Inflation Targeting and Monetary Integration under ERM 2: Modeling Third-Country Effects from Production Sharing[*]

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April 2008

Recent papers emphasize outsourcing and offshoring for the transmission of business cycles. Euro area accession countries are significantly integrated with third countries through the production chain. How do external shocks originating from a third country affect monetary policy under ERM 2? We analyze a third-country technology shock in a New Keynesian model with three countries. Our results show that a Taylor rule extended for an exchange rate term is a good simple rule for different kinds of integration. Nevertheless, the costs of ERM 2 in terms of a traditional central bank loss function are considerable.

1 Introduction

We analyze the potential cost of regional monetary integration, i.e., targeting the exchange rate to an anchor currency, while being at the same time integrated with third countries. Recent empirical papers point to the relevance of outsourcing and offshoring for the transmission of business cycle shocks and thereby for the conduct of monetary policy (see, among others, Fontagné and Freudenberg 1999, Imbs 2004, Kalemli-Ozcan, Sørensen, and Yosha 2003, Kose, Otrok and Whiteman 2003, Kose, Prasad, and Terrones 2003, IMF 2007). This is especially true for the countries that are about to join the European Economic and Monetary Union (EMU), which have to stay for two years in the European Exchange Rate Mechanism (ERM 2) and therefore target inflation and the exchange rate simultaneously. These countries are significantly integrated with third countries through the production chain.

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[*] I would like to thank Paul Bergin, Alper Çenesiz, Ester Faia, Jordi Galí, Rafael Gerke, Rolf Langhammer, Thomas Lux, Tommaso Monacelli, Christian Pierdzioch, Rainer Schweickert, Mewael Tesfaselassie, and Roland Winkler as well as seminar and conference participants at the University of Kiel and the Silesian University in Karvina for helpful comments and suggestions. This paper was written during my time at the Kiel Institute for the World Economy. I am also grateful for the hospitality of the Universitat Pompeu Fabra and financial support of the German Academic Exchange Service (DAAD) as well as the Monetary Stability Foundation of the Deutsche Bundesbank. The views expressed are my own and do not involve the responsibility of the institutions mentioned above. I am responsible for all remaining shortcomings.

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How do external shocks originating from a third country affect monetary policy under ERM 2?

Up to now, the empirical analysis had to focus on the early years characterized by inflation stabilization. The central and eastern European countries (CEEC) had to deal with the structural change from centrally planned to market economies. In the beginning of the 1990s, price liberalization and the abolition of price controls led to hyperinflation. The situation got stabilized by pegging the exchange rate. When the economies were ready for a more independent monetary policy, the central banks of the Czech Republic (1998), Poland (1998), Hungary (2001), and Slovakia (2005)[1] introduced inflation targeting. Mohanty and Klau (2005) and Frömmelt and Schobert (2006) estimate Taylor rules in these inflation targeting countries. Krusec (2005) investigates the transmission mechanism under inflation targeting in a VECM, whereas Hammermann (2005) showed the reaction of the interest rate to shocks in inflation, output, and the exchange rate in a VAR.

Empirical studies could not yet analyze how central banks actually solve the trade-off between inflation and exchange rate stabilization under ERM 2 (see Orlowski and Rybinski 2006).[2] In November 2005, Slovakia was the first inflation targeting country to move into ERM 2. In the next years, other countries of the CEEC that currently target the inflation rate may join ERM 2 and thus target the exchange rate at the same time. ERM 2 allows only for exchange rate movements within a ±15 percent band. After two successful years in ERM 2 and fulfillment of the other convergence criteria specified in the treaty of Maastricht, countries would adopt the euro. In any case, the results from the empirical literature support the assumption that even the inflation targeters among the CEEC did not completely give up exchange rate targeting, which was, of course, more dominant during the initial phase of disinflation and structural change. Incorporating the exchange rate in the conduct of monetary policy may be interpreted as simulating ERM 2, while still avoiding its strictly binding rules.

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[1] Slovakia had an implicit inflation target since 1999.

[2] The currency board countries Estonia, Latvia, and Lithuania are already in ERM 2; Slovenia adopted the euro in January 2007.

The theoretical literature looks either at the strategic role of targeting the exchange rate in competitive devaluations and its role as a shock absorber or rejects the role for targeting the exchange rate as the central bank should target domestic inflation and allow the exchange rate to float (Clarida, Galí, and Gertler 2001). Svensson (2000) shows in his simulations that a Taylor rule without an exchange rate term is a robust monetary policy strategy despite ignoring part of the available information. De Paoli (2006) finds only for implausibly high elasticities of substitution that exchange rate targeting enters the optimal monetary policy (see also Galí 2008).

Nonetheless, the existing models are incomplete as they do not address any potential trade-off between the strategic role of the exchange rate and achieving an announced inflation target given third-country effects. As shown in Table 1, central European inflation targeting countries are well integrated into production sharing with the euro area, documented by high trade shares, but a substantial share of their trade is still with the rest of the world (see also Crespo and Fontoura 2007).

Table 1: Trade Shares and Openness of Central European Inflation Targeting Countries and the Euro Area in 2006

	Imports		Exports		
	Euro Area	Rest of the World	Euro Area	Rest of the World	Openness
Czech Republic	0.59	0.41	0.58	0.42	1.31
Hungary	0.52	0.48	0.55	0.45	1.35
Poland	0.56	0.44	0.53	0.47	0.69
Slovakia	0.42	0.58	0.52	0.49	1.56
Average IT Countries	0.52	0.48	0.54	0.46	1.23
Euro Area	0.49	0.51	0.50	0.50	0.65

Source: Eurostat and IFS.
Note: Openness is measured as imports and exports over GDP.

Because a two-country model cannot adequately cope with potential third-country effects, we develop a New Keynesian three-country model. As a starting point, we take a three-country model in which Teo (2005) analyzes the choice of invoice currency in Asia but that does not address the role of monetary policy. We, therefore, integrate Teo's three-country framework into a model that analyzes monetary policy in a New Keynesian two-country model developed by Monacelli (2001). As a result, we are able to analyze regional monetary integration based on a dynamic, microfounded model allowing for third-country effects. Additionally, following Corsetti, Pesenti, Roubini, and Tille (2000), we incorporate a nested consumption basket to distinguish between goods produced in two periphery countries and a core country.

The model develops a set of equations for each of the three countries *A, B,* and *C*. Country *A* is the country under consideration and may represent a CEEC country integrating into EMU by targeting the euro as its anchor currency. Country *B* constitutes the third country, which is not directly affected by the European integration process and, therefore, stays outside ERM 2. Country *B* may represent either another transition country like Russia or the rest of the world. Both countries *A* and *B* together form the periphery, while country *C* represents the core country, which also provides the anchor currency for country *A*. Hence, country *C* features the euro area.

We analyze monetary policy in this setting given alternative degrees of integration between the euro area (core country *C*), an inflation targeting accession country like the Czech Republic, Hungary, Poland, and Slovakia (country *A*), and a non-EU country or the rest of the world as the third country (country *B*). As a short-cut for modeling production linkages we use alternative elasticities in consumption baskets. This framework allows us to trace the transmission mechanism of a third-country technology shock. Evaluating the central bank loss function for different simple rules and determining the corresponding optimal simple rules allows us to assess the costs of ERM 2 and derive the implications of production sharing for monetary policy. As a robustness check, we introduce home bias in consumption.

Our results show that a Taylor rule extended for an exchange rate term is a good simple rule for different kinds of integration with a third country. Nevertheless, the costs of ERM 2 in terms of a traditional central bank loss function are considerable. The paper proceeds as follows. In Section 2, we derive the New Keynesian three-country model. In Section 3, we present the simulation results. Section 4 concludes.

2 A New Keynesian Three-Country Model for Analyzing Optimal Monetary Rules under ERM 2

The New Keynesian three-country model incorporates explicit microfoundations with dynamic and intertemporal effects as well as Keynesian building blocks such as nominal rigidities and monopolistic competition. Following the microfoundation of the model, all individuals are at the same time consumers and producers. In their role as consumers, we look at the demand side of the economy. The representative household maximizes its utility by deciding about its optimal consumption. In the individuals' role as producers, we look at the supply side of the economy. The representative firm maximizes its profits by deciding about the product's optimal price. Putting the resulting optimality conditions together, the New Keynesian model is made of three core equations for each country. First, the dynamic IS curve stems form the household's choice on the optimal consumption path. Second, the New Keynesian Phillips curve stems from the firm's choice on the optimal price. Third, the model is closed with a monetary policy rule. These three equations form together with market clearing and international risk sharing the three-country model. The derivation follows along the lines of Galí and Monacelli (2005).

2.1 Households

The representative household in country *i, i=A, B, C,* maximizes the expected lifetime utility

$$(1) \qquad E_0 \sum_{t=0}^{\infty} \beta^t U_t^i \left(C_t^i, L_t^i\right),$$

where β is the subjective discount factor, *C* is consumption and *L* are hours worked, with the respective period utility

$$(2) \qquad U_t^i = \frac{1}{1-\mu} C_t^{i\,1-\mu} - \frac{1}{1+\gamma} L_t^{i\,1+\gamma},$$

where μ is the risk aversion and γ the inverse of the elasticity of labor supply. Households consume from a nested consumption basket as in Corsetti, Pesenti, Roubini, and Tille (2000). The utility-based consumption basket distinguishes between goods from the periphery *P* and the center *C,* where n_P is the size of the periphery relative to the center

$$C_t^i = \left[\left(n_P\right)^{1/\theta} \left(C_{P,t}^i\right)^{(\theta-1)/\theta} + \left(1-n_P\right)^{1/\theta} \left(C_{C,t}^i\right)^{(\theta-1)/\theta} \right]^{\theta/(\theta-1)}. \tag{3}$$

The periphery itself is made up of the two countries *A* and *B,* where n_A is the size of country *A* relative to country *B*. The consumption basket for the periphery is given by

$$C_{P,t}^i = \left[\left(n_A\right)^{1/\psi} \left(C_{A,t}^i\right)^{(\psi-1)/\psi} + \left(1-n_A\right)^{1/\psi} \left(C_{B,t}^i\right)^{(\psi-1)/\psi} \right]^{\psi/(\psi-1)}. \tag{4}$$

Taken together, the size of country *A* is $n_P\, n_A$, of country *B* is $n_P\,(1-n_A)$ and of the center *C* is $(1-n_P)$. The nested consumption basket for country *i, i=A,B,C,* is

$$\begin{aligned} C_t^i = \Big[\left(n_P\right)^{1/\theta} \Big(\Big[\left(n_A\right)^{1/\psi} \left(C_{A,t}^i\right)^{(\psi-1)/\psi} + \left(1-n_A\right)^{1/\psi} \left(C_{B,t}^i\right)^{(\psi-1)/\psi} \Big]^{\psi/(\psi-1)} \Big)^{(\theta-1)/\theta} \\ + \left(1-n_P\right)^{1/\theta} \left(C_{C,t}^i\right)^{(\theta-1)/\theta} \Big]^{\theta/(\theta-1)}. \end{aligned} \tag{5}$$

