parameter, D_t is an exogenous preference shock, η_L is the inverse of the labor supply elasticity, l is the parameter measuring relative disutility of labor supply, $C_t(i)$ and $L_t^s(i)$ are consumption and labor supply of household i. Assuming perfect substitution between hours worked in nontradable and tradable sectors, aggregate labor supply equals:

$$L_t^s = L_t^N + L_t^H \tag{2}$$

Total consumption is a constant elasticity of substitution (CES) composite index of nontradable and tradable consumption goods:

$$C_t = \left[(\gamma_n)^{\frac{1}{\rho_N}} (C_{N,t})^{\frac{\rho_N - 1}{\rho_N}} + (1-\gamma_n)^{\frac{1}{\rho_N}} (C_{T,t})^{\frac{\rho_N - 1}{\rho_N}} \right]^{\frac{\rho_N}{\rho_N - 1}}, \tag{3}$$

where $0 \leq \gamma_n \leq 1$ is the share of nontradables in consumption, and $\rho_N > 0$ is the elasticity of substitution between nontradable and tradable consumption goods. The tradable consumption good is a CES composite of home and foreign tradable goods:

$$C_{T,t} = \left[(\gamma_h)^{\frac{1}{\rho_H}} (C_{H,t})^{\frac{\rho_H - 1}{\rho_H}} + (1-\gamma_h)^{\frac{1}{\rho_H}} (C_{F,t})^{\frac{\rho_H - 1}{\rho_H}} \right]^{\frac{\rho_H}{\rho_H - 1}}, \tag{4}$$

where $0 \leq \gamma_h \leq 1$ is the share of domestic tradable goods in tradable consumption, and $\rho_H > 0$ is the elasticity of substitution between domestic and foreign consumption goods.[4] The nontradable consumption good is an aggregate over a continuum of differentiated goods:

$$C_{N,t} = \left[\int_0^1 (C_{N,t})^{\frac{\epsilon_N - 1}{\epsilon_N}} (z) dz \right]^{\frac{\epsilon_N}{\epsilon_N - 1}} \tag{5}$$

where the elasticity between nontradable good varieties $\epsilon_N > 1$ and $z \in [0, 1]$.

Based on the above preferences, it is possible to derive consumption-based price indices:

$$P_t = \left[\gamma_n (P_{N,t})^{1-\rho_N} + (1-\gamma_n) (P_{H,t})^{1-\rho_N} \right]^{\frac{1}{1-\rho_N}} \tag{6}$$

$$P_{N,t} = \left[\int_0^1 (P_{N,t})^{1-\epsilon_N} (z) dz \right]^{\frac{1}{1-\epsilon_N}} \tag{7}$$

where P_t, and $P_{N,t}$ are the consumer price index (CPI), and the price index for nontradable consumption goods. It is assumed that the price of tradable goods is determined abroad, and the law of one price holds for tradable goods, and the exchange rate pass-through is complete.[5] So, the price for tradable goods is given

[4] The posterior estimate of this elasticity turned out to be flat (see Figure 2), which suggests that tradable aggregation may be simplified, for instance using Cobb-Douglas specification.

[5] Ravenna and Natalucci (2008) also tried the specification with local currency pricing for foreign-produced goods. Its impact on the dynamics of aggregate variables following the B-S shock was limited, which may be explained by the low share of foreign goods in tradable baskets.

as:

$$P_{H,t} = ER_t P_t^*, \tag{8}$$

where P_t^* is the exogenous foreign-currency price of tradable good, and ER_t is the nominal exchange rate, which is expressed as the value of foreign currency in units of domestic currency. Investments in the nontradable and domestic tradable sector are defined similarly as consumption aggregates:

$$I_t^J = \left[(\gamma_n)^{\frac{1}{\rho_N}} \left(I_{N,t}^J \right)^{\frac{\rho_N - 1}{\rho_N}} + (1-\gamma_n)^{\frac{1}{\rho_N}} \left(I_{T,t}^J \right)^{\frac{\rho_N - 1}{\rho_N}} \right]^{\frac{\rho_N}{\rho_N - 1}} \tag{9}$$

$$I_{T,t}^J = \left[(\gamma_h)^{\frac{1}{\rho_H}} \left(I_{H,t}^J \right)^{\frac{\rho_H - 1}{\rho_H}} + (1-\gamma_h)^{\frac{1}{\rho_H}} \left(I_{F,t}^J \right)^{\frac{\rho_H - 1}{\rho_H}} \right]^{\frac{\rho_H}{\rho_H - 1}} \tag{10}$$

$$I_{N,t}^J = \left[\int_0^1 (I_{N,t}^J)^{\frac{\epsilon_N}{\epsilon_N - 1}}(z) dz \right]^{\frac{\epsilon_N}{\epsilon_N - 1}}, \ J = N, H \tag{11}$$

The superscript J refers to the nontradable and tradable sector. By specification, investment price indices coincide with consumption price indices counterparts.

The households hold physical capital, and rent it to the firms. Capital is sector-specific, e.g. it is assumed to be immobile between the tradable and nontradable sectors. The capital in both sectors depreciates at a common constant rate $\delta > 0$. To avoid possible excessive investment volatility, capital is subject to convex adjustment costs. Specifically, the law of accumulation of the capital stocks follows:

$$K_t^J = \Phi \left(\frac{I_t^J}{K_{t-1}^J} \right) K_{t-1}^J + (1-\delta) K_{t-1}^J, \ J = N, H \tag{12}$$

where I_t^J denotes gross investment, and $\Phi(.)$ is an increasing and concave function, which satisfies: $\Phi(\frac{I}{K}A) = \frac{I}{K}A$ and $\Phi'(\frac{I}{K}A) = 1$, where $\frac{I}{K}$ is a steady-state investment-capital ratio and A is a steady-state growth rate of technology. The following functional form for adjustment cost is chosen:

$$\Phi \left(\frac{I_t^J}{K_{t-1}^J} \right) = \phi_0 + \phi_1 \left(\frac{I_t^J}{K_{t-1}^J} \right)^{\phi_2}, \tag{13}$$

where coefficients ϕ_0, ϕ_1, ϕ_2 are calibrated so as to match desired functional properties.

Nevertheless, this paper could be extended by relaxing the assumption of perfect competition in the tradable sector, which might be responsible for the relatively benign results of this paper.

Households face the following budget constraint:

$$P_t C_t + B_t + ER_t B_t^* + P_t \left(I_t^N + I_t^H \right) = W_t \left(L_t^H + L_t^N \right) + \\ + R_{t-1} B_{t-1} + R_{t-1}^* ER_t B_{t-1}^* + P_{N,t} R_t^N K_{t-1}^N + P_{H,t} R_t^H K_{t-1}^H + \Pi_t \qquad (14)$$

where W_t denotes the nominal wage common in both sectors; B_t, B_t^* holdings of bounds denominated in domestic and foreign currency, R_t, R_t^* domestic and foreign interest rate paid on bonds; R_t^N, R_t^H the real return to capital in the tradable and nontradable sector, and Π_t nominal profits from monopolistically competitive firms. The right-hand side of (14) represents households' wealth, that is, income received from supplying labor and renting capital to firms, from interest on bonds, and from firms' profits in the monopolistically competitive nontradable sector. The left-hand side of (14) represents the usage of wealth, that is, purchases of consumption and investment goods, or savings in bonds.

3.2 Firms

Nontradable sector. There is a continuum of nontradable goods firms $z \in [0,1]$, which combine labor $L_t^N(z)$ and capital $K_{t-1}^N(z)$ inputs into a single variety of nontradable good according to Cobb-Douglas production technology:

$$Y_{N,t}(z) = \left[A_t^N L_t^N(z) \right]^{1-\alpha_n} \left[K_{t-1}^N(z) \right]^{\alpha_n}, \qquad (15)$$

where A_t^N is a labor-augmenting technology process in the nontradable sector, and labor input is defined as $L_t^N(z) = (\int_0^1 [L_t^N(z,i)]^{\frac{\epsilon_W - 1}{\epsilon_W}} di)^{\frac{\epsilon_W}{\epsilon_W - 1}}$, where ϵ_W is the elasticity of substitution for labor services between individual households. Due to common production technology, sector-wide nontradable production equals:

$$\int_0^1 Y_{N,t}(z) dz = \left(A_t^N L_t^N \right)^{1-\alpha_n} \left(K_{t-1}^N \right)^{\alpha_n} \qquad (16)$$

Nontradable firms minimize the total costs of production $P_{N,t} R_t^N K_{t-1}^N(z) + W_t L_t^N(z) - \tau_N P_{N,t} Y_t^N(z)$, given their production function in (15). According to Erceg, Henderson, and Levin (2000) nontradable production is subsidized at a fixed rate τ_N to ensure that the equilibrium would be Pareto optimal if prices were flexible. Cost minimization yields the following factor demands:

$$\begin{aligned} R_t^N &= \alpha_n \frac{Y_t^N}{K_{t-1}^N} \left(rmcn_t + \tau_N \right) \\ \frac{W_t}{P_{N,t}} &= (1-\alpha_n) \frac{Y_t^N}{L_t^N} \left(rmcn_t + \tau_N \right), \end{aligned} \qquad (17)$$

where the firm's index z is omitted because of symmetry, and $rmcn_t$ denotes real marginal costs in the nontradable sector. The prices of intermediate goods are sticky *à la* Calvo (1983). In each period, firm z has the opportunity to optimally adjust prices with probability $1 - \xi_N$. The remaining firms, which are not allowed to optimally adjust their prices in a given period, automatically index prices using the last-known nontradable sector-wide inflation rate $\Pi_{N,t}$ (e.g. $P_{N,t}(z) = P_{N,t-1}(z)\Pi_{N,t-1}$). This pricing implies the following Phillips curve:

$$\log \frac{\Pi_{N,t}}{\Pi_{N,t-1}} = \beta \log \frac{\Pi_{N,t+1}}{\Pi_{N,t}} + \frac{(1-\xi_N)(1-\beta\xi_N)}{\xi_N} \log(rmcn_t \Theta_N) + \varepsilon_{N,t}, \tag{18}$$

where $\Theta_N = \frac{\epsilon_N}{\epsilon_N - 1}$ is the price markup and $\varepsilon_{N,t}$ is the cost-push shock.