Introducing home bias in consumption changes the trade shares. If consumers in each country prefer home goods over foreign goods, the degree of openness, *η,* is smaller than one. The nested consumption baskets for each country depend on the intratemporal elasticity of substitution between goods from the center versus the periphery, *θ,* as well as on the intratemporal elasticity of substitution between goods from country *A* versus country *B,* i.e., between the two goods from the periphery, *ψ*. Thus, the nested consumption baskets with home bias are given by

$$\begin{aligned} C_t^A = \Big[\left[1-\eta\left(1-n_P\right)\right]^{1/\theta} \Big(\Big[\left[1-\eta\left(1-n_A\right)\right]^{1/\psi} \left(C_{A,t}^A\right)^{(\psi-1)/\psi} \\ + \left[\eta\left(1-n_A\right)\right]^{1/\psi} \left(C_{B,t}^A\right)^{(\psi-1)/\psi} \Big]^{\psi/(\psi-1)} \Big)^{(\theta-1)/\theta} \\ + \left[\eta\left(1-n_P\right)\right]^{1/\theta} \left(C_{C,t}^A\right)^{(\theta-1)/\theta} \Big]^{\theta/(\theta-1)} \end{aligned} \tag{6}$$

$$\begin{aligned} C_t^B = \Big[\left[1-\eta\left(1-n_P\right)\right]^{1/\theta} \Big(\Big[\left(\eta\, n_A\right)^{1/\psi} \left(C_{A,t}^B\right)^{(\psi-1)/\psi} \\ + \left(1-\eta\, n_A\right)^{1/\psi} \left(C_{B,t}^B\right)^{(\psi-1)/\psi} \Big]^{\psi/(\psi-1)} \Big)^{(\theta-1)/\theta} \\ + \left[\eta\left(1-n_P\right)\right]^{1/\theta} \left(C_{C,t}^B\right)^{(\theta-1)/\theta} \Big]^{\theta/(\theta-1)} \end{aligned} \tag{7}$$

$$\begin{aligned} C_t^C = \Big[\left(\eta\, n_P\right)^{1/\theta} \Big(\Big[\left(n_A\right)^{1/\psi} \left(C_{A,t}^C\right)^{(\psi-1)/\psi} \\ + \left(1-n_A\right)^{1/\psi} \left(C_{B,t}^C\right)^{(\psi-1)/\psi} \Big]^{\psi/(\psi-1)} \Big)^{(\theta-1)/\theta} \\ + \left[\eta\left(1-n_P\right)\right]^{1/\theta} \left(C_{C,t}^C\right)^{(\theta-1)/\theta} \Big]^{\theta/(\theta-1)}. \end{aligned} \tag{8}$$

The consumption indexes for the three countries *i, i=A,B,C,* are given by

(9) $$C^i_{A,t} = \left[\left(\frac{1}{n_P n_A}\right)^{1/\phi} \int_0^{n_P n_A} \left(C^i_{A,t}(z)\right)^{\phi-1/\phi} dz\right]^{\phi/(\phi-1)}$$

(10) $$C^i_{B,t} = \left[\left(\frac{1}{n_P(1-n_A)}\right)^{1/\phi} \int_{n_P n_A}^{n_P} \left(C^i_{B,t}(z)\right)^{\phi-1/\phi} dz\right]^{\phi/(\phi-1)}$$

(11) $$C^i_{C,t} = \left[\left(\frac{1}{1-n_P}\right)^{1/\phi} \int_{n_P}^{1} \left(C^i_{C,t}(z)\right)^{\phi-1/\phi} dz\right]^{\phi/(\phi-1)},$$

where the subscript refers to the country of production and the superscript refers to the country of consumption. The elasticity of substitution for goods of different brands *z,* i.e., “varieties” is given by ϕ.

Prices

The utility-based price indexes are defined analogously to the consumption basket and are therefore broken down into the overall index

(12) $$P^i_t = \left[n_P\left(P^i_{P,t}\right)^{1-\theta} + (1-n_P)\left(P^i_{C,t}\right)^{1-\theta}\right]^{1/(1-\theta)}$$

and the sub-index for prices of goods from the two periphery countries

(13) $$P^i_{P,t} = \left[n_A\left(P^i_{A,t}\right)^{1-\psi} + (1-n_A)\left(P^i_{B,t}\right)^{1-\psi}\right]^{1/(1-\psi)}.$$

As with the consumption basket, introducing home bias renders the consumer price index for each country

(14) $$\begin{aligned} P^A_t = [[1-\eta(1-n_P)]&\left(\left[[1-\eta(1-n_A)]\left(P^A_{A,t}\right)^{1-\psi} + \eta(1-n_A)\left(P^A_{B,t}\right)^{1-\psi}\right]^{1/(1-\psi)}\right)^{1-\theta} \\ &+ \eta(1-n_P)\left(P^A_{C,t}\right)^{1-\theta}\Big]^{1/(1-\theta)} \end{aligned}$$

(15) $$\begin{aligned} P^B_t = [[1-\eta(1-n_P)]&\left(\left[\eta n_A\left(P^B_{A,t}\right)^{1-\psi} + (1-\eta n_A)\left(P^B_{B,t}\right)^{1-\psi}\right]^{1/(1-\psi)}\right)^{1-\theta} \\ &+ \eta(1-n_P)\left(P^B_{C,t}\right)^{1-\theta}\Big]^{1/(1-\theta)} \end{aligned}$$

(16) $$P_t^C = \left[\eta n_P \left(\left[n_A \left(P_{A,t}^C \right)^{1-\psi} + (1-n_A) \left(P_{B,t}^C \right)^{1-\psi} \right]^{1/(1-\psi)} \right)^{1-\theta} + (1-\eta n_P) \left(P_{C,t}^C \right)^{1-\theta} \right]^{1/(1-\theta)}$$

with

(17) $$P_{A,t}^i = \left[\frac{1}{n_P n_A} \int_0^{n_P n_A} \left(P_{A,t}^i(z) \right)^{1-\phi} dz \right]^{1/(1-\phi)}$$

(18) $$P_{B,t}^i = \left[\frac{1}{n_P (1-n_A)} \int_{n_P n_A}^{n_P} \left(P_{B,t}^i(z) \right)^{1-\phi} dz \right]^{1/(1-\phi)}$$

(19) $$P_{C,t}^i = \left[\frac{1}{1-n_P} \int_{n_P}^{1} \left(P_{C,t}^i(z) \right)^{1-\phi} dz \right]^{1/(1-\phi)}$$

where $P_{i,t}^i$ is the price index of domestic goods or producer price index (PPI) in country *i*.

Exchange Rates

The terms of trade between country *i* and country i' are defined as the relative price of imports

(20) $$ToT_{i',t}^i = \frac{P_{i',t}^i}{P_{i,t}^i},$$

i.e., the price of imported goods (produced in country i') in home (country *i*) currency relative to the price of home goods.

For convenience, we define the following CPI-PPI ratios, $g_{i,t}(ToT)$, for each country *i*. The expression links CPI prices and domestic prices to the terms of trade (Faia and Monacelli 2004, 2007)

(21) $$\frac{P_t^A}{P_{A,t}^A} = \left[\left[1-\eta(1-n_P) \right] \left[\left(\left[1-\eta(1-n_A) \right] + \eta(1-n_A) \left(ToT_{B,t}^A \right)^{1-\psi} \right)^{1/(1-\psi)} \right]^{1-\theta} + \eta(1-n_P) \left(ToT_{C,t}^A \right)^{1-\theta} \right]^{1/(1-\theta)} \equiv g_{A,t}(ToT)$$

(22)
$$\frac{P_t^B}{P_{B,t}^B} = \left[\left[1-\eta\left(1-n_P\right)\right] \left[\left(\eta\, n_A \left(ToT_{A,t}^B\right)^{1-\psi} + \left(1-\eta\, n_A\right) \right)^{1/(1-\psi)} \right]^{1-\theta} + \eta\left(1-n_P\right)\left(ToT_{C,t}^B\right)^{1-\theta} \right]^{1/(1-\theta)} \equiv g_{B,t}\left(ToT\right)$$

(23)
$$\frac{P_t^C}{P_{C,t}^C} = \left[\eta\, n_P \left[\left(n_A \left(ToT_{A,t}^C\right)^{1-\psi} + \left(1-n_A\right)\left(ToT_{A,t}^C\right)^{1-\psi} \right)^{1/(1-\psi)} \right]^{1-\theta} + \left(1-\eta\, n_P\right) \right]^{1/(1-\theta)} \equiv g_{C,t}\left(ToT\right).$$

Households maximize their lifetime utility subject to the period budget constraint,

(24)
$$\sum_{h^{t+1}} Q_{t,t+1} \frac{1}{S_{i,t}^C} B_{t+1}^i + P_t^i C_t^i = \frac{1}{S_{i,t}^C} B_t^i + W_t^i L_t^i + \Psi_t^i ,$$

where nominal bonds, B_t^i, are state-contingent claims denominated only in country *C*'s currency, $S_{i,t}^{i'}$ is the nominal exchange rate defined as the price of currency *i*' in currency *i*, $Q_{t,t+1} \equiv Q\left(h^{t+1} \middle| h^t\right)$ is the period-*t* price of one unit of country *C*'s currency in state h^{t+1} divided by the probability of occurrence of that state,[3] W_t^i is the nominal wage; L_t^i are hours worked, and Ψ_t^i are nominal profits of the domestic monopolistic firms, which shares are owned by domestic residents. Complete markets ensure stationarity of bonds and consumption (Schmitt-Grohé and Uribe 2003).

Deriving Demand Functions

First, we derive the individual demand functions for good *z* as well as the aggregate demand functions from the intratemporal cost minimization of the household's consumption across different countries *i* and brands *z*.[4]

Individual demand functions for country *i, i = A, B, C:*

(25)
$$C_{A,t}^i(z) = \left(\frac{C_{A,t}^i(z)}{C_{A,t}^i(z)} \right)^{-\phi} \left(n_P n_A\right)^{-1} C_{A,t}^i$$

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[3] Each asset in the portfolio B_{t+1}^i pays one unit of country *C*'s currency at time *t*+1 and in state h^{t+1}.

[4] The detailed optimization is available upon request.

(26) $$C^{i}_{B,t}(z)=\left(\frac{C^{i}_{B,t}(z)}{C^{i}_{B,t}(z)}\right)^{-\phi}\left(n_P(1-n_A)\right)^{-1}C^{i}_{B,t}$$

(27) $$C^{i}_{C,t}(z)=\left(\frac{C^{i}_{C,t}(z)}{C^{i}_{C,t}(z)}\right)^{-\phi}(1-n_P)^{-1}C^{i}_{C,t}\,.$$

Aggregate demand functions for country *i, i* = *A, B, C:*

(28) $$C^{i}_{A,t}=v^{i}_{A}\left(\frac{P^{i}_{A,t}}{P^{i}_{P,t}}\right)^{-\psi}\left(\frac{P^{i}_{P,t}}{P^{i}_{t}}\right)^{-\theta}C^{i}_{t}\,,$$

(29) $$C^{i}_{B,t}=v^{i}_{B}\left(\frac{P^{i}_{B,t}}{P^{i}_{P,t}}\right)^{-\psi}\left(\frac{P^{i}_{P,t}}{P^{i}_{t}}\right)^{-\theta}C^{i}_{t}\,,$$

(30) $$C^{i}_{C,t}=v^{i}_{C}\left(\frac{P^{i}_{C,t}}{P^{i}_{t}}\right)^{-\theta}C^{i}_{t}\,,$$

where the trade shares are given by Table 2.