Tradable sector. Perfect competition is assumed in the tradable sector. Firms in the tradable sector combine an imported intermediate good ($X_{M,t}$) and domestic value added goods ($V_{H,t}$) with the following CES production function:

$$Y_{H,t} = \left[(\gamma_v)^{\frac{1}{\rho_V}} (V_{H,t})^{\frac{\rho_V - 1}{\rho_V}} + (1-\gamma_v)^{\frac{1}{\rho_V}} (X_{M,t})^{\frac{\rho_V - 1}{\rho_V}} \right]^{\frac{\rho_V}{\rho_V - 1}}, \tag{19}$$

where $0 \leq \gamma_v \leq 1$ is the share of domestic tradable goods in tradable output, and $\rho_V > 0$ is the elasticity of substitution between imported intermediate goods and domestic value added goods. Domestic value added goods are produced with labor and tradable capital:

$$V_{H,t} = \left[A_t^H L_t^H \right]^{1-\alpha_h} \left[K_{t-1}^H \right]^{\alpha_h}, \tag{20}$$

where A_t^H is a labor-augmenting technology process in the tradable sector.

Productivity. Labor-augmenting technology processes are given by:

$$\frac{A_t^J}{A_{t-1}^J} = e^{\mu_{J,t}} \tag{21}$$

$$\mu_{J,t} = (1-\rho_{aJ}) \log A + \rho_{aJ} \mu_{J,t-1} + \varepsilon_{aJ,t}, \; J = N, H \tag{22}$$

where $\varepsilon_{aJ,t} \sim N(0, \sigma_{aJ}^2)$, $0 \leq \rho_{aJ} < 1$, $\mu_{J,t}$ is the growth rate of technology, which follows an AR(1) process, and $A > 0$ is the steady state growth rate of technology. This specification is convenient since it allows for the simulation of permanent productivity increases, e.g. a productivity shock at time t propagates in the level of productivity in future periods. Note that this kind of productivity specification with permanent growth introduces nonstationarity into the model, and in order to compute the steady state of the model it is necessary to stationarize growing variables.

3.3 Wage Contracts

The households supply their labor services to an employment agency, which costlessly bundles labor services into the CES aggregate. Wages are set by the employment agency in the Calvo manner, so each period the employment agency is able to renegotiate nominal wages for its workers with probability $1 - \xi_W$. Nominal wages for the remaining workers, for which the employment agency did not have the chance to renegotiate wages, are automatically indexed to the last-known sector-wide wage inflation. Having determined wages, the employment agency distributes workers to the firms in both sectors according to their demand. At the end, the employment agency collects the wage income, and pools it equally among all households. Therefore, the wage is common for all households.

Formally, when renegotiating wages, the employment agency chooses the new nominal wage $W_t^*(i)$ for workers of type i to maximize the following objective function:

$$\max_{W_t^*(i)} E_t \sum_{s=0}^{\infty} (\beta\xi_W)^{t+s} \left\{ \lambda_{t+s}^c(i) W_t^*(i) \frac{W_{t+s-1}}{W_{t-1}} L_{t+s}(i) - l \frac{(L_{t+s}(i))^{1+\eta_L}}{1+\eta_L} \right\}, \tag{23}$$

subject to the labor demand condition:

$$L_t(i) = \left[\frac{W_t(i)}{W_t} \right]^{-\epsilon_W} L_t, \tag{24}$$

where $\lambda_{t+s}^c(i)$ is the shadow price of consumption for labor type i, and $W_t = (\int_0^1 [W_t(i)]^{1-\epsilon_W} di)^{\frac{1}{1-\epsilon_W}}$ is the aggregate wage index. The first order condition gives the following expression:

$$E_t \sum_{s=0}^{\infty} (\beta\xi_W)^{t+s} \frac{L_{t+s}(i)^{1+\eta_L}}{W_t^*(i)} \left[\frac{W_t^*(i)}{MRS_{t+s}(i)} \frac{W_{t+s-1}}{W_{t-1}} - \Theta_W \right] = 0, \tag{25}$$

where $\Theta_W = \frac{\epsilon_W}{\epsilon_W - 1}$ is the wage markup, and $MRS_t(i)$ is the marginal rate of substitution between labor and consumption for labor type i. Log-linearizing this condition, and using the definition for the aggregate wage index W_t above, one can obtain the following wage Phillips curve:

$$\log \frac{\Pi_{W,t}}{\Pi_{W,t-1}} = \beta \log \frac{\Pi_{W,t+1}}{\Pi_{W,t}} + \frac{(1-\xi_W)(1-\beta\xi_W)}{\xi_W} \log (rmcw_t \Theta_W) + \varepsilon_{W,t}, \tag{26}$$

where $rmcw_t$ is the real marginal cost for wages and $\varepsilon_{W,t}$ is the wage cost-push shock. Wage inflation rises with real marginal cost for wages and expected higher wage inflation in the next period.

3.4 Foreign Sector

The price of exported goods and imported goods, expressed in the domestic currency, is equal to the tradable price. Thus, in this model the terms of trade are unitary by assumption. The so-called internal real exchange rate is given by:

$$Q_t^c = \frac{P_{H,t}}{P_{N,t}} \tag{27}$$

The CPI-based real exchange rate is calculated as:

$$RER_t = \frac{ER_t}{P_t} \tag{28}$$

Furthermore, as in Schmitt-Grohe and Uribe (2001), households can borrow from abroad at the nominal interest rate which is given by the exogenous world interest rate R_t^w multiplied by a risk premium, which increases in the real value of foreign debt, expressed in the domestic currency:

$$R_t^* = R_t^w \exp\left(-\phi_b \frac{B_t^*}{P_{H,t}}\right) \tag{29}$$

where $\phi_b > 0$ is the feedback parameter to foreign debt. This condition ensures the stationarity of the small open economy model.

The model features a version of the uncovered interest rate parity (UIP) condition as follows:

$$R_t = \frac{E_t\left(ER_{t+1}\right)}{ER_t} R_t^* * ers_t * \exp(ns_t^{ers}) \tag{30}$$

where ers_t is a UIP shock with persistence $\rho_e \in [0,1)$, and η_t^{ers} is a UIP news shock, defined in the following manner:

$$\begin{aligned} ns_t^{ers} &= ns_{1,t-1}^{ers} \\ ns_{1,t}^{ers} &= ns_{2,t-1}^{ers} \\ &\cdots \\ ns_{T-1,t}^{ers} &= ns_{T,t-1}^{ers} \\ ns_{T,t}^{ers} &= \eta_t^{ers}, \end{aligned} \tag{31}$$

where η_t^{ers} is a normally distributed shock, and T denotes the length of announcement period.

The trade balance (net exports) equals the value of exports minus the value of imports:

$$NX_t = P_{H,t}\left[X_t - \left(C_{F,t} + X_{M,t} + I_{F,t}^H + I_{F,t}^N\right)\right], \tag{32}$$

where X_t are exports. In equilibrium trade is balanced.[6] The net foreign debt law of motion is given by the following relationship:

$$B_t^* = \frac{ER_t}{ER_{t-1}} B_{t-1}^* R_{t-1}^* + NX_t \tag{33}$$

Modeling a small open economy, foreign variables – specifically foreign inflation, and the foreign gross nominal interest rate – are exogenously given:

$$\begin{aligned} \frac{\Pi_t^*}{\Pi} &= \left(\frac{\Pi_{t-1}^*}{\Pi}\right)^{\rho_{pi*}} \exp(\varepsilon_t^{pi*}) \\ \frac{R_t^w}{R} &= \left(\frac{R_{t-1}^w}{R}\right)^{\rho_{rw}} \exp(\varepsilon_t^{rw}) \end{aligned} \tag{34}$$

where $\Pi_t^* = P_t^*/P_{t-1}^*$, the steady states for foreign inflation and world nominal interest rates equal the steady states of their domestic counterparts, the ρ's from $[0,1)$ measure the persistences of the exogenous processes, and ε's are normally distributed shocks.

3.5 Monetary Policy

The central bank operates under a regime of inflation targeting and sets the nominal gross interest rate according to the following Taylor-type rule:

$$R_t = (R_{t-1})^{\chi} \left[R \left(\frac{\Pi_t}{\Pi}\right)^{\phi_p} \right]^{1-\chi} \exp\left(mps_t + ns_t^{mps}\right) \tag{35}$$

where R is the steady state nominal gross interest rate, $\phi_p \geq 0$ is the feedback coefficient to CPI inflation, Π is the central bank's inflation target, Π_t is the CPI inflation rate, $0 \leq \chi < 1$ is the interest rate smoothing parameter, mps_t is exogenous monetary policy shock, and ns_t^{mps} is monetary policy news shock, defined similarly to the UIP news shock in the array of equations (31).

3.6 Market Clearing and Aggregation

Nontradable and tradable sector resource constraints are as follows:

$$Y_{N,t} = C_{N,t} + I_{N,t}^N + I_{N,t}^H \tag{36}$$

$$Y_{H,t} = C_{H,t} + I_{H,t}^N + I_{H,t}^H + X_t \tag{37}$$

[6] This is an abstraction because the trade and current account imbalance could be large during the productivity catch-up with advanced economies. Nonetheless, impulse responses show that the B-S effect in this model is accompanied by large capital inflows under both exchange rate regimes (see Figure 5).

Aggregate output equals the value of nontradable and tradable output deflated by the CPI price:

$$Y_t = \frac{P_{N,t}}{P_t} Y_{N,t} + \frac{P_{H,t}}{P_t} Y_{H,t} \tag{38}$$

3.7 Calibration

The parameters of the model were either calibrated or estimated. In this section the parameters which were calibrated are described. For comparison purposes, our calibration follows mainly Ravenna and Natalucci (2008). A complete list of calibrated parameters can be found in Table 1 in the Appendix.

The discount factor is set to conventional value $\beta = 0.99$, which corresponds to a steady state real interest rate of 4%. The parameter of disutility of providing labor supply l is set roughly so that steady state labor supply $L^s = \frac{1}{3}$. The share of nontradables in consumption and investment baskets $\gamma_n = 0.6$, and the share of domestic tradable goods in the tradable consumption and investment good is $\gamma_h = 0.8$. The elasticity of substitution between nontradable varieties equals $\epsilon_N = 11$. The production in the tradable sector is more capital-intensive compared to the nontradable sector, specifically $\alpha_h = \frac{2}{3}$ and $\alpha_n = \frac{1}{3}$. The share of domestic value added in tradable production is $\gamma_v = 0.5$. The capital depreciates at a quarterly rate of $\delta = 0.025$. The steady state growth rate of technology A is set so that the yearly growth rate of technology equals 4%.

3.8 Data and Estimation

The model is estimated on a total of 14 variables for the period from 1998 to 2013 at quarterly frequency. Specifically, the data set covers the GDP expenditure components (consumption, investment, imports), including both real variables and their respective deflators, domestic variables (nominal wages, 3-month PRIBOR rate, nominal exchange rate CZK/EUR), and foreign variables (3-month EURIBOR rate, PPI for EMU). The majority of data were collected from the Czech Statistical Office, domestic financial variables from the Czech National Bank, and foreign variables come from EUROSTAT.

Having a two-sector model, it is also desirable to utilize some sector specific data in the estimation. Therefore, tradable and nontradable components of consumption, investment and CPI inflation were extracted. Tradable consumption includes durable, semi-durable, and non-durable goods, whereas services are included in nontradable consumption. Tradable investment covers cultivated assets, transport equipment, and other machinery and equipment. Nontradable investment comprises of dwellings, other buildings and structures, and intangible fixed assets. Nontradable inflation covers services, whereas tradable inflation follows price changes in food, fuel and other tradable goods.

In the estimation, a stationary version of the model is used, e.g. productivity growth is temporary, and the inflation target is set to zero. Input data are detrended with an HP-filter, which means that only the business cycle information is retained. Observed data are linked to the model variables through a block of measurement equations. In these equations, the model variables are the sum of observed data and the measurement error. The standard deviation of specific measurement error is calibrated at roughly one fourth of the standard deviation of the corresponding observed data.

The prior distributions for the estimated parameters were chosen as follows. For parameters constrained on the interval $\langle 0, 1\rangle$, the beta distribution is used. This concerns, for example, the elasticity of substitution between nontradable and tradable goods in the CES aggregates ρ_N, which reflects the idea that nontradable and tradable goods are likely to be complements. The standard errors of shocks have priors from inverse gamma distributions. Also, the feedback parameter to foreign debt ϕ_b has prior from inverse gamma distribution, since it attains rather low values. For remaining parameters, the priors take form of normal distribution.

Estimation itself is carried out in the Dynare Toolbox.[7] The prior distributions of a subset of the model parameters get combined with the likelihood function based on the observed data. This results in posterior distributions for particular parameters. First, the Dynare is instructed to use numerical optimization techniques to search for the posterior modes of the parameters. Next, the draws from the posterior distributions around these modes are taken using the random walk Metropolis-Hastings (MH) algorithm. To ensure that convergence of the posterior simulations has been achieved, three parallel MH blocks are run, with a length of 200,000 draws. The first half of the draws get thrown away as a burn-in. Both simulations result in average acceptance rates of approximately 26%. Figures 2 through 4 in the Appendix show the comparison of the prior/posterior distributions and the results of the multivariate convergence diagnostic test. During the estimation, two parameters – persistences of nontradable technology and world nominal interest rate – indicated the presence of computational problems, thus they were removed from the estimation, and their values were calibrated.

A comparison of the prior and posterior distributions for the estimated parameters can be found in Table 2 in the Appendix. A high posterior mean of the inverse elasticity of labor supply $\eta_L = 4.4$ suggests low elasticity of labor supply in the Czech Republic. The estimated value of habit parameter $\chi_c = 0.6$ implies that the households care about smoothing their consumption over time. Observed data fa-

[7]Matlab-based toolbox, for further information see www.dynare.org.

vored the posterior mean for the elasticity of substitution between nontradable and tradable goods in the CES aggregates $\rho_N = 0.76$; however, there was little information in the data for the elasticities of substitution between domestic and foreign goods (ρ_H, ρ_V), for which prior and posterior means are roughly the same. Calvo probabilities in the nontradable sector and wage setting (ξ_N, ξ_L) turned out to be rather low, showing that nontradable firms adjust their prices on average every two quarters ($\sim 1/(1-0.4)$) and that wage contracts are rather flexible, renewed on average every quarter. The interest rate smoothing parameter $\chi = 0.4$ achieves slightly lower value than its prior mean. The feedback coefficient to the inflation gap is rather strong, with posterior mean $\phi_p = 2.7$. The feedback parameter to foreign debt achieves $\phi_b = 0.002$, which is lower than its prior mean. Posterior means for persistences in autoregressive processes attain values between 0.4 to 0.8, with the smallest one associated with the UIP shock and the largest one with the demand shock. The estimates of the standard deviations of structural shocks point to the fact that productivity shock in the tradable sector is the most volatile.

3.9 Steady State

Given the calibrated and estimated parameters of the model, the steady state of the model is computed. Estimated parameters are evaluated at their posterior means. Since the model involves several price levels, one price level is taken as a numeraire and the remaining prices are expressed with respect to this chosen numeraire. Further, as was pointed out earlier, the presence of permanent productivity shocks makes the model nonstationary, and consequently it is not possible to directly compute its steady state. Therefore, one needs to perform additional transformations – a detrending of growing variables – in order to solve for the steady state. The detrending of the variables is as follows. Except for the labor supply, real variables are divided by the level of the labor-augmenting technology process in the nontradable sector, e.g. $\tilde{X}_t = X_t/A_t^N$, where $\tilde{X}_t$ is the transformed or detrended variable. The selection of technology process for detrending is arbitrary, but in the simulations of the B-S effect the productivity growth in the tradable sector is faster than in the nontradable sector, and to judge directly the effects of excessive growth in the tradable sector on real variables, it is preferable to express real variables with respect to the technology process in the nontradable sector. Another issue here is that the detrending of the shadow price of consumption λ_t^c (or the Lagrange multiplier associated with the budget constraint) is somewhat more complicated because a transformed version of this variable is given by the original one multiplied both by the numeraire price level and by the technology process in the nontradable sector. Afterwards, all optimality conditions are rewritten in detrended variables. Using substitutions within the system of steady-state versions of the optimality conditions, it is possible to numerically compute steady-state values for all the model variables. Having computed the steady state, the system of optimality conditions is log-linearized around the steady state and solved using the IRIS toolbox.[8]

4 The Results

In this section several simulations are carried out. Firstly, impulse responses to productivity shock in the tradable sector are inspected, both under flexible- and fixed-exchange-rate regimes. Secondly, transition from flexible to fixed exchange rate is modeled on the background of the B-S effect. Thirdly, the issue raised by Masten (2008) about the appropriate simulation of the B-S effect is briefly addressed. Lastly, the robustness of the results is checked.

4.1 The B-S Effect under Flexible and Fixed Exchange Rate Regime

For the purposes of comparison, the B-S effect is simulated as in Ravenna and Natalucci (2008), assuming a 30% gradual productivity increase in the tradable sector over 10 years. This growth is also relative to the foreign economy, and thus can be re-interpreted as excess relative productivity growth against the foreign economy (Euro Area). At the beginning of the simulation it is assumed that the economy is in its steady state. Impulse responses to such calibrated productivity shocks are depicted in Figure 5 in the Appendix. Blue lines represent the simulation with a fixed exchange rate, and red lines in the case of a flexible exchange rate. In the simulation with a fixed exchange rate, the monetary policy rule is turned off, and the domestic interest rate equals the foreign interest rate, as defined in equation 29.

Except for the nominal exchange rate, it does not matter what kind of exchange rate regime is adopted in the economy, flexible or fixed, since the impulse responses overlap in the long run. Under the flexible-exchange-rate regime, the nominal exchange rate appreciates by about 6% in the long run, as productivity grows by 30% in the tradable sector. However, in the short run, the dynamics differ between these two exchange rate regimes. With a fixed-exchange-rate regime, there are stronger inflationary pressures, with CPI inflation rising on impact by approximately 7 percentage points in annualized terms. This inflation arises solely from the nontradable sector because tradable inflation is linked to foreign tradable inflation, which is un-

[8]IRIS is a MATLAB toolbox for macroeconomic modeling and forecasting, developed by Beneš (2014). For further information see www.iris-toolbox.com.

affected by the shock to domestic tradable productivity. Note that under a fixed exchange rate the inflationary pressures cannot be mitigated with the monetary policy by definition. With a flexible exchange rate, inflation drops on impact, which is given by an initial appreciation of the nominal exchange rate. There are still some inflationary pressures coming from the nontradable sector, albeit notably smaller compared to the fixed-exchange-rate regime. The CPI-based real exchange rate appreciates approximately 6% in the long run under both exchange rate regimes.

Comparing the two exchange rate regimes, there is an obvious trade-off between nominal exchange rate appreciation and inflationary pressures in response to the productivity shock in the tradable sector. Either there are higher inflationary pressures with a fixed-exchange-rate regime, or higher nominal exchange rate appreciation in the case of a flexible-exchange-rate regime.

Qualitatively, these results resemble those of Ravenna and Natalucci (2008), but the extent of exchange rate appreciation in this paper is found to be somewhat smaller. Some difference might be attributable to different calibration and structure of their model (for details see Table 3 in the Appendix). Overall, the model mimics the theoretical predictions of the B-S effect well, captured by appreciating exchange rates and/or rising inflationary pressures in response to growing productivity in the tradable sector.

4.2 Transition from Flexible to Fixed Exchange Rate

Currently, the Czech economy has a floating exchange rate, which will switch to a fixed exchange rate after the adoption of the Euro. Therefore, it is interesting to inspect what is likely to happen to the economy before, during and after the adoption of the Euro on the back of the productivity catch-up process to the rest of Europe.