Table 2: Trade Shares for Countries *A, B,* and *C*

Country *A*	Country *B*	Country *C*
$v^{A}_{A}=[1-\eta(1-n_P)][1-\eta(1-n_A)]$	$v^{B}_{A}=[1-\eta(1-n_P)]\eta\, n_A$	$v^{C}_{A}=\eta\, n_P\, n_A$
$v^{A}_{B}=[1-\eta(1-n_P)]\eta(1-n_A)$	$v^{B}_{B}=[1-\eta(1-n_P)]\,(1-\eta\, n_A)$	$v^{C}_{B}=\eta\, n_P\,(1-n_A)$
$v^{A}_{C}=\eta(1-n_P)$	$v^{B}_{C}=\eta(1-n_P)$	$v^{C}_{C}=1-\eta\, n_P$

Second, we solve the intertemporal optimization by maximizing the lifetime utility function (1) subject to the budget constraint (24). Combining the first order conditions for consumption and labor determines the consumption labor trade-off and, thereby, the nominal wage

(31) $$W^{i}_{t}=\frac{-\partial U^{i}_{t}/\partial C^{i}_{t}}{\partial U^{i}_{t}/\partial L^{i}_{t}}=\frac{\left(L^{i}_{t}\right)^{\gamma}}{\left(C^{i}_{t}\right)^{-\mu}}P^{i}_{t}\,.$$

Combining the first order conditions for consumption and bonds leads to the familiar Euler equation

(32) $$\beta\left(\frac{C_{t+1}^{i}}{C_{t}^{i}}\right)^{-\mu}\frac{P_{t}^{i}}{P_{t+1}^{i}}=\frac{S_{i,t+1}^{C}}{S_{i,t}^{C}}Q_{t,t+1}.$$

Taking expectations conditional on the information available in period t and defining the gross nominal interest rate, R_t^i, on a riskless one-period bond in country i as

(33) $$R_{t}^{i}\equiv\frac{1}{E_{t}\left\{\left(S_{i,t+1}^{C}/S_{i,t}^{C}\right)Q_{t,t+1}\right\}},$$

we rewrite the Euler equation as

(34) $$\beta\,R_{t}^{i}\,E_{t}\left\{\left(\frac{C_{t+1}^{i}}{C_{t}^{i}}\right)^{-\mu}\frac{P_{t}^{i}}{P_{t+1}^{i}}\right\}=1.$$

The Euler equation (34) leads to the dynamic IS curve, where today's consumption depends on tomorrow's consumption and the interest rate.

International Risk Sharing

The three countries are linked by international risk sharing. Combining the Euler equation (32) for two countries i and i'

(35) $$\beta\left(\frac{C_{t+1}^{i}}{C_{t}^{i}}\right)^{-\mu}\frac{P_{t}^{i}}{P_{t+1}^{i}}=\beta\left(\frac{C_{t+1}^{i'}}{C_{t}^{i'}}\right)^{-\mu}\frac{S_{i',t}^{i}\,P_{t}^{i'}}{S_{i',t+1}^{i}\,P_{t+1}^{i'}}$$

and defining the real exchange rate as

(36) $$RER_{i',t}^{i}\equiv\frac{S_{i',t}^{i}\cdot P_{t}^{i'}}{P_{t}^{i}}$$

the following risk sharing condition holds in every period

(37) $$C_{t}^{i}=C_{t}^{i'}\cdot\left(RER_{i',t}^{i}\right)^{1/\mu}.$$

The real exchange rate may be written in terms of trade

(38) $$RER_{i',t}^{i}=ToT_{i',t}^{i}\cdot g_{i',t}\left(ToT\right)\cdot g_{i,t}\left(ToT\right)^{-1}.$$

In a three country model we have two risk sharing conditions expressed in terms of trade

(39) $$C_t^A = C_t^B \left(ToT_{B,t}^A\right)^{1/\mu} g_{B,t}\left(ToT\right)^{1/\mu} g_{A,t}\left(ToT\right)^{-1/\mu}$$

and

(40) $$C_t^A = C_t^C \left(ToT_{C,t}^A\right)^{1/\mu} g_{C,t}\left(ToT\right)^{1/\mu} g_{A,t}\left(ToT\right)^{-1/\mu}.$$

If purchasing power parity holds, which is the case if there is no home bias in consumption, the real exchange rate in (37) is one and international risk sharing implies perfect consumption smoothing across countries, i.e.,

(41) $$C_t^i = C_t^{i'}.$$

2.2 Firms

Differences in production and thereby in economic integration along the production chain are modeled via the consumption basket to keep the supply side of the model simple. We also abstract from capital as labor is the only input factor. Each monopolistically competitive firm *z* in country *i* produces

(42) $$Y_t^i(z) = F_t^i \, L_t^i(z),$$

where $Y_t^i(z)$ is the output of firm *z* in period *t* and F_t^i is country specific productivity that follows a first order autoregressive process

(43) $$F_t^i = \rho^i F_{t-1}^i + \varepsilon_t^i.$$

Firms maximize profits subject to the production function, demand, and staggered producer currency pricing à la Calvo (1983), where α is the degree of price stickiness. The optimal price of variety *z* is

(44) $$\widetilde{P}_{i,t}^i(z) = \frac{\phi}{\phi - 1} \cdot \frac{E_t \sum_{\tau=0}^{\infty} \alpha^\tau \, \rho_{t,t+\tau} \, Y_{t+\tau}^i(z) \, MC_{t+\tau}^i(z)}{E_t \sum_{\tau=0}^{\infty} \alpha^\tau \, \rho_{t,t+\tau} \, Y_{t+\tau}^i(z)},$$

where $MC_t^i(z) = W_t^i / F_t^i$ are nominal marginal costs given by the Lagrange multiplier associated with the demand constraint, $Y_t^i(z)$ is total ("world") output of country *i*'s firm *z,* and $\phi/(\phi-1)$ is the mark-up of prices over marginal costs.

Market Clearing

Market clearing requires the demand and supply of goods to be equalized in each of the three countries

$$
\begin{aligned}
Y_t^A &= v_A^A \left(ToT_{P,t}^A\right)^{\psi-\theta} \left(g_A(ToT)\right)^{\theta} C_t^A \\
&+ v_B^A \left(ToT_{P,t}^B\right)^{\psi-\theta} \left(ToT_{B,t}^A\right)^{\psi} \left(g_B(ToT)\right)^{\theta} C_t^B \\
&+ v_C^A \left(ToT_{P,t}^C\right)^{\psi-\theta} \left(ToT_{C,t}^A\right)^{\psi} \left(g_C(ToT)\right)^{\theta} C_t^C
\end{aligned}
\tag{45}
$$

$$
\begin{aligned}
Y_t^B &= v_A^B \left(ToT_{P,t}^A\right)^{\psi-\theta} \left(ToT_{A,t}^B\right)^{\psi} \left(g_A(ToT)\right)^{\theta} C_t^A \\
&+ v_B^B \left(ToT_{P,t}^B\right)^{\psi-\theta} \left(g_B(ToT)\right)^{\theta} C_t^B \\
&+ v_C^B \left(ToT_{P,t}^C\right)^{\psi-\theta} \left(ToT_{C,t}^B\right)^{\psi} \left(g_C(ToT)\right)^{\theta} C_t^C
\end{aligned}
\tag{46}
$$

$$
\begin{aligned}
Y_t^C &= v_A^C \left(ToT_{C,t}^A\right)^{-\theta} \left(g_A(ToT)\right)^{\theta} C_t^A \\
&+ v_B^C \left(ToT_{C,t}^B\right)^{-\theta} \left(g_B(ToT)\right)^{\theta} C_t^B \\
&+ v_C^C \left(g_C(ToT)\right)^{\theta} C_t^C .
\end{aligned}
\tag{47}
$$

2.3 Solving the Model

The model cannot be solved analytically. We follow the strategy of linear approximation of the model's nonlinear equations established in the real business cycle literature (e.g., Campbell 1994, Uhlig 1999). Kydland and Prescott (1982) proposed taking a linear-quadratic approximation to the true model around its steady state. This method is valid in the special case of Kydland and Prescott (1982) but may not be generalized. Kim and Kim (2007) demonstrate in a small model that loglinearizing the model before deriving the optimality conditions (first order conditions) leads to inaccurate results. Such a "naïve" (Benigno and Woodford 2007) linear-quadratic problem is not correct up to first order. King, Plosser, and Rebelo (1988, 2002) use instead a loglinear-quadratic approximation of the model's (nonlinear) optimality conditions.

However, the limitations of this method need to be kept in mind. Ascari and Merkl (2007) show the shortcomings of loglinearizations in a model with a disinflation experiment. The economy moves from one steady state with high inflation to a new steady state with low inflation. Especially with respect to inflation at the starting point (the first steady state) of the disinflation experiment, the economic results may differ dramatically.

Summing up, loglinear approximations are suitable if (i) the nonlinearities are not essential (in contrast to models in finance where risk matters) and (ii) the model analyzes only small deviations from the steady state. In our model, we derived the optimality conditions for the household in Section 2.1 and for the firm in Section 2.2, i.e., before taking the loglinear approximation. Next, we loglinearize the model around a steady state with no inflation.

Like a closed economy, the model's core equations are an IS curve, a Phillips curve and a monetary policy rule for each country. In an open economy, we need additionally goods market clearing for each country as consumption may deviate from output and, to link the three economies, two international risk sharing conditions. For convenience, we use two shorthand notations. First, the real marginal costs, $\hat{mc}_t^i$, and, second, the frequently used CPI-PPI ratio, $\hat{g}_{i,t}(ToT)$. To analyze monetary policy under ERM 2, we also back out CPI inflation, $\hat{\pi}_t^i$, and the change in the nominal exchange rate, $\Delta\hat{S}_{i',t}^i$, where an increase corresponds to a change in the rate of depreciation of the currency in country *i*. Country *A* is the accession country. Equations of the loglinearized model for country *A*:

$$\hat{C}_t^A = \hat{C}_{t+1}^A - \frac{1}{\mu}\hat{R}_t^A + \frac{1}{\mu}\hat{\pi}_{A,t+1}^A + \frac{v_B^A}{\mu}\hat{ToT}_{B,t+1}^A - \frac{v_B^A}{\mu}\hat{ToT}_{B,t}^A + \frac{v_C^A}{\mu}\hat{ToT}_{C,t+1}^A - \frac{v_C^A}{\mu}\hat{ToT}_{C,t}^A \tag{48}$$

$$\hat{\pi}_{A,t}^A = \beta\,\hat{\pi}_{A,t+1}^A + \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\hat{mc}_t^A \tag{49}$$

$$\hat{mc}_t^A = \mu\hat{C}_t^A + \gamma\hat{Y}_t^A - (1+\gamma)\hat{F}_t^A + \hat{g}_{A,t}(ToT) \tag{50}$$

$$\hat{g}_{A,t}(ToT) = v_B^A\,\hat{ToT}_{B,t}^A + v_C^A\,\hat{ToT}_{C,t}^A \tag{51}$$

$$\hat{R}_t^A = \varphi_\pi\,\hat{\pi}_t^A + \varphi_Y\,\hat{Y}_t^A + \varphi_S\,\Delta\hat{S}_{C,t}^A \tag{52}$$

$$\begin{aligned}\hat{Y}_t^A &= v_A^A \hat{C}_t^A + \theta v_A^A \hat{g}_{A,t}(ToT) - (\psi - \theta) v_B^A \left[1 - \eta(1 - n_A)\right] \hat{T}oT_{B,t}^A \\ &+ v_B^A \hat{C}_t^B + \theta v_B^A \hat{g}_{B,t}(ToT) + (\psi - \theta) v_B^A \eta n_A \hat{T}oT_{A,t}^B + \psi v_B^A \hat{T}oT_{B,t}^A \\ &+ v_C^A \hat{C}_t^C + \theta v_C^A \hat{g}_{C,t}(ToT) + (\psi - \theta) v_C^A n_A \hat{T}oT_{A,t}^C \\ &+ (\psi - \theta) v_C^A (1 - n_A) \hat{T}oT_{B,t}^C + \psi v_C^A \hat{T}oT_{C,t}^A\end{aligned} \tag{53}$$

$$\hat{\pi}_t^A = \hat{\pi}_{A,t}^A + v_B^A \hat{T}oT_{B,t}^A - v_B^A \hat{T}oT_{B,t-1}^A + v_C^A \hat{T}oT_{C,t}^A - v_C^A \hat{T}oT_{C,t-1}^A \tag{54}$$

$$\Delta \hat{S}_{C,t}^A = \hat{T}oT_{C,t}^A - \hat{T}oT_{C,t-1}^A + \hat{\pi}_{A,t}^A - \hat{\pi}_{C,t}^C \tag{55}$$