Performing such a simulation is not straightforward, since after the switch, a different set of equations describe the economy. Specifically, monetary policy loses its power to control the domestic interest rate, and the domestic interest rate equals the foreign interest rate (including a risk premium). To allow for such a change in the model, one possible way is to adjust affected equations with desired calibrated shocks. Firstly, the UIP shocks (in Eq. 30) are calibrated so that the nominal exchange rate remains fixed after the switch. Secondly, after the switch to a fixed exchange regime, monetary policy shocks to the monetary policy rule (in Eq. 35) are calibrated so as to make the domestic interest rate equal to the foreign interest rate. The calibration of monetary policy shocks is somewhat tricky, since the domestic interest rate is an endogenous variable, whose trajectory is unknown prior to the simulation. Hence, initially, the trajectory of the domestic interest rate is conditionally set after the switch to its steady state level. A preliminary simulation is run, and the difference between the trajectories of domestic and foreign interest rates is computed. In the next iteration, the trajectory of the domestic interest rate is set according to the last known trajectory of the foreign interest rate. The iterations continue until the difference between the trajectories of the domestic and foreign interest rates are minimized. This way one searches for desired monetary policy shocks that would deliver a state in which the domestic interest rate equals the foreign interest rate, e.g. the condition valid in a fixed exchange rate regime.

Again, as in the previous section, a 30% gradual productivity increase in the tradable sector over 10 years is assumed, but at some point the transition from a flexible to a fixed exchange rate occurs. What is relevant for the dynamics in the transition is the level of nominal exchange rate which will be valid after the adoption of the Euro, e.g. what the conversion rate is that will fix the Czech crown against the Euro. Basically, the country might fix its exchange rate at a depreciated, appreciated or consistent level as compared to the previous level of nominal exchange rate in the floating regime. Furthermore, the story is different when transition to a fixed exchange rate regime happens during episodes of higher or lower productivity gains. What also matters for the transition is whether the conversion rate is preannounced to the public or not. All these issues are addressed in the following text.

In Figure 6 in the Appendix the trajectories of selected variables are shown for the transition from a flexible to a fixed exchange rate. The switch occurs in the 8th quarter, and the level of fixed exchange rate is preannounced 4 quarters ahead of the switch, which is highlighted by a shaded area. Gold trajectories are for the case of a flexible exchange rate, that is, without the switch to a fixed exchange rate. Red trajectories are for the case when the fixed exchange rate is set to the last value of the flexible exchange rate. Black/blue trajectories are for depreciated/appreciated fixed exchange rates by 1 percentage point compared to the case when the exchange rate would remain flexible at the time of the switch. Comparing the results, the highest inflation pressures occur in the case of a depreciated fixed exchange rate, as a large proportion of inflation is imported from abroad through a depreciated currency. Across different conversion rates the dynamics of real variables, such as output or consumption, remain largely intact, especially in the long run. Soon after the switch to a fixed exchange rate regime, CPI inflation reaches similar trajectories for all cases. In the "red" case, which represents the fix at the last value of the flexible exchange rate, CPI inflation in the first year after the switch is on average approximately 0.4 percentage points higher compared to the case of the flexible exchange rate.

The timing of the transition from a flexible to a fixed exchange rate regime is also of key importance. The comparison of two different timings of transition is shown in Figure 7 in the Appendix. Red lines depict the simulation when a fixed exchange rate is adopted in period 8, when the average productivity growth of a tradable sector is approximately 4% annually. Blue lines represent the case where a fixed exchange rate is adopted in period 20, with slower productivity growth in the tradable sector reaching around 1% annually. Comparing these two simulations, early adoption of the Euro brings additional inflation costs, amounting on average to 0.3 percentage points higher CPI inflation when compared to the alternative case of a later transition. However, the timing of the transition does not matter for the inflationary pressures prior to the adoption of the Euro. Also, the dynamics of real variables are almost unaffected by different timing of the transition. The results suggest that a country should consider during what stage of the productivity catch-up process it should enter the EA, since early transition might be associated initially with higher inflation, rising by some 0.4 percentage points in the first year after the adoption of the Euro. These higher inflation pressures do not seem large, but one should bear in mind that they cannot be mitigated against by domestic monetary policy, since its power is lost in the fixed exchange rate regime.

To be more realistic, this timing exercise is also repeated using a labor productivity differential as a proxy for actual productivity improvement between the Czech Republic and the Euro Area, depicted in Figure 8 over the time periods of 2000–2015. Real labor productivity per hour worked is extracted from the Eurostat database (variable namq_10_lp_ulc), and seasonally adjusted by the Tramo/Seats method. To eliminate short-run fluctuations, the productivity differential is smoothed with the H-P filter, with the smoothing parameter set to 5. For comparison, this productivity differential is also plotted against the autoregressive process for the tradable/nontradable technology wedge used in previous simulations. Current data show that productivity improved in the Czech Republic relative to the Euro Area by more than 30% between 2000 and 2008, but from the Great Recession the productivity catch-up process has stalled. Figure 9 shows different timing of the transition from a flexible to a fixed exchange rate regime on the background of a current productivity differential. Early transition occurs in the 2nd quarter of 2004 (to reflect the entry of the Czech Republic into the European Union), whereas later transition is at the beginning of 2009 (chosen as the time when Slovakia entered the Euro Area). Comparing these two timings, hypothetical early adoption of the Euro brings additional inflationary costs, reaching on average 0.4 percentage points higher CPI inflation when compared to the later transition. Initially, inflation rises by 0.6 percentage points in the first year after early adoption of the Euro. In the event that the exchange rate remains flexible until the later transition, the nominal exchange rate appreciation driven by the B-S effect is stronger by approximately 2 percentage points compared to the case of early transition.

The country might opt to adopt a single currency by surprise. Such simulation is available in Figure 10 in the Appendix, with red/blue lines showing the unexpected/expected switch to a fixed exchange rate regime. Further, it is arbitrarily assumed that a depreciated fixed exchange rate by 1 percentage point is going to be adopted, compared to the case where the exchange rate would remain flexible at the time of the switch. Inspecting the results, the adoption of the Euro by surprise does not seem to be preferable, since it is associated with higher inflation at the time of the switch.

4.3 Masten's Critique

In this section, the issue of proper simulation of the B-S effect raised by Masten (2008) is briefly addressed. Masten (2008) criticizes Ravenna and Natalucci (2008) for inappropriate simulation of the B-S effect, saying that: *"..real appreciation in response to their simulation of BS effect is not an equilibrium process. On the contrary, it is a consequence of a large deviation from the actual equilibrium productivity level of the economy leading to model dynamics that appear empirically unlikely."* Further in his paper he repeats his critique in other words: *"Natalucci and Ravenna (2002) construct the BS experiment by pushing a stationary process of tradable productivity very far away from equilibrium with a sequence of positive productivity shocks for 40 quarters. This means that at the time when tradable productivity is supposed to reach a new steady state value (in 10 years) is in fact the farthest away from the steady state. The tradable productivity increase is thus not constructed as an equilibrium-driving process."* As a remedy to this issue Masten (2008) proposes using permanent sector-specific shocks so as to properly simulate the B-S effect as an equilibrium-driving process.

The model in this paper allows using permanent sector-specific productivity shocks in the simulation of the B-S effect. Nonetheless, both the simulation of the B-S effect with permanent shocks and the simulation with temporary shocks in the manner of Ravenna and Natalucci (2008) were tried and lead to the same results. For instance, the impulse responses shown in Figure 5 in the Appendix are identical for the simulation with permanent productivity shocks and for the simulation with temporary shocks, where a stationary productivity process in the tradable sector is exogenized so to match desired productivity path. In light of these results, Masten's critique of the paper by Ravenna and Natalucci (2008) seems to be unjustified.

Concerning exchange rate appreciation, driven by the B-S effect, in Masten (2008) it is only present when the model assumes exogenous externality in the production costs. In this paper such externality is not considered, and the simulation of the B-S effect results in exchange rate appreciation. Nonetheless, the conclusions of both papers are similar that the B-S effect is not an issue for the Czech Republic to fulfill the inflation and nominal exchange rate criteria.

4.4 Robustness

The results were checked against several alternative assumptions. Concerning the parameters of the model, perhaps the largest sensitivity of the results is found with respect to the elasticity of substitution between nontradable and tradable goods in the CES aggregates and the degree of price rigidity in the nontradable sector. Therefore, in this section these two parameters are varied to check the implications for the B-S effect.

Blue lines in Figures 11–12 in the Appendix show the simulations of the B-S effect assuming lower elasticity of substitution between nontradable and tradable goods $\rho_N = 0.5$, compared to the baseline in red lines with $\rho_N = 0.76$. Black lines in the same figures depict the simulations of the B-S effect assuming higher price rigidity in the nontradable sector $\xi_N = 0.8$, compared to the baseline where $\xi_N = 0.4$. Alternative calibrations of these two parameters are adopted from Ravenna and Natalucci (2008). Gold lines represent the combination of both lower elasticity of substitution between nontradable and tradable goods and higher price rigidity in the nontradable sector. Impulse responses in Figure 11 are in the case of a flexible exchange rate, and Figure 12 in case of a fixed exchange rate.

Lower elasticity of substitution between nontradable and tradable goods makes the B-S effect under a flexible exchange rate regime more pronounced through nominal exchange rate appreciation. The nominal exchange rate appreciates by almost 8% over ten years; however, it does not breach the limit imposed by the ERM II mechanism. The effect on CPI inflation is similar to the baseline. There is a shift in the production patterns, with more production occurring in the nontradable sector in comparison to the baseline, which is given by different preferences over nontradable and tradable goods in the consumption/investment baskets. The B-S effect under a flexible exchange rate with a higher degree of price rigidity in the nontradable sector resembles the baseline; however, some differences are notable. The nominal exchange rate appreciates slightly more in the long run. Further, the response of nontradable inflation is initially below the baseline, but thereafter persistently higher in the long run.

The B-S effect under a fixed exchange rate regime with lower elasticity of substitution between nontradable and tradable goods is more amplified through CPI inflation, which reaches 13% on impact in annualized terms, compared to the 7% initial increase in the baseline. The impulse responses of real variables, such as output, consumption and real exchange rate, are similar to the case of flexible exchange rate in the long run. The B-S effect under a fixed exchange rate regime with a higher degree of price rigidity in the nontradable sector becomes less pronounced through the response of the CPI inflation. The initial response is roughly half compared to the baseline, but the response is longer-lived over the first two years.

Interestingly, the alternative calibrations do not change significantly the main conclusions of this paper concerning the additional inflation costs of early adoption of the Euro. The same simulations as in Figure 7 in the Appendix were replicated for alternative values of the elasticity of substitution between nontradable and tradable goods and the degree of price rigidity in the nontradable sector. In these simulations, early adoption of the Euro brings additional inflation costs, amounting to on average 0.2 percentage-point higher CPI inflation when compared to the alternative case of later transition. This is slightly less compared to the baseline, with on average 0.3 percentage-point higher CPI inflation over the period of early and later transition.

5 Conclusion

The B-S effect implies that highly productive countries have higher inflation and appreciating real exchange rates because of larger productivity growth differentials between tradable and nontradable sectors relative to advanced economies. This is also particularly important for the Czech Republic, in which a catch-up process with advanced European countries is still ongoing. At some point, the Czech Republic is obliged to adopt the Euro as a single currency. Before adopting the Euro the Maastricht convergence criteria have to be fulfilled, imposing among others limits on inflation and nominal exchange rate fluctuations. An ongoing convergence process or the presence of the B-S effect might restrain a country from complying with these Maastricht criteria. Therefore, the main goal of this paper is to answer the question whether the B-S effect could be an issue for the Czech Republic in its ability to meet the Maastricht criteria.

For this purpose, I build a two-sector DSGE model of a small open economy, estimated for the Czech Republic using Bayesian techniques. The structure of the model is close to the one in Ravenna and Natalucci (2008), but is extended by several more realistic features, including staggered wages, consumption habits, permanent productivity growth, and a non-zero inflation target. The prices are sticky in the nontradable sector, whereas in the tradable sector flexible prices are assumed and purchasing power parity holds for tradable goods.

The simulations from the model point to the fact that the B-S effect does not pose a problem for the Czech Republic in meeting the Maastricht convergence criteria before adopting the Euro. The costs of early adoption of the Euro are not so large in terms of additional inflationary pressures, which materialize after the adoption of the single currency. More specifically, early transition is associated with initially higher inflation, rising by some 0.4 percentage points in the first year after the adoption of the Euro. Also, nominal exchange rate appreciation, driven by the B-S effect, does not breach the limit imposed by the ERM II mechanism. In the baseline version of the model, the nominal exchange rate appreciates by about 6% in the long run, as productivity increases by 30%.

This paper can be extended in several ways. For example, the model can be improved by relaxing some of its underlying assumptions, such as a perfectly competitive tradable sector and balanced trade in the equilibrium. Further, one can extend its structure to include the fiscal block in order to study the implications of the B-S effect on the Maastricht fiscal criteria, which impose the limits on government budget balance and debt. Another interesting extension would be to search for optimal monetary policy, which would minimize the costs of the B-S effect before the adoption of the Euro.

References

Balassa, B. (1964). The Purchasing-Power Parity Doctrine: A Reappraisal. *Journal of Political Economy 72*, 584–596.

Beneš, J. (2014). Iris toolbox reference manual. Ver. 2014-04-02.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics 12*(3), 383–398.

Cihak, M. and T. Holub (2003). Price Convergence: What Can the Balassa-Samuelson Model Tell Us? *Czech Journal of Economics and Finance (Finance a úvěr) 53*(7-8), 334–355.

Devereux, M. B. (2003). A Macroeconomic Analysis of EU Accession under Alternative Monetary Policies. *Journal of Common Market Studies 41*(5), 941–964.

Erceg, C. J., D. W. Henderson, and A. T. Levin (2000). Optimal Monetary Policy with Staggered Wage and Price Contracts. *Journal of Monetary Economics 46*(2), 281–313.

Égert, B. (2011). Catching-up and inflation in europe: Balassa-samuelson, engel's law and other culprits. *Economic Systems 35*(2), 208–229.

Égert, B., I. Drine, K. Lommatzsch, and C. Rault (2003). The Balassa-Samuelson Effect in Central and Eastern Europe: Myth or Reality? *Journal of Comparative Economics 31*(3), 552–572.

Égert, B., L. Halpern, and R. MacDonald (2006). Equilibrium exchange rates in transition economies: Taking stock of the issues. *Journal of Economic Surveys 20*(2), 257–324.

Ghironi, F. and M. J. Melitz (2005). International Trade and Macroeconomic Dynamics with Heterogeneous Firms. *The Quarterly Journal of Economics 120*(3), 865–915.

Konopczak, K. (2013). The Balassa-Samuelson effect and the channels of its absorption in the Central and Eastern European Countries. National Bank of Poland Working Papers 163, National Bank of Poland, Economic Institute.

Laxton, D. and P. Pesenti (2003). Monetary Rules for Small, Open, Emerging Economies. *Journal of Monetary Economics 50*(5), 1109–1146.

Lipinska, A. (2008). The Maastricht Convergence Criteria and Optimal Monetary Policy for the EMU Accession Countries. Working Paper Series 0896, European Central Bank.

Masten, I. (2008). Optimal Monetary Policy with Balassa-Samuelson-type Productivity Shocks. *Journal of Comparative Economics 36*(1), 120–141.

Mihaljek, D. and M. Klau (2004). The Balassa–Samuelson Effect in Central Europe: A Disaggregated Analysis. *Comparative Economic Studies 46*(1), 63–94.

Mihaljek, D. and M. Klau (2008). Catching-up and inflation in transition economies: the Balassa-Samuelson effect revisited. BIS Working Papers 270, Bank for International Settlements.

Miletic, M. (2012). Estimating the Impact of the Balassa-Samuelson Effect in Central and Eastern European Countries: A Revised Analysis of Panel Data Cointegration Tests. Working papers 22, National Bank of Serbia.

Rabanal, P. (2009). Inflation Differentials between Spain and the EMU: A DSGE Perspective. *Journal of Money, Credit and Banking 41*(6), 1141–1166.

Ravenna, F. and F. M. Natalucci (2008). Monetary Policy Choices in Emerging Market Economies: The Case of High Productivity Growth. *Journal of Money, Credit and Banking 40*(2-3), 243–271.

Sadeq, T. (2008). Bayesian estimation of a dsge model and convergence dynamics analysis for central europe transition economies. Université d'Evry Val d'Essonne, mimeo.

Samuelson, P. A. (1964). Theoretical Notes on Trade Problems. *Review of Economics and Statistics 46*, 145–154.

Schmitt-Grohe, S. and M. Uribe (2001). Stabilization Policy and the Costs of Dollarization. *Journal of Money, Credit and Banking 33*(2), 482–509.

Appendix A

Table 1: Calibrated Parameters

Parameter	Description	Value
Preferences		
β	Discount factor	0.99
l	Disutility of labor supply	20
Technology		
A	Growth rate of technology	1.01
α_n	Capital share in nontradable sector	1/3
α_h	Capital share in tradable sector	2/3
δ	Depreciation rate	0.025
ϕ_0	Investment adjustment cost	0.5
Monetary policy		
$\overline{\Pi}$	Inflation target	1.05
Shares		
γ_n	Share of nontradables in CES aggregates	0.6
γ_h	Share of domestic tradable goods in CES aggregates	0.8
γ_v	Share of domestic value added in tradable production	0.5
Elasticity		
ϵ_W	Between labor varieties	11
ϵ_N	Between nontradable good varieties	11
Persistences		
ρ_{an}	Nontradable technology	0.95
ρ_{rw}	World nominal interest rate	0.95

Table 2: Estimated Parameters

Parameter		Prior distribution	Posterior distribution			
equation	figure		mode	mean	10%	90%
Utility parameters						
η_L	etaL	N(2.5,0.2)	4.76	4.45	3.93	4.89
χ_c	chi_c	N(0.5,0.2)	0.51	0.55	0.43	0.68
Elasticities in CES aggregates						
ρ_N	rhoN	B(0.5,0.5)	0.75	0.76	0.67	0.84
ρ_H	rhoH	N(1.5,0.2)	1.47	1.51	1.26	1.76
ρ_V	rhoV	N(1.5,0.2)	1.47	1.50	1.25	1.76
Calvo probabilities						
ξ_N	xiN	B(0.5,0.5)	0.43	0.42	0.31	0.52
ξ_L	xiL	B(0.5,0.5)	0.19	0.17	0.11	0.23
Feedback coefficients						
ϕ_p	phi_p	N(2,0.2)	2.62	2.66	2.39	2.94
ϕ_b	phi_b	IG(0.01,0.1)	0.002	0.002	0.001	0.002
Persistences						
χ	chi	N(0.5,0.2)	0.43	0.43	0.34	0.52
ρ_{ah}	rho_ah	B(0.5,0.5)	0.71	0.69	0.61	0.77
ρ_{pi*}	rho_pi_star	B(0.5,0.5)	0.47	0.46	0.38	0.54
ρ_d	rho_d	B(0.5,0.5)	0.84	0.77	0.62	0.88
ρ_e	rho_e	B(0.5,0.5)	0.35	0.35	0.25	0.45
Standard errors of shocks						
$\varepsilon_{H,t}$	SE_eah	IG(0.01,0.1)	0.08	0.08	0.07	0.09
$\varepsilon_{N,t}$	SE_ean	IG(0.01,0.1)	0.02	0.03	0.02	0.03
ε_t^{rw}	SE_erworld	IG(0.01,0.1)	0.01	0.01	0.01	0.02
ε_t^{N}	SE_ecostpushPN	IG(0.01,0.1)	0.03	0.04	0.03	0.05
ε_t^{mps}	SE_emps	IG(0.01,0.1)	0.02	0.02	0.02	0.02
ε_t^{W}	SE_ecostpushW	IG(0.01,0.1)	0.05	0.06	0.04	0.09
ε_t^{pi*}	SE_epistar	IG(0.01,0.1)	0.02	0.02	0.01	0.02
ε_t^{d}	SE_ed	IG(0.01,0.1)	0.03	0.03	0.02	0.03
ε_t^{s}	SE_es	IG(0.01,0.1)	0.02	0.02	0.02	0.02