Consumption in this economy is determined by expected consumption, the interest rate, expected domestic inflation as well as expected changes in the terms of trade between country *A* and countries *B* and *C*, the dynamic IS curve (48). Inflation, in turn, is determined by the forward-looking Phillips curve (49), which reflects the impact of marginal costs on inflation. To guarantee determinacy the monetary policy rule (52) needs to respond to inflation by more than one to one and thereby fulfill the Taylor principle (Woodford 2003). A productivity shock for country *A* would reduce marginal costs (50) and thereby reduce inflation. The central bank would react to lower inflation with an interest rate cut. Consumers would respond to a lower interest rate with increases in today's consumption. In a closed economy, the changes in consumption would lead to equal changes in output. In an open economy, the lower interest rate improves also the terms of trade and thereby the increase in domestic output is shared with the rest of the world (goods market clearing, equation 53).

The equations for countries *B* and *C* mirror those for country *A* except for the international risk sharing condition (equations 56 and 57). In a three-country model, we need two risk sharing conditions to link financial markets

$$\hat{C}_t^A = \hat{C}_t^B + \frac{1}{\mu} \hat{T}oT_{B,t}^A + \frac{1}{\mu} g_{B,t}(ToT) - \frac{1}{\mu} g_{A,t}(ToT) \tag{56}$$

$$\hat{C}_t^A = \hat{C}_t^C + \frac{1}{\mu} \hat{T}oT_{C,t}^A + \frac{1}{\mu} g_{C,t}(ToT) - \frac{1}{\mu} g_{A,t}(ToT). \tag{57}$$

Calibration

The numerical solution requires calibrating the structural parameters of the model (Table 3). Most parameters are standard in the real business cycle literature. The discount factor β

equals 0.99, so that the steady state annual real interest rate is 4 percent. The period utility function has a risk aversion of 2 to depart from the case of logarithmic utility[5] and an inverse of the labor supply of 3. The Calvo price staggering parameter is set to 0.75, implying an average frequency of price adjustment of four quarters (Galí 2003).

In the three-country model, we explicitly consider different types of production sharing. The elasticity of substitution between goods from two countries follows Backus, Kehoe and Kydland (1995). We take this conventional assumption for the elasticity between goods from the core country C and the two periphery countries A and B and set θ equal to 1.5. Within the two periphery countries, we distinguish two scenarios. Countries A and B producing complements implies vertical integration along the production chain. We follow Burstein, Kurz and Tesar (2008) and model complements with a relatively low elasticity of substitution as ψ equals 0.05. Their calibration is based on survey data on outsourcing and offshoring in eastern Europe reported in Marin (2006). Horizontal production sharing implies countries producing substitutes. To model strong substitutes, we follow De Paoli (2006) and set ψ equal to 3.

As we focus on the qualitative results, we do not calibrate the model for specific countries. In the benchmark calibration, each country's size is 1/3 and there is no home bias in consumption, i.e., η equals 1. We relax this assumption and introduce home bias as a robustness check (η equals 0.5).

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[5] External shocks would not affect the home country under complete markets and logarithmic utility (Ghironi 2006: 429).

Table 3: Calibration of the Model

Structural Parameters		Calibration
α	Calvo staggering	0.75
β	subjective discount factor	0.99
γ	inverse of the elasticity of labor supply	3
μ	risk aversion	2
θ	elasticity of substitution between country *C* vs. *P*	1.5
ψ	elasticity of substitution between country *A* vs. *B*	0.05 (complements) 3 (substitutes)
ρ	autocorrelation of technology shock process	0.9
η	degree of openness	1 (completely open) 0.5 (with home bias)
n_P	size of country *C* vs. *P*	2/3
n_A	size of country *A* vs. *B*	0.5

3 Simulation Results

3.1 Technology Shock in a Two-Country Model

In order to provide a benchmark for the value added of this model, we briefly revisit a technology shock in a two-country model, where the two countries produce complements in one case and strong substitutes in the other case.[6] We analyze the impulse responses with respect to consumption, output, and domestic inflation. The technology shock process is modeled by a first order autoregressive process to productivity in country *B*

$$\hat{F}_t^B = \rho^B \hat{F}_{t-1}^B + \varepsilon_t^B , \tag{58}$$

where the persistence parameter ρ^B is set to 0.9 (see Faia 2007).

As already pointed out by Mundell (1961), monetary policy faces difficulties of dealing with asymmetric shocks in a monetary union. If the two countries produce complements to each other, output would increase in both countries (Figure 1, Table 4). The technology shock, however, reduces inflation only in country *B*. In country *A,* higher consumption and a higher production increase marginal costs (50) and thereby domestic inflation increases (49). Thus, the inflation rates in the two countries would be negatively correlated. If, in contrast, the two countries produce strong substitutes, output would be negatively correlated (Figure 2). The

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[6] In this two-country example both central banks target domestic inflation.

technology shock would again reduce the price of products from country *B*. The consumers in country *A* would switch from their own products to the cheaper imports from country *B*. Consequently, output would fall only in country *A*, but inflation would fall in both countries. For both cases, we may distinguish between a central bank of the monetary union that is dominated by one country and a central bank of the union that targets the average of the two countries. Obviously, given the negative correlations in either inflation or output, a monetary policy in favor of one country would be inadequate for the other country. If the central bank bases its decisions on the union-wide aggregates, the negative correlations would partly offset each other and none of the two countries would benefit from an appropriate monetary policy.

Table 4: Correlation Coefficients of Inflation and Output in a Two-Country Model

	Inflation	Output
Complements	-0.24	0.69
Substitutes	0.07	-1.10

Figure 1: Technology Shock in a Two-Country Model, Complements

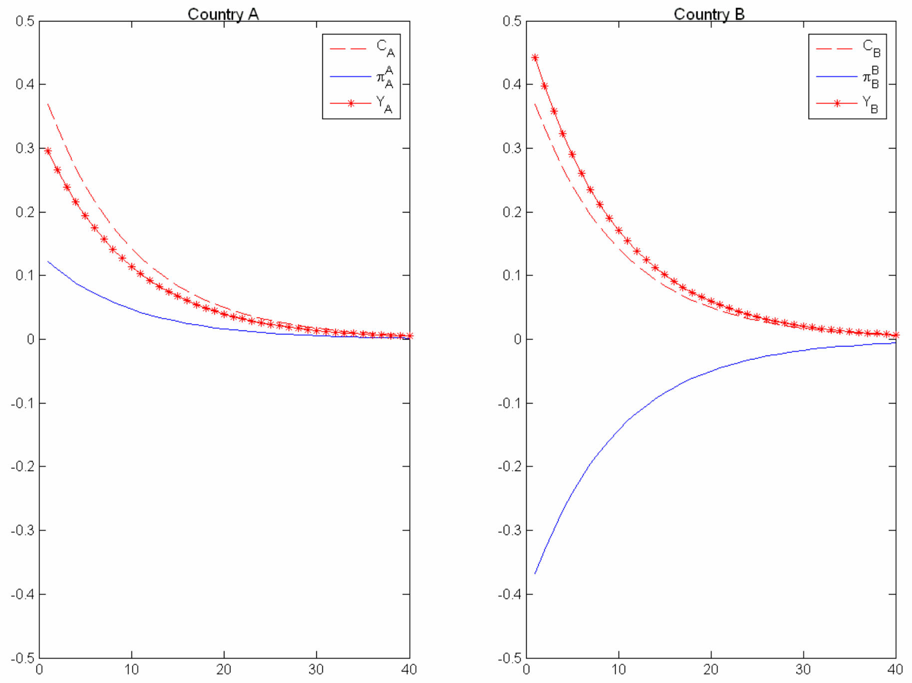
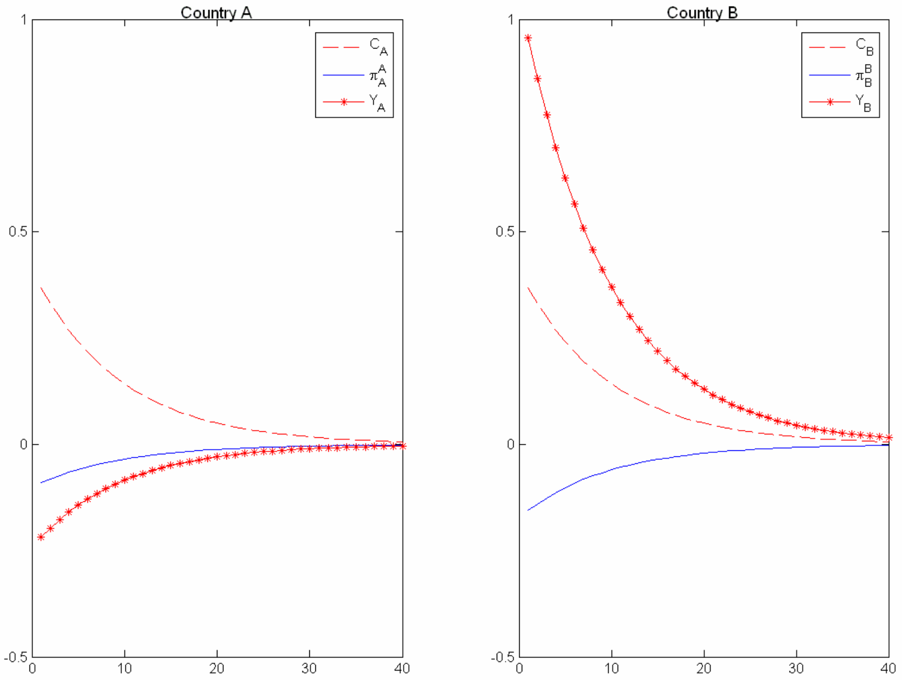


Figure 2: Technology Shock in a Two-Country Model, Substitutes



3.2 Technology Shock in a Three-Country Model

The three-country model with a nested consumption basket studies the transmission of a technology shock in the third country (country *B*) and its implications for monetary policy in the accession country (country *A*).[7] The model addresses the run up to a monetary union as the central bank in country *A* may have to target the exchange rate vis-à-vis the anchor country *C*. Further, the model emphasizes the implications of asymmetric production sharing among the three countries. Countries *A* and *C* are not affected by the third-country shock in the same way. Thus, under fully flexible exchange rates, the exchange rate between countries *A* and *C* would also bear part of the adjustment. In particular, this model distinguishes between countries *A* and *B* producing complements and strong substitutes.