Table 3: Selected DSGE models with the B-S effect for the Czech Republic

Study	**Model features**	**Parameters**	**Main results**
Ravenna and Natalucci (2008)	• Price rigidity in nontradable sector • Perfect competition in tradable sector • Production with capital and labor • Capital accumulation with adjustment costs • Stationary productivity process • Taylor monetary rule	Calibrated	• In the presence of the B-S effect there is no monetary policy that would allow for meeting both the nominal exchange rate criterion and the inflation rate criterion. • The B-S effect raises the welfare loss of rules that prescribe a strong policy response to movements of the nominal exchange rate. • A productivity increase (30% over 10 years) induces approximately 2% nominal exchange rate appreciation per year.
Masten (2008)	• Price rigidities in tradable and nontradable sector • Cost externality • Permanent productivity growth • Production with labor • Optimal monetary policy	Calibrated	• The B-S effect is not a threat to meeting the Maastricht inflation criterion. • Optimal monetary policy, which targets both tradable and nontradable inflation, is able to stabilize inflation at levels of the rest of the world. • A productivity increase (30% over 10 years) induces on average 1.4% nominal exchange rate appreciation per year.
Ambrisko (2015)	• Price rigidity in nontradable sector • Perfect competition in tradable sector • Production with capital and labor • Capital accumulation with adjustment costs • Staggered wages • Consumption habits • Permanent productivity growth • Non-zero inflation target • Taylor monetary rule	Calibrated / Estimated	• The B-S effect is not an issue for the Czech Republic in meeting the inflation and nominal exchange rate criteria. • The costs of early adoption of the Euro are not so large in terms of additional inflation pressures, which materialize after the adoption of the single currency. • Early transition is associated with initially higher inflation, rising by some 0.4 percentage points in the first year after adoption of the Euro. • A productivity increase (30% over 10 years) induces on average 0.6% nominal exchange rate appreciation per year.

Figure 2: Bayesian Estimation: Priors and Posteriors of Estimated Parameters

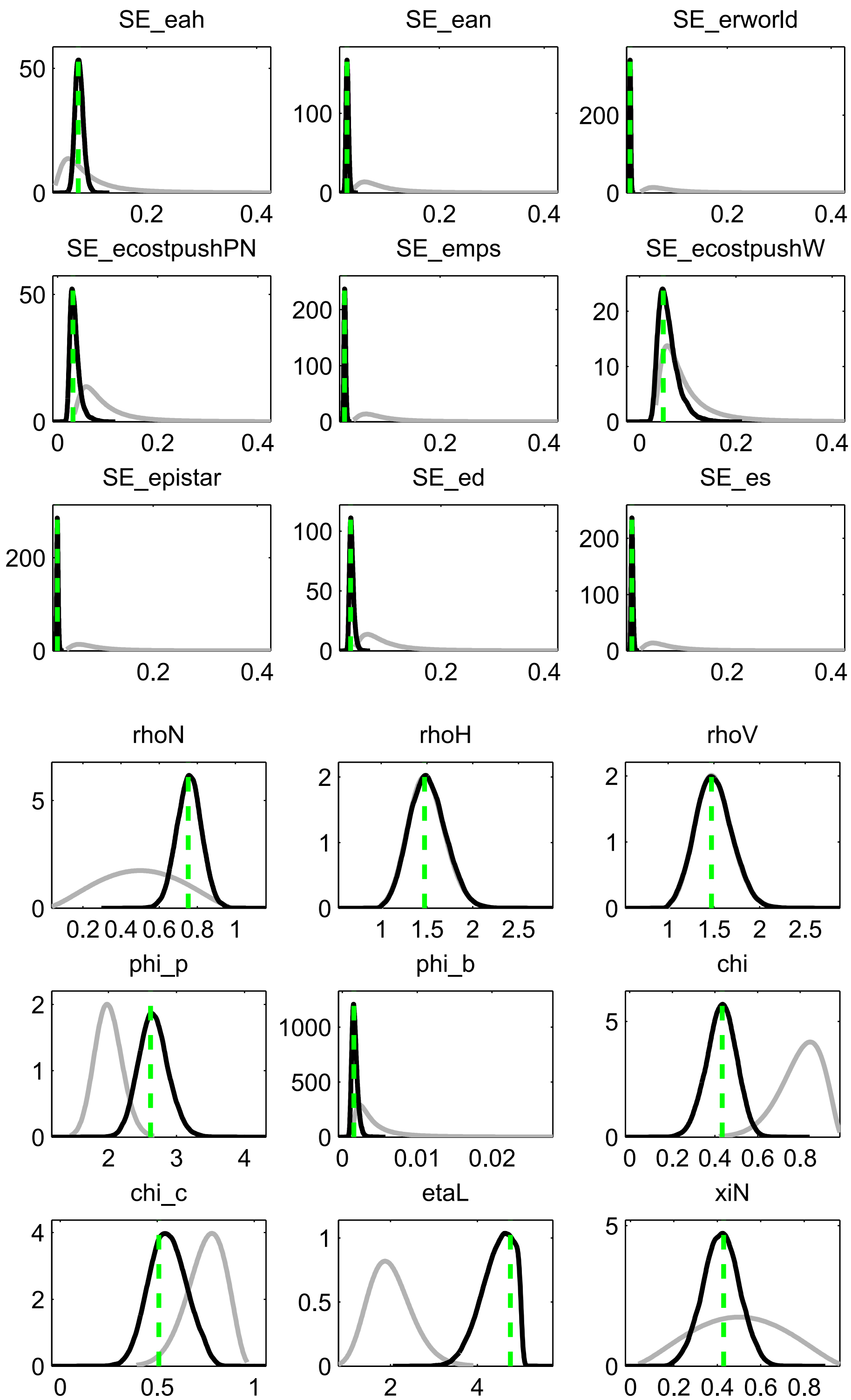


Figure 3: Bayesian Estimation: Priors and Posteriors of Estimated Parameters (Continued)

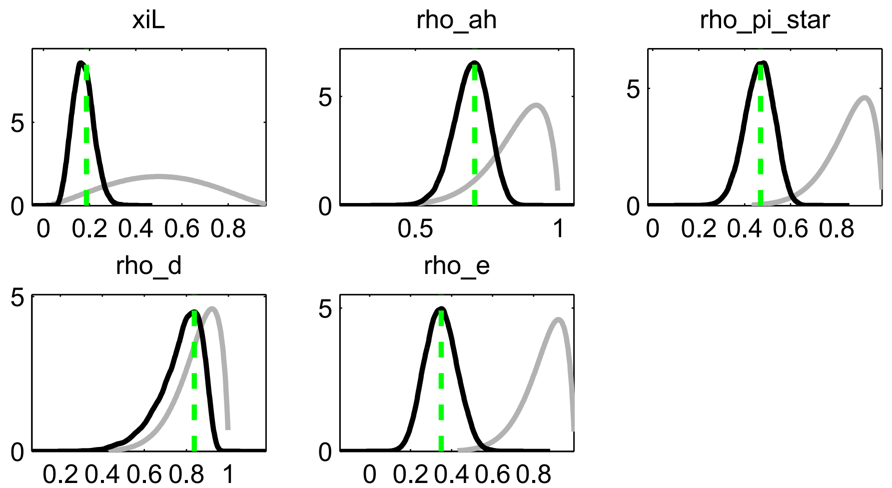


Figure 4: Bayesian Estimation: Multivariate Convergence Statistics

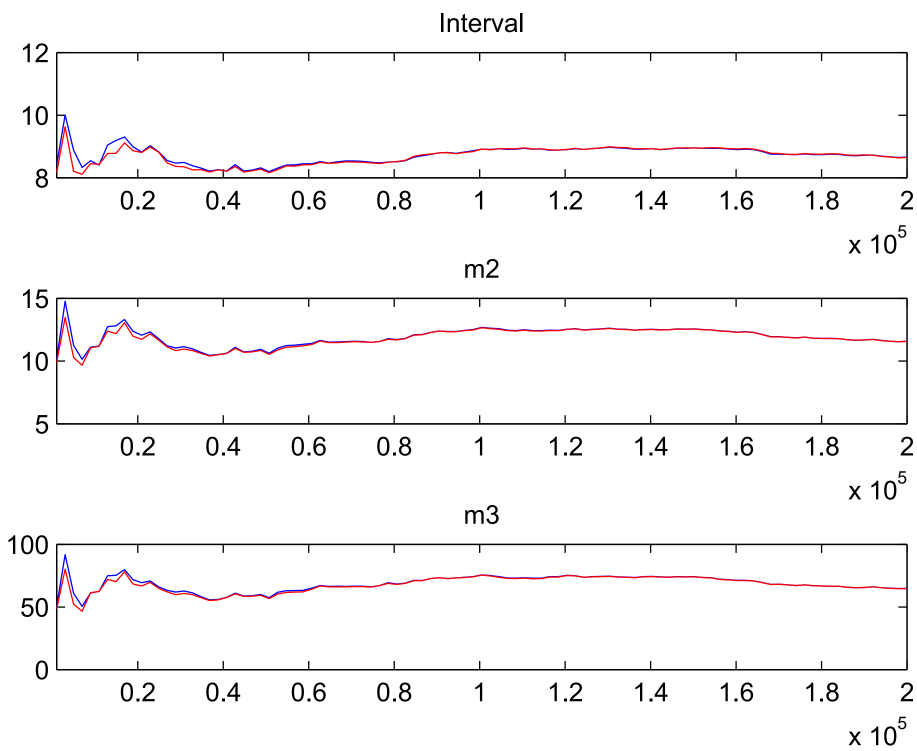


Figure 5: Tradable Productivity Growth by 30% over 10 Years

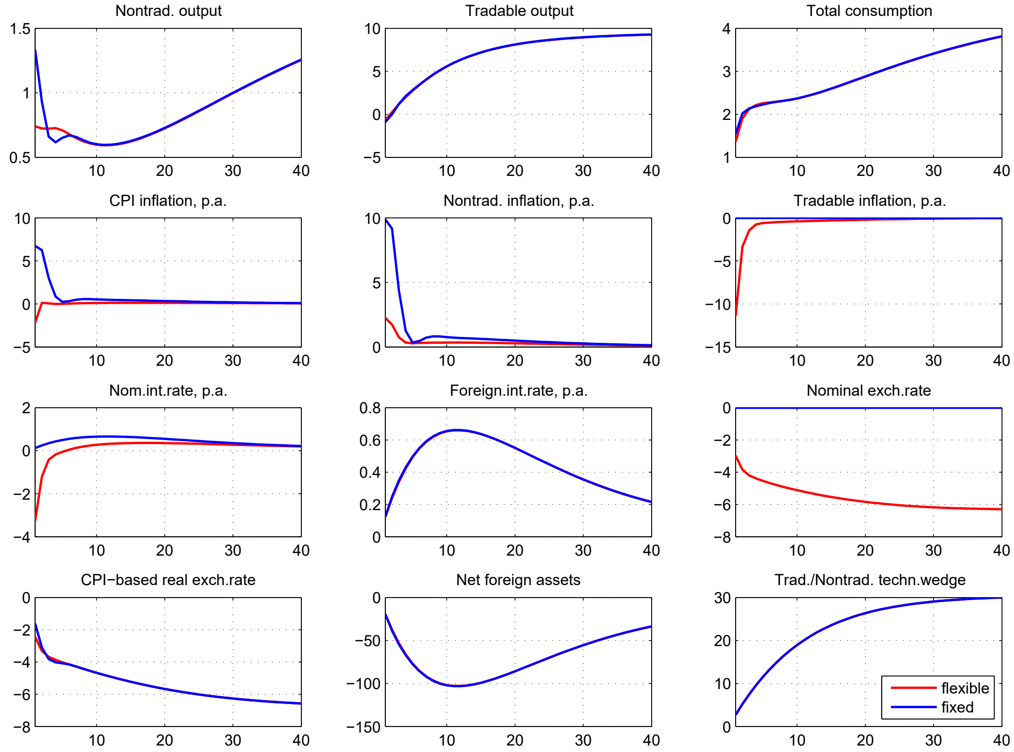


Figure 6: Transition from Flexible to Fixed Exchange Rate

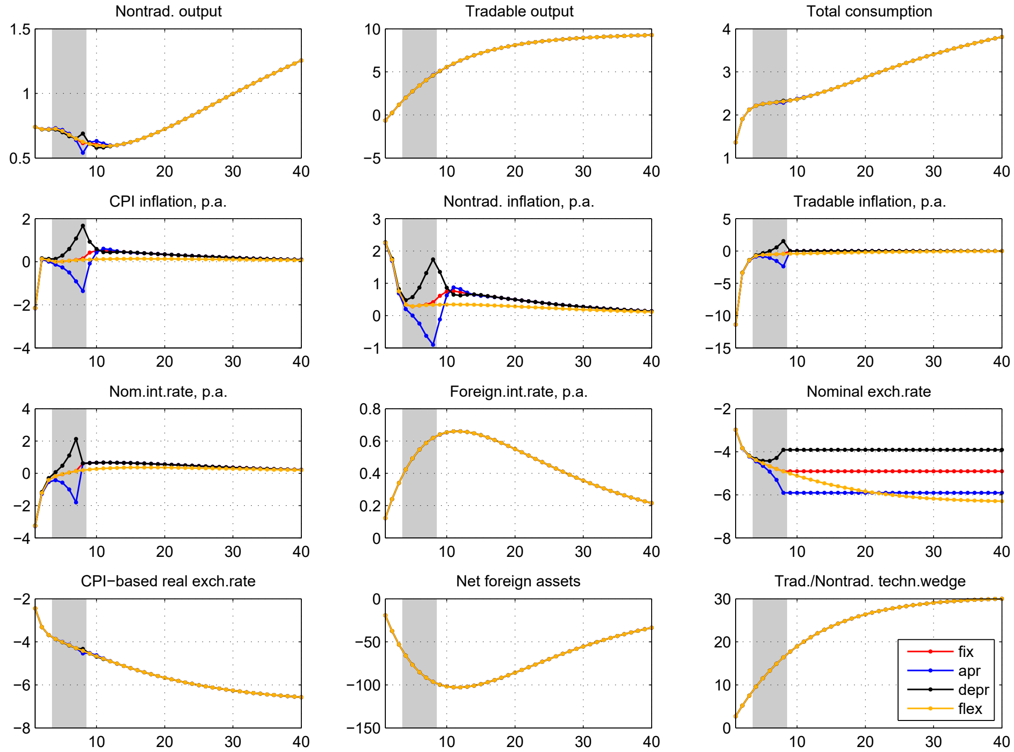


Figure 7: Different Timing of Transition

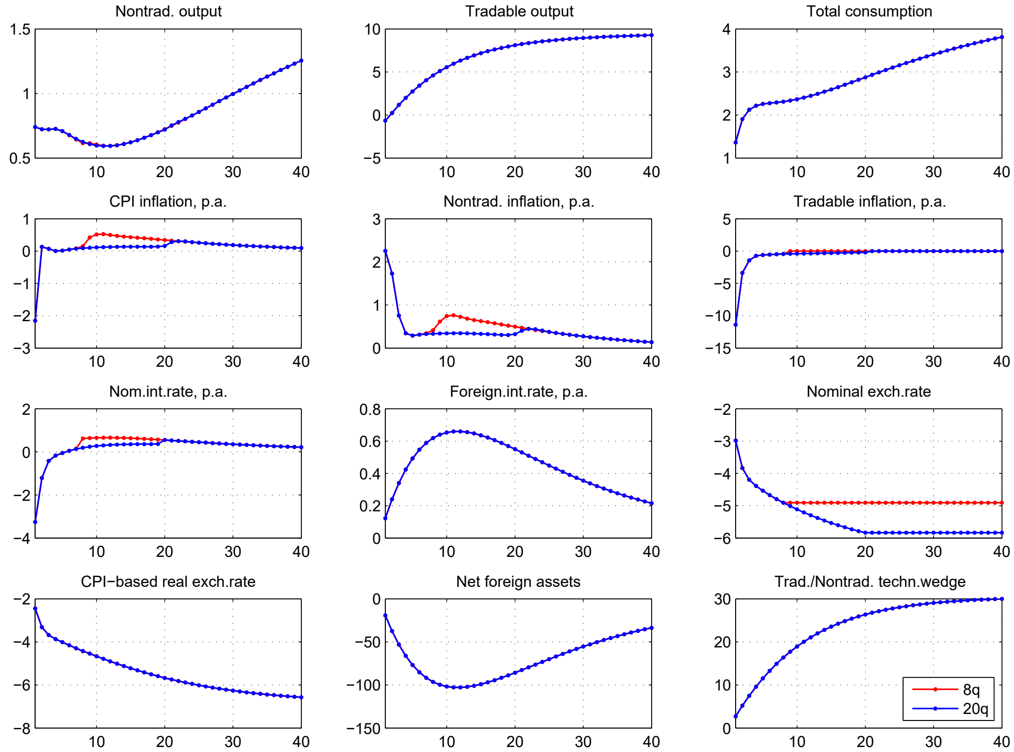


Figure 8: Labor Productivity