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[7] In principle, the model could be extended to the analysis of monetary shocks. Such a shock could be implemented by a reduction in the third country's interest rate, which could be interpreted as a competitive devaluation or contagion following a financial crisis. The evaluation of simple monetary policy rules could give insights on the strategic costs of ERM 2 and giving up a floating exchange rate for the accession country. We leave this for future research and focus on a third-country technology shock.

We evaluate the effects of eight different simple monetary policy rules (52) for country *A,* the euro area accession country. Rules 1 and 2 in Table 5 stand for strict inflation targeting, where rule 1 targets the domestic (i.e., core) inflation rate and rule 2 targets the inflation of the consumer price index (CPI). Their respective Taylor rule counterparts are rules 3 and 4, including output targeting. Rules 5 to 8 add an exchange rate term to rules 1 to 4 in order to investigate the implications of exchange rate targeting under ERM 2. For the impulse responses presented in the graphs, we focus on the traditional CPI inflation Taylor rule (rule 4) and adding an exchange rate term for ERM 2 (rule 8).

Countries *B* and *C* conduct strict domestic inflation targeting, $\varphi_{\pi_i^i}$ equals 1.5. The central bank in country *B* neither mitigates the effect of the technology shock on output nor second-round effects from abroad showing up in CPI inflation. Otherwise, positive weights for output targeting in the monetary policy rule would reduce the shock in country *B* and, hence, also its impact on the other countries. Countries *B* and *C* are assumed to produce substitutes throughout the simulations. Hence, their output reactions are negatively correlated. Again, a positive weight for output targeting in the monetary policy rule of country *C* would dampen the (inverse) shock in the anchor currency country. Any weight on output targeting in the monetary policy rules of countries *B* and *C* would lead to biased results with respect to the analysis of monetary policy in country *A*.

Table 5: Simple Monetary Policy Rules for Country *A*

Monetary Policy Rule		$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S
Rule 1	domestic inflation targeting	1.5	–	–	–
Rule 2	CPI inflation targeting	–	1.5	–	–
Rule 3	domestic inflation Taylor rule	1.5	–	0.5	–
Rule 4	CPI inflation Taylor rule	–	1.5	0.5	–
Rule 5	domestic inflation targeting under ERM 2	1.5	–	–	0.5
Rule 6	CPI inflation targeting under ERM 2	–	1.5	–	0.5
Rule 7	domestic inflation Taylor rule under ERM 2	1.5	–	0.5	0.5
Rule 8	CPI inflation Taylor rule under ERM 2	–	1.5	0.5	0.5

As standard in the literature, we evaluate the different monetary policy rules based on the loss function of the central bank. The central bank wishes to minimize volatility in output and inflation (Monacelli 2005).[8] The loss function is defined as

$$L_0^{CB} = E_0 \sum_{t=0}^{\infty} \delta^t \left(\lambda_\pi \hat{\pi}_t^2 + \lambda_Y \hat{Y}_t^2 \right), \tag{59}$$

where $0 < \delta < 1$ is a discount factor. Woodford (2003) shows that such a loss function is consistent with maximizing a social utility function in a closed economy setup. Both, society as well as the Maastricht criteria specify inflation measured by the CPI. As weights in the loss function we take $\lambda_\pi = \lambda_Y = 0.5$.

However, although such a loss function is meaningful as a benchmark for the evaluation of monetary policy, it would be incomplete for the case of regional monetary integration. If the central bank in country *A* would not give any positive weight to exchange rate smoothing, it would be difficult to establish the case for integrating into EMU. Hence, we assume that the central bank minimizes the volatility in the exchange rate as an additional objective. In case the central bank operates under ERM 2, the loss function with a positive weight on exchange rate smoothing could be defined as

$$L_0^{ERM2} = E_0 \sum_{t=0}^{\infty} \delta^t \left(\lambda_\pi \hat{\pi}_t^2 + \lambda_Y \hat{Y}_t^2 + \lambda_S \Delta \hat{S}_t^2 \right), \tag{60}$$

where $\lambda_\pi = 1$ and $\lambda_Y = \lambda_S = 0.5$. The value of the intertemporal loss functions approaches the unconditional mean of the period loss functions as $\delta \to 1$, which equals the sum of the unconditional variances of the policy objectives.

Thus, the two loss functions for country *A* are

$$\text{Loss CB: } \quad 0.5\left(\pi^A\right)^2 + 0.5\left(\hat{Y}^A\right)^2 \tag{61}$$

$$\text{Loss ERM 2: } \quad \left(\pi^A\right)^2 + 0.5\left(\hat{Y}^A\right)^2 + 0.5\left(\Delta \hat{S}_C^A\right)^2. \tag{62}$$

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[8] In principle, it would be possible to calculate welfare as a second-order approximation to the representative agent's utility function, see Benigno (2004), Pappa (2004), De Paoli (2006), Lipińska (2006), and Liu and Pappa (2007). We take the perspective of the policy maker and focus on the central bank's loss function.

Technology Shock I: Countries A and B Producing Complements

We start by analyzing the case where countries *A* and *B*, the two periphery countries, produce complements, while the periphery goods and country *C*'s goods are substitutes. A common feature for all countries stems from international risk sharing. Consequently, in the absence of home bias in consumption, the technology shock is evenly distributed and leads to equal increases in consumption in the three countries (see equation 41).

First, we consider the impulse responses according to rule 4, when country *A* conducts a CPI inflation Taylor rule without exchange rate smoothing (Figure 3, left column). Following the technology shock in country *B*, output in that country increases. Country *A*, producing complements to country *B*, benefits by a significant increase in its output. Country *C* in contrast looses output as its consumers substitute home goods by the products from the periphery countries *A* and *B,* taking also upward pressure from prices. As a consequence, inflation decreases in all countries. However, the decline in prices is more pronounced in country *A* than in country *C*. The inflation differential leads to an increased appreciation of country *A*'s currency vis-à-vis country *C*'s currency (Figure 3, right column, dashed line).

Second, we turn to the case when country *A*'s central bank operates under ERM 2 (Figure 3, middle column). The exchange rate between country *A* and *C* is not allowed to adjust to the full extent as the central bank in country *A* conducts a CPI inflation Taylor rule augmented for exchange rate smoothing (rule 8). As implicitly uncovered interest rate parity holds in the model, the central bank of country *A* has to reduce its interest rate in order to counter the appreciation vis-à-vis the anchor currency, thereby driving up inflation at home. Table 6 shows how volatility in domestic as well as CPI inflation increases when comparing the rules without an exchange rate term (rules 1 to 4) with their ERM 2 counterparts (rules 5 to 8). Hence, with relatively stable exchange rates, domestic inflation in country *A* increases sharply, displaying the costs of an asymmetric shock under exchange rate targeting.

Figure 3: Technology Shock in a Three-Country Model, Complements

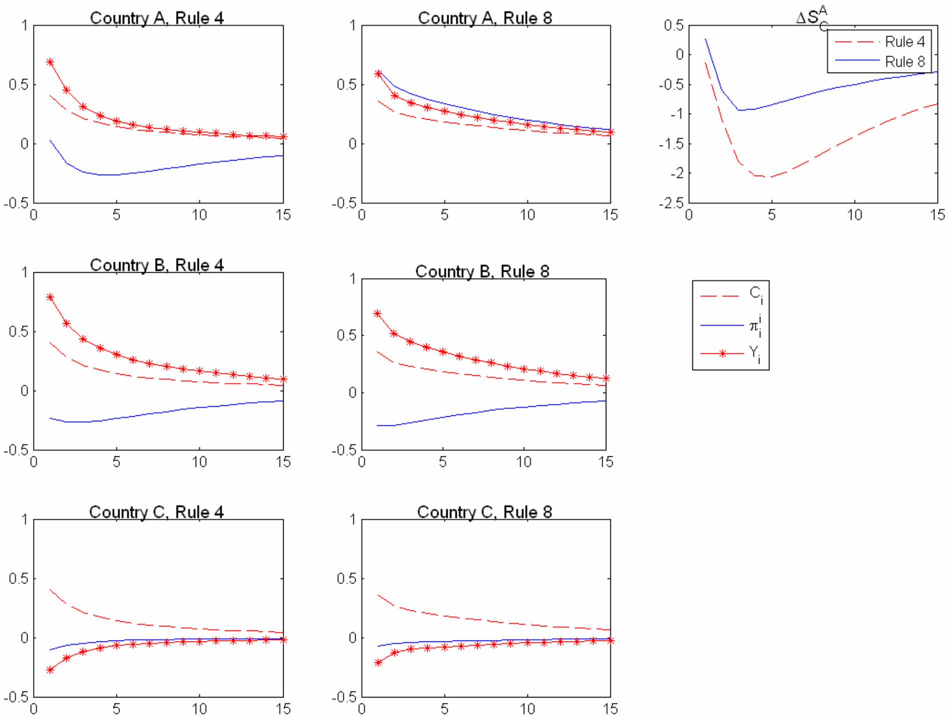

Table 6: Performance of Simple Monetary Policy Rules, Complements

Rule		Standard Deviation					Loss	
		π_A^A	π^A	Y^A	ΔS_C^A	C^A	CB	ERM 2
Rule 1	domestic inflation targeting	0.33	1.35	0.8	4.59	0.56	1.23	12.67
Rule 2	CPI inflation targeting	0.46	0.37	1.11	4.71	0.70	0.68	11.85
Rule 3	domestic inflation Taylor rule	0.19	1.57	0.70	5.76	0.52	1.49	19.34
Rule 4	CPI inflation Taylor rule	0.77	1.03	0.99	5.96	0.64	1.02	19.33
Rule 5	domestic inflation ERM 2	1.65	1.86	1.01	1.69	0.67	2.24	5.40
Rule 6	CPI inflation ERM 2	1.51	1.43	1.10	1.91	0.71	1.63	4.48
Rule 7	domestic Taylor ERM 2	1.39	1.71	0.96	2.28	0.65	1.92	5.98
Rule 8	CPI Taylor ERM 2	1.24	1.22	1.05	2.44	0.68	1.30	5.02

Table 7: Ratio of Loss for Joining ERM 2, Complements

Ratio	Rule	Loss CB	Loss ERM 2
Rule 5 / Rule 1	domestic inflation targeting	1.82	0.43
Rule 6 / Rule 2	CPI inflation targeting	2.39	0.38
Rule 7 / Rule 3	domestic inflation Taylor rule	1.29	0.31
Rule 8 / Rule 4	CPI inflation Taylor rule	1.28	0.26

To analyze the relative change in the central bank loss of joining ERM 2, we construct the ratio of the loss for each monetary policy rule with an exchange rate term over its counterpart without that term (Table 7). Moving to ERM 2 more than doubles the loss for the traditional central bank loss function (Loss CB) as it increases up to 2.39-times. For the two Taylor rules 3 and 4 moving to their ERM 2 counterparts still increases the loss but by less than 30 percent. If the central bank adapts ERM 2 as its policy targets (Loss ERM 2), the loss drops when adding the exchange rate to the policy rule to half or almost a quarter of the loss without exchange rate term (Table 7, last column).

Technology Shock II: Countries A and B Producing Substitutes

As it was in the case with countries *A* and *B* producing complements, the technology shock in country *B* increases consumption in all three countries by the same amount due to perfect international risk sharing when the two periphery countries produce strong substitutes (Figure 4). This time, however, the technology shock goes one to one into country *B*'s output. As not only country *A* but also country *C* produces substitutes to country *B,* output declines in both countries. Without a reaction of monetary policy to the shock, CPI inflation would decline in all three countries. However, country *A* conducting monetary policy with a CPI inflation Taylor rule (rule 4), the central bank reacts evenly to inflation and output

(Figure 4, left column). Table 8 shows how the volatility in domestic and CPI inflation as well as output falls when moving from strict inflation targeting (rules 1 and 2) to a Taylor rule (rules 3 and 4). As a result of the central bank lowering the interest rate to accommodate the decline in output, inflation in country *A* increases slightly. In the case of substitutes, the technology shock in country *B* affects only a little the exchange rate between countries *A* and *C*. The magnitude of the exchange rate reaction to the external shock is small with the peak of the devaluation at only 0.43 standard deviations compared to the peak of the appreciation at 2.07 standard deviations in the case of complements. Thus, moving to a monetary policy rule consistent with ERM 2, where the interest rate reacts also to movements in the exchange rate (rule 8), exhibits less changes in the impulse responses as seen before in the case of complements in Figure 3. Table 8 shows that volatility in the domestic and CPI inflation as well as output has to increase in order to reduce volatility in the exchange rate (rules 1 to 4 versus rules 5 to 8).

Figure 4: Technology Shock in a Three-Country Model, Substitutes

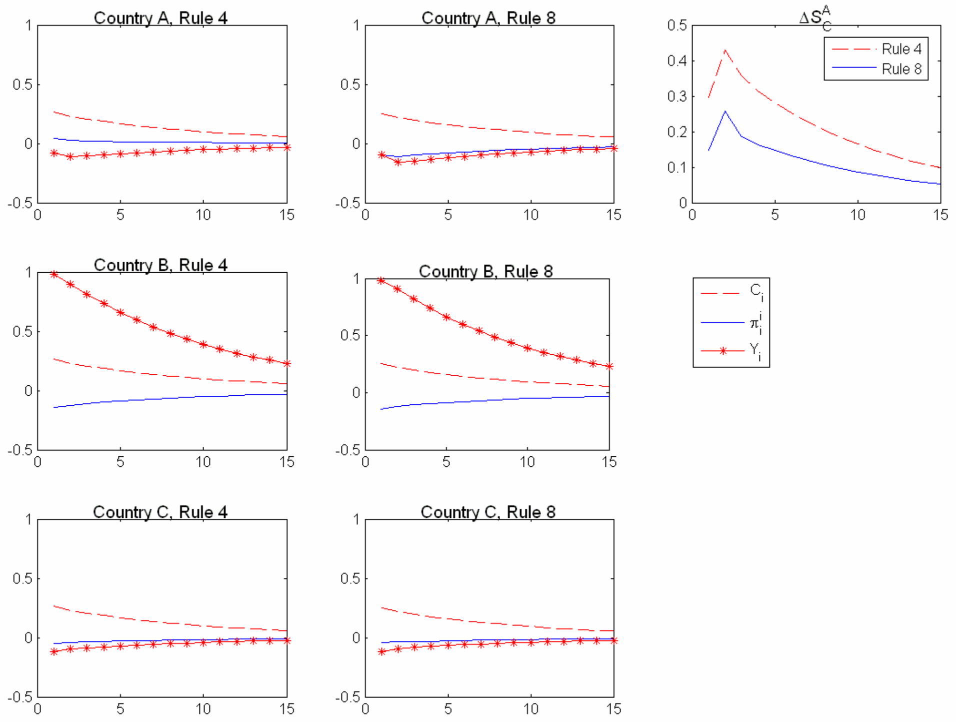

Table 8: Performance of Simple Monetary Policy Rules, Substitutes

Rule		Standard Deviation					Loss	
		π_A^A	π^A	Y^A	ΔS_C^A	C^A	CB	ERM 2
Rule 1	domestic inflation targeting	0.16	0.19	0.38	0.63	0.56	0.092	0.3104
Rule 2	CPI inflation targeting	0.18	0.20	0.35	0.65	0.57	0.081	0.3095
Rule 3	domestic inflation Taylor rule	0.08	0.10	0.30	0.96	0.58	0.050	0.5121
Rule 4	CPI inflation Taylor rule	0.07	0.06	0.28	0.95	0.59	0.042	0.4992
Rule 5	domestic inflation ERM 2	0.41	0.44	0.45	0.30	0.55	0.199	0.3403
Rule 6	CPI inflation ERM 2	0.43	0.45	0.43	0.31	0.55	0.194	0.3423
Rule 7	domestic Taylor ERM 2	0.26	0.28	0.40	0.51	0.56	0.121	0.2901
Rule 8	CPI Taylor ERM 2	0.27	0.29	0.39	0.51	0.56	0.117	0.2908

Table 9: Ratio of Loss for Joining ERM 2, Substitutes

Ratio	Rule	Loss CB	Loss ERM 2
Rule 5 / Rule 1	domestic inflation targeting	2.17	1.10
Rule 6 / Rule 2	CPI inflation targeting	2.40	1.11
Rule 7 / Rule 3	domestic inflation Taylor rule	2.41	0.57
Rule 8 / Rule 4	CPI inflation Taylor rule	2.79	0.58

Concerning the consequences for the loss function (Loss CB), adding the exchange rate more than doubles the loss for all four rules (Table 9). However, the loss for the classical CPI inflation Taylor rule increases 2.79-times when the exchange rate term is incorporated. For the strict inflation targeting rules (rules 1 and 2), the loss for an ERM 2 central bank (Loss ERM 2) is virtually alike with or without the exchange rate term as the ratio is close to 1. For the two Taylor rules (rules 3 and 4), the loss halves.

The evaluation of simple monetary policy rules leads us to the following conclusions (Table 10). For countries *A* and *B* producing complements the CPI inflation Taylor rule with exchange rate smoothing (rule 8), shows in the ranking a remarkably good performance for Loss ERM 2. Under Loss CB, this rule even outperforms the domestic inflation Taylor rule (rule 3). For countries *A* and *B* producing substitutes, each of the monetary policy rules without an exchange rate term performs better than the rules that are in line with ERM 2 under the traditional central bank loss function. This result does not hold when adjusting the central bank loss function to take into account exchange rate smoothing (Loss ERM 2). The last two columns of Table 10 serve as a robustness check in case the kind of production sharing is not known. Under a traditional central bank loss function (Loss CB) the best performance is given by rule 4, the traditional CPI inflation Taylor rule. In case the central bank operates under ERM 2 (Loss ERM 2), the best results are achieved by the CPI inflation Taylor rule with exchange rate smoothing (rule 8).

Table 10: Ranking of Simple Monetary Policy Rules

Rule		Complements		Substitutes		Sum	
		Loss CB	Loss ERM 2	Loss CB	Loss ERM 2	Loss CB	Loss ERM 2
Rule 1	domestic inflation targeting	3	6	4	4	7	10
Rule 2	CPI inflation targeting	1	5	3	3	4	8
Rule 3	domestic inflation Taylor rule	5	8	2	8	7	16
Rule 4	CPI inflation Taylor rule	2	7	1	7	3	14
Rule 5	domestic inflation ERM 2	8	3	8	5	16	8
Rule 6	CPI inflation ERM 2	6	1	7	6	13	7
Rule 7	domestic Taylor ERM 2	7	4	6	1	13	5
Rule 8	CPI Taylor ERM 2	4	2	5	2	9	4

Robustness Checks

As a robustness check, we introduce home bias in consumption in all three countries by setting the parameter for openness, η, equal to 0.5. The home bias affects also the nested consumption basket as we could think of a bias not only towards home goods but also towards goods from the periphery countries generally. The altered trade shares are shown in Table 11. Country A trades not anymore as much as before with countries B and C. The technology shock in country B affects country A less, leading to strictly lower losses for the central bank. The ranking of the eight monetary policy rules alters only little in the case of complements and not at all for substitutes (Table 12 and Appendix A1).

Table 11: Trade Shares under Home Bias in Consumption

Country A	Country B	Country C
$v_A^A = 0.6250$	$v_A^B = 0.2083$	$v_A^C = 0.1667$
$v_B^A = 0.2083$	$v_B^B = 0.6250$	$v_B^C = 0.1667$
$v_C^A = 0.1667$	$v_C^B = 0.1667$	$v_C^C = 0.6667$

Note: Trade shares are based on relative country size $n_A = 0.5$ and $n_P = 2/3$ and degree of openness $\eta = 0.5$.

Table 12: Ranking of Simple Monetary Policy Rules, Home Bias

Rule		Complements		Substitutes		Sum	
		Loss CB	Loss ERM 2	Loss CB	Loss ERM 2	Loss CB	Loss ERM 2
Rule 1	domestic inflation targeting	2	5	4	4	6	9
Rule 2	CPI inflation targeting	1	6	3	3	4	9
Rule 3	domestic inflation Taylor rule	4	7	2	8	6	15
Rule 4	CPI inflation Taylor rule	3	8	1	7	4	15
Rule 5	domestic inflation ERM 2	8	3	8	5	16	8
Rule 6	CPI inflation ERM 2	7	1	7	6	14	7
Rule 7	domestic Taylor ERM 2	6	4	6	1	12	5
Rule 8	CPI Taylor ERM 2	5	2	5	2	10	4

3.3 Optimal Simple Rules in a Three-Country Model

In this section, we identify optimal monetary policy rules by minimizing the central bank loss function. The Matlab routine `fminsearch` is an unconstrained nonlinear optimization using the Simplex search method of Lagarias, Reeds, Wright, and Wright (1998). The method does not rely on numerical or analytical gradients and may therefore handle discontinuity. The search starts from initial values and may only give a local solution. We take the parameters of the respective simple monetary policy rules specified in Table 5 as starting values. As the method is unconstrained, it searches the entire parameter space and may find optimal coefficients minimizing the loss for implausible policy parameters.

To circumvent this problem, we follow Schmitt-Grohé and Uribe (2007) and conduct additionally a grid search.[9] Rules 3 to 6 are evaluated on a grid in 0.05 steps for $\varphi_{\pi_i^i}$ or φ_{π^i} from 1 to 3 and for φ_Y or φ_S from 0 to 1.51. The grid for rules 7 and 8 is in 0.1 steps for $\varphi_{\pi_i^i}$ or φ_{π^i} from 1 to 3 and for φ_Y or φ_S from 0 to 1.51. Our interpretation focuses on the optimal simple rules based on that grid search. We limit our attention on the traditional Taylor rule (rule 4) and its ERM 2 counterpart with an exchange rate term (rule 8).[10]

The traditional central bank loss function (Loss CB) minimizes the volatility in CPI inflation and output. All results in Tables 13 and 15, including those based on `fminsearch`, in

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[9] Rules 1 and 2 are only one-dimensional and are therefore not evaluated on a grid. The density of the grid needs to be adjusted in the case of three parameters to avoid the well-known curse of dimensionality (Miranda and Fackler 2002).