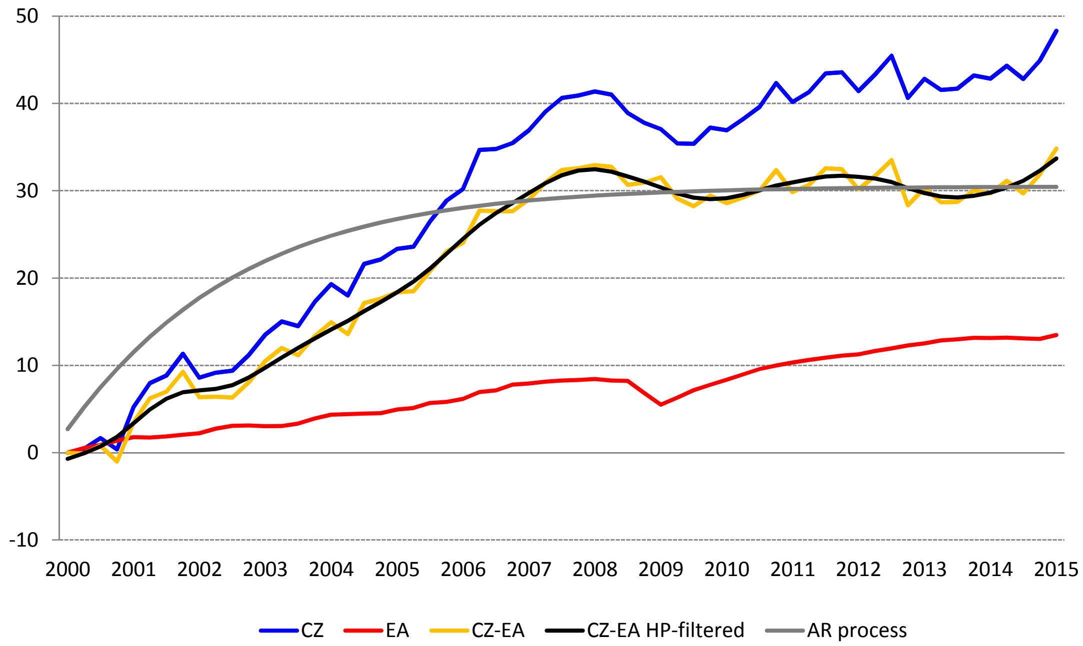


Figure 9: Different Timing of Transition with Actual Productivity Path

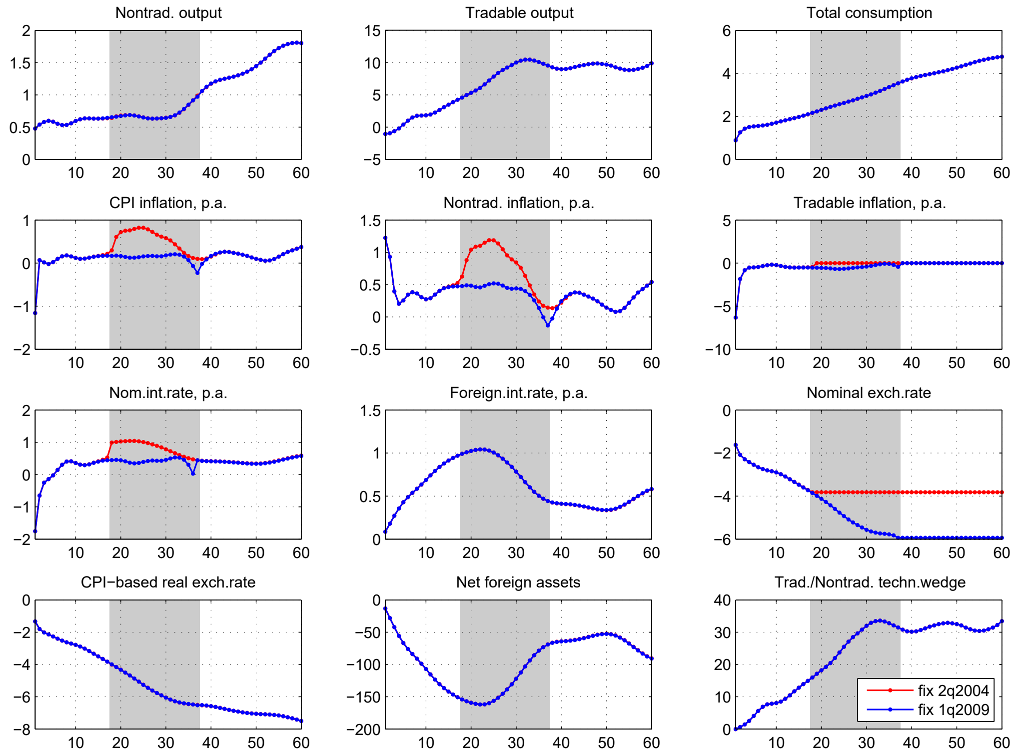


Figure 10: Euro Adopted by Surprise

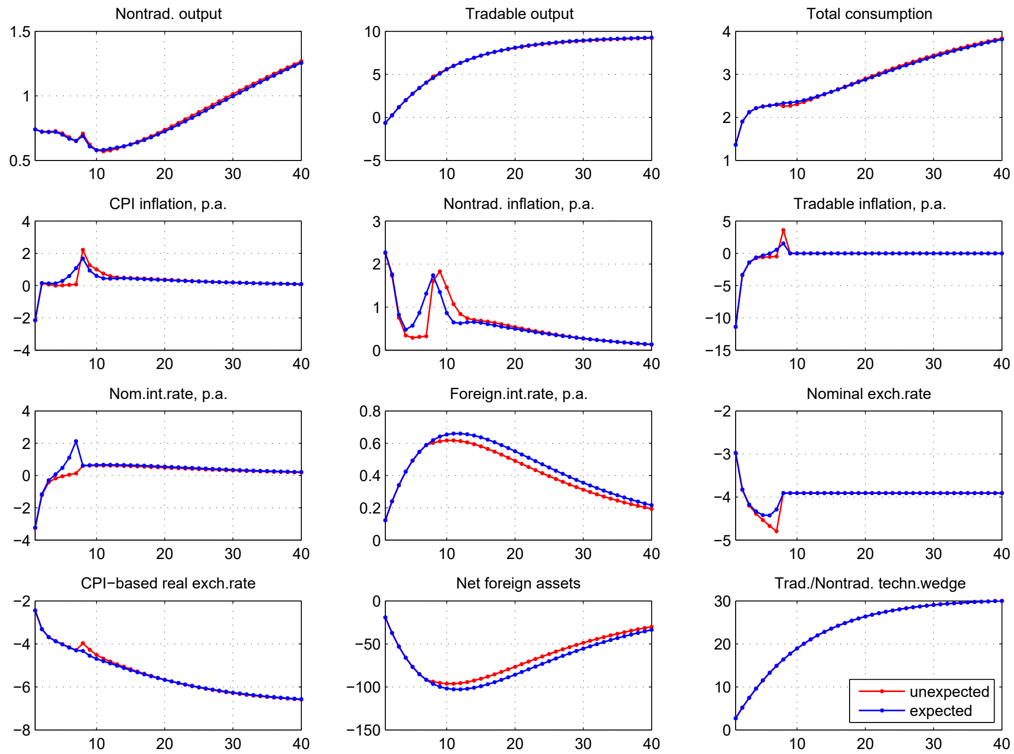


Figure 11: Sensitivity, Flexible Exchange Rate

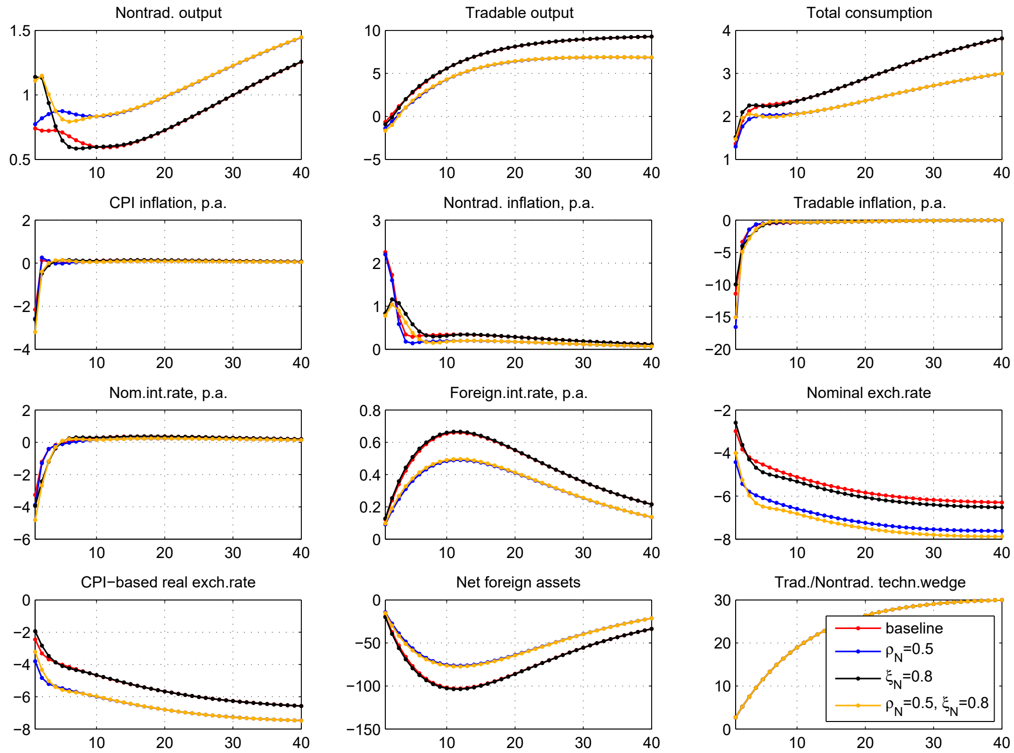
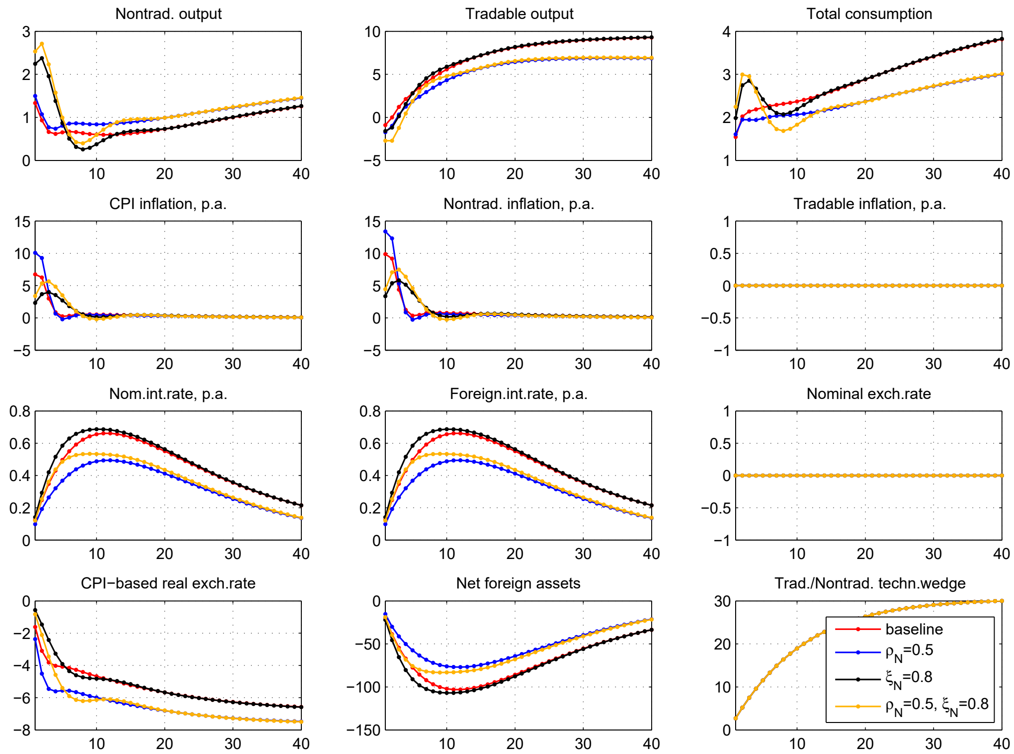


Figure 12: Sensitivity, Fixed Exchange Rate



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