[10] The results with home bias in consumption are extremely similar (Appendix Tables A5 to A8).

general adhere to the Taylor principle (Woodford 2003). Most of the time, there is no role for targeting the exchange rate as the respective coefficient is zero. Only in the case of complements, rules 6 and 8 find a positive but small coefficient for the exchange rate term (Table 13). In the analysis of simple monetary policy rules, we already saw that the exchange rate between countries *A* and *C* is hardly affected in the case of substitutes. However, in the case of complements, the exchange rate bears part of the macroeconomic adjustment. The exchange rate plays a more important role in the model with complements than in the model with substitutes. The analysis of optimal simple rules confirms the findings of Svensson (2003: 442), who states: "A first obvious problem for a Taylor-type rule, with or without interest-rate smoothing, is that, if there are other important state variables than inflation and the output gap, it will not be optimal." The numerical analysis reveals that the exchange rate approximates other important state variables of the model in the case of complements but not in the case of substitutes. Having an additional policy parameter available pays off as even a small exchange rate coefficient of 0.1 reduces the central bank loss to 0.64 down from 0.67 (Table 13, rules 4 and 8).

If the loss function captures the requirements of ERM 2 (Loss ERM 2) and therefore the central bank aims to additionally reduce volatility in the exchange rate, the monetary policy rules with the lowest loss include the exchange rate as a target. If the central bank includes an exchange rate in the monetary policy rule, the Taylor principle is occasionally violated (Tables 14 and 16). For a technology shock being the only disturbance, the optimal coefficients are in general lower for production sharing via complements than via substitutes. In the latter case, the exchange rate has the same weight as inflation (Table 16, rule 8). This result applies also with home bias in consumption (Appendix Table A8).

Table 13: Optimal Simple Rules, Complements, Loss CB

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss CB	Variance	
							π^A	Y^A
Rule 1	Fminsearch	1.29565	–	–	–	1.219640	1.7629	0.6764
Rule 2	Fminsearch	–	2.01042	–	–	0.669571	0.0508	1.2883
Rule 3	Fminsearch	1.29552	–	8.98453e-005	–	1.219640	1.7629	0.6764
	Grid search	1.3	–	0	–	1.219650	1.7642	0.6752
Rule 4	Fminsearch	–	1.00253	-0.162455	–	0.646189	0.0510	1.2414
	Grid search	**–**	**2**	**0**	**–**	**0.669573**	**0.0517**	**1.2875**
Rule 5	Fminsearch	1.03148	–	–	-0.0280402	1.189650	1.7064	0.6729
	Grid search	1.3	–	–	0	1.219650	1.7642	0.6752
Rule 6	Fminsearch	–	1.15006	–	0.0268152	0.636567	0.1259	1.1472
	Grid search	–	1.6	–	0.05	0.645318	0.0692	1.2215
Rule 7	Fminsearch	1.02709	–	0.0222517	-0.0244431	1.193740	1.7142	0.6733
	Grid search	1.3	–	0	0	1.219650	1.7642	0.6752
Rule 8	Fminsearch	–	0.986577	-0.0645642	0.0128559	0.636252	0.1226	1.1499
	Grid search	**–**	**2**	**0.3**	**0.1**	**0.637657**	**0.1208**	**1.1545**

Table 14: Optimal Simple Rules, Complements, Loss ERM 2

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss ERM 2	Variance		
							π^A	Y^A	ΔS_C^A
Rule 1	Fminsearch	1	–	–	–	5.81508	2.2870	0.9289	6.1273
Rule 2	Fminsearch	–	2.06158e+012	–	–	9.04763	0.0000	1.3926	16.7027
Rule 3	Fminsearch	1.00213	–	-0.0851034	–	4.90540	3.3575	1.1037	1.9921
	Grid search	1	–	0.05	–	7.05050	1.9478	0.8415	9.3639
Rule 4	Fminsearch	–	11.3824	-8.45006	–	5.70174	1.0793	1.7714	7.4735
	Grid search	**–**	**3**	**0**	**–**	**9.89654**	**0.0164**	**1.3329**	**18.4274**
Rule 5	Fminsearch	0.97303	–	–	0.0240273	4.93290	3.3747	1.0976	2.0187
	Grid search	1	–	–	0.05	4.96559	3.3362	1.0840	2.1748
Rule 6	Fminsearch	–	0.993576	–	0.130897	4.39416	2.1007	1.3280	3.2589
	Grid search	–	1	–	0.15	4.40392	2.2836	1.3322	2.9084
Rule 7	Fminsearch	0.848377	–	0.385686	0.12972	5.04889	3.3308	1.0636	2.3725
	Grid search	1	–	0.1	0.1	5.04632	3.2389	1.0560	2.5589
Rule 8	Fminsearch	–	0.900737	0.0663188	0.0875105	4.39003	2.0795	1.3330	3.2880
	Grid search	**–**	**1**	**0.1**	**0.2**	**4.40475**	**2.3042**	**1.2828**	**2.9182**

Table 15: Optimal Simple Rules, Substitutes, Loss CB

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss CB	Variance	
							π^A	Y^A
Rule 1	Fminsearch	6.32156e+006	–	–	–	0.0570222	0.0055	0.1086
Rule 2	Fminsearch	–	2.47116e+012	–	–	0.0401281	0.0000	0.0803
Rule 3	Fminsearch	30.1037	–	11.853	–	0.0495594	0.0143	0.0848
	Grid search	2.55	–	1	–	0.0495594	0.0143	0.0848
Rule 4	Fminsearch	–	1.18711e+009	736567	–	0.0401213	0.0000	0.0802
	Grid search	**–**	**3**	**0.95**	**–**	**0.0405818**	**0.0051**	**0.0760**
Rule 5	Fminsearch	3.16537e+008	–	–	-1.25152e+006	0.0570221	0.0056	0.1085
	Grid search	3	–	–	0	0.0642976	0.0095	0.1191
Rule 6	Fminsearch	–	6.46762e+007	–	-4.5584e+006	0.0371697	0.0050	0.0693
	Grid search	–	3	–	0	0.0480413	0.0035	0.0926
Rule 7	Fminsearch	1.04055	–	0.23504	-0.046206	0.0508892	0.0146	0.0872
	Grid search	1.1	–	1.5	0.3	0.0467120	0.0119	0.0816
Rule 8	Fminsearch	–	1.3221	-0.244637	-0.212216	0.0310472	0.0117	0.0504
	Grid search	**–**	**3**	**0.9**	**0**	**0.0405892**	**0.0043**	**0.0769**

Table 16: Optimal Simple Rules, Substitutes, Loss ERM 2

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss ERM 2	Variance π^A	Variance Y^A	Variance ΔS_C^A
Rule 1	Fminsearch	1.2746	–	–	–	0.294700	0.0774	0.1697	0.2650
Rule 2	Fminsearch	–	1.30269	–	–	0.293541	0.0827	0.1439	0.2779
Rule 3	Fminsearch	1.27441	–	0.00012667	–	0.294700	0.0774	0.1697	0.2650
	Grid search	1.2	–	0.05	–	0.294783	0.0739	0.1679	0.2739
Rule 4	Fminsearch	–	0.99373	0.205343	–	0.290535	0.0795	0.1503	0.2717
	Grid search	**–**	**1**	**0.2**	**–**	**0.290590**	**0.0814**	**0.1509**	**0.2675**
Rule 5	Fminsearch	2.9138	–	–	0.798454	0.289506	0.0781	0.1592	0.2637
	Grid search	2.9	–	–	0.8	0.289510	0.0788	0.1596	0.2618
Rule 6	Fminsearch	–	1.36127	–	0.0319936	0.293514	0.0829	0.1442	0.2771
	Grid search	–	1.4	–	0.05	0.293536	0.0814	0.1437	0.2806
Rule 7	Fminsearch	2.95509	–	-0.0589136	0.773123	0.289506	0.0781	0.1592	0.2637
	Grid search	2.2	–	1.1	1.3	0.289507	0.0781	0.1592	0.2636
Rule 8	Fminsearch	–	0.699423	1.64128	0.974668	0.289414	0.0783	0.1575	0.2647
	Grid search	**–**	**1**	**1.5**	**1**	**0.289519**	**0.0771**	**0.1553**	**0.2694**

4 Conclusions

We analyze monetary policy given alternative degrees of integration between the euro area, an inflation targeting accession country like the Czech Republic, Hungary, Poland, and Slovakia, and a non-EU country as the third country.

The model developed in the paper is based on Teo (2005) and Monacelli (2001) and allows us to simulate the impact of a technology shock originating in a third country on an accession country considering feedback from the euro area as well. The New Keynesian three-country model incorporates explicit microfoundations with dynamic and intertemporal effects as well as Keynesian building blocks such as nominal rigidities and monopolistic competition. The core equations, i.e., the IS curve, the Phillips curve, and the monetary policy rule, are derived following Galí and Monacelli (2005). As a short-cut for modeling production linkages, we use alternative elasticities in consumption baskets. This allows us to trace the transmission mechanism of a third-country technology shock in the alternative cases that a third country produces complements or substitutes, i.e., that a third country is vertically or horizontally integrated with the accession country.

Evaluating the central bank loss function without ERM 2 (Loss CB) and with ERM 2 (Loss ERM 2) under strict inflation targeting and Taylor rules as well as both types of rules extended by exchange rate smoothing allows us to assess the costs of ERM 2 and derive the implications of production sharing for monetary policy. Optimal rules are derived by minimizing the central bank loss function. The Matlab routine `fminsearch` uses the entire parameter space and therefore tends to find optimal coefficients minimizing the loss for implausible policy parameters. To circumvent this problem, we follow Schmitt-Grohé and Uribe (2007) and conduct additionally a grid search.

The simulations reveal the following results. First, we revisit an asymmetric shock in a two-country model. A common monetary policy cannot address the implications of a technology shock on inflation and output adequately. Under production sharing via complements, inflation in one country is negatively correlated with inflation in the other country. If the two countries produce strong substitutes, output is negatively correlated.

Second, our simulation of a third-country technology shock show that the exchange rate between the accession country and the anchor currency country bears part of the adjustment if production sharing is via complements, but only little if the accession country and the third-country produce strong substitutes.

Third, our evaluation of simple monetary policy rules reveals that targeting the exchange rate, if the central bank has no exchange rate objective (Loss CB), increases the loss. The loss more than doubles in case the accession country and the third country produce substitutes. If the loss of the central bank takes into account the volatility of the exchange rate (Loss ERM 2), the CPI inflation Taylor rule augmented for exchange rate smoothing performs well under any type of production sharing.

Fourth, our results for optimal monetary policy rules depend on the assumed loss function of the central bank. For a traditional central bank loss function (Loss CB), minimizing volatility in CPI inflation and output, the exchange rate generally does not matter. However, having an additional policy parameter still pays off in the case of complements as even a small exchange rate coefficient of 0.1 reduces the central bank loss. If the loss function captures the requirements of ERM 2 (Loss ERM 2), i.e., exchange rate smoothing is an objective of the central bank, allowing for a reaction of the interest rate to the exchange rate lowers the loss. Further, the optimal coefficients are lower for production sharing via complements than via substitutes. In the latter case, the exchange rate has in fact the same coefficient in the optimal monetary policy rule as inflation.

All in all, the results show that a Taylor rule extended for an exchange rate term is a good simple rule for different kinds of integration with a third country and even in case the loss function does not account for a preference for exchange rate smoothing.

Appendix

A1 Technology Shock with Home Bias in Consumption

Figure A1: Technology Shock in a Three-Country Model, Complements, Home Bias ($\eta = 0.5$)

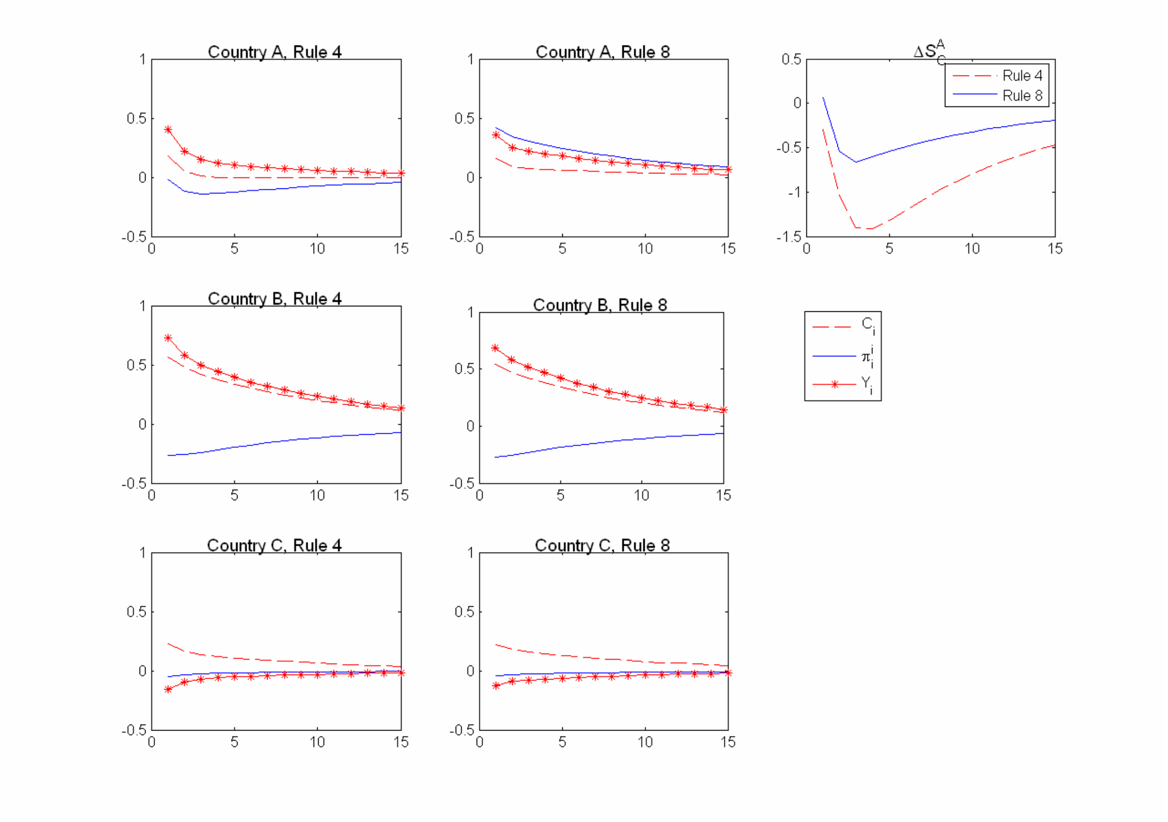

Table A1: Performance of Simple Monetary Policy Rules, Complements, Home Bias

Rule		Standard Deviation					Loss	
		π_A^A	π^A	Y^A	ΔS_C^A	C^A	CB	ERM 2
Rule 1	domestic inflation targeting	0.20	0.60	0.48	3.06	0.09	0.2976	5.1600
Rule 2	CPI inflation targeting	0.18	0.26	0.63	3.20	0.25	0.2342	5.3750
Rule 3	domestic inflation Taylor rule	0.11	0.69	0.41	3.70	0.04	0.3210	7.3843
Rule 4	CPI inflation Taylor rule	0.37	0.56	0.54	3.82	0.19	0.3039	7.7696
Rule 5	domestic inflation ERM 2	1.15	1.18	0.67	1.19	0.26	0.9209	2.3208
Rule 6	CPI inflation ERM 2	1.07	1.02	0.71	1.29	0.29	0.7781	2.1325
Rule 7	domestic Taylor ERM 2	0.96	1.03	0.63	1.56	0.22	0.7278	2.4756
Rule 8	CPI Taylor ERM 2	0.88	0.86	0.67	1.63	0.25	0.5964	2.2995

Table A2: Ratio of Loss for Joining ERM 2, Complements, Home Bias

Ratio	Rule	Loss CB	Loss ERM 2
Rule 5 / Rule 1	domestic inflation targeting	3.09	0.45
Rule 6 / Rule 2	CPI inflation targeting	3.32	0.40
Rule 7 / Rule 3	domestic inflation Taylor rule	2.27	0.34
Rule 8 / Rule 4	CPI inflation Taylor rule	1.96	0.30

Figure A2: Technology Shock in a Three-Country Model, Substitutes, Home Bias ($\eta = 0.5$)

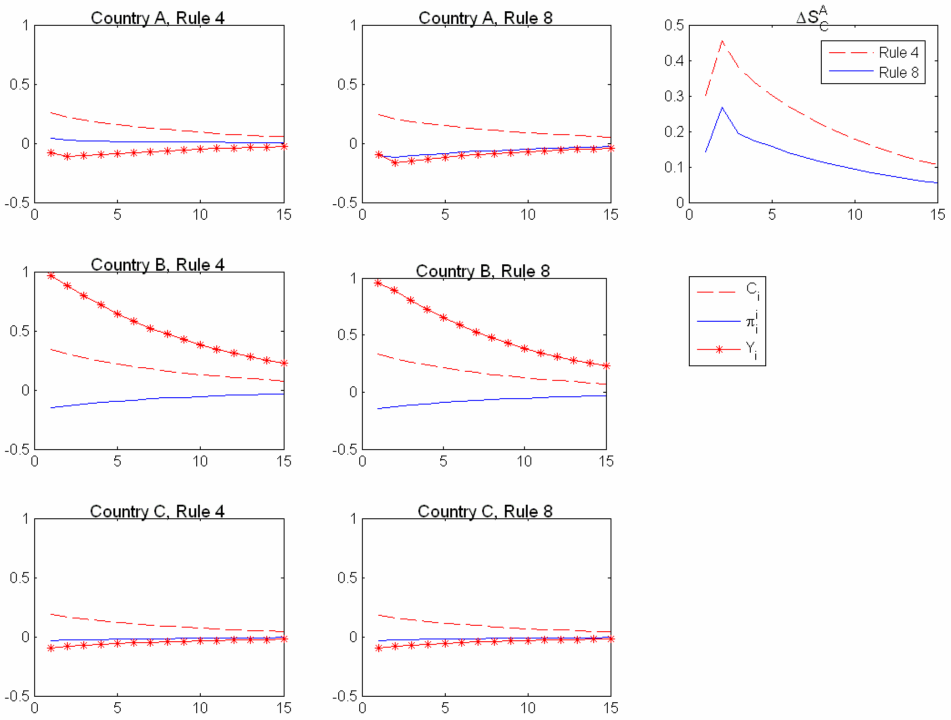

Table A3: Performance of Simple Monetary Policy Rules, Substitutes, Home Bias

Rule		Standard Deviation					Loss	
		π_A^A	π^A	Y^A	ΔS_C^A	C^A	CB	ERM 2
Rule 1	domestic inflation targeting	0.15	0.18	0.37	0.70	0.53	0.0842	0.3438
Rule 2	CPI inflation targeting	0.18	0.19	0.35	0.70	0.54	0.0777	0.3423
Rule 3	domestic inflation Taylor rule	0.08	0.09	0.29	1.02	0.56	0.0467	0.5732
Rule 4	CPI inflation Taylor rule	0.06	0.06	0.28	1.02	0.56	0.0405	0.5603
Rule 5	domestic inflation ERM 2	0.43	0.45	0.45	0.33	0.51	0.1993	0.3531
Rule 6	CPI inflation ERM 2	0.44	0.46	0.43	0.33	0.51	0.1976	0.3573
Rule 7	domestic Taylor ERM 2	0.28	0.30	0.40	0.53	0.52	0.1229	0.3097
Rule 8	CPI Taylor ERM 2	0.29	0.30	0.39	0.54	0.53	0.1214	0.3115

Table A4: Ratio of Loss for Joining ERM 2, Substitutes, Home Bias

Ratio	Rule	Loss CB	Loss ERM 2
Rule 5 / Rule 1	domestic inflation targeting	2.37	1.03
Rule 6 / Rule 2	CPI inflation targeting	2.54	1.04
Rule 7 / Rule 3	domestic inflation Taylor rule	2.63	0.54
Rule 8 / Rule 4	CPI inflation Taylor rule	3.00	0.56

A2 Optimal Simple Rules with Home Bias in Consumption

Table A5: Optimal Simple Rules, Complements, Home Bias, Loss CB

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss CB	Variance	
							π^A	Y^A
Rule 1	Fminsearch	2.03489	–	–	–	0.293288	0.3740	0.2126
Rule 2	Fminsearch	–	1.23384	–	–	0.232098	0.1003	0.3639
Rule 3	Fminsearch	2.03205	–	0.000667867	–	0.293288	0.3740	0.2126
	Grid search	1.4	–	0.15	–	0.293288	0.3738	0.2127
Rule 4	Fminsearch	–	1.00097	-0.0493207	–	0.223295	0.0883	0.3583
	Grid search	–	1.25	0	–	0.232109	0.0978	0.3664
Rule 5	Fminsearch	1.03481	–	–	-0.0316297	0.286932	0.3597	0.2142
	Grid search	2.05	–	–	0	0.293289	0.3743	0.2123
Rule 6	Fminsearch	–	0.99373	–	0.00569856	0.222809	0.0971	0.3485
	Grid search	–	1.25	–	0	0.232109	0.0978	0.3664
Rule 7	Fminsearch	7.59237	–	-3.66024	-0.458846	0.225457	0.1097	0.3413
	Grid search	1.2	–	0.2	0	0.293290	0.3743	0.2123
Rule 8	Fminsearch	–	0.989931	0.0432973	0.0106893	0.222696	0.1048	0.3406
	Grid search	–	1.7	0.6	0.1	0.222947	0.1062	0.3397

Table A6: Optimal Simple Rules, Complements, Home Bias, Loss ERM 2

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss ERM 2	Variance		
							π^A	Y^A	ΔS_C^A
Rule 1	Fminsearch	1	–	–	–	2.60228	0.7560	0.3753	3.3172
Rule 2	Fminsearch	–	4.28486e+012	–	–	4.29760	0.0000	0.5821	8.0131
Rule 3	Fminsearch	1.00535	–	-0.0910312	–	2.21439	1.3348	0.4734	1.2857
	Grid search	1	–	0.05	–	3.09735	0.5607	0.3298	4.7436
Rule 4	Fminsearch	–	1.00481	-0.244666	–	2.14450	0.8653	0.6207	1.9376
	Grid search	–	3	0	–	4.75461	0.0156	0.4947	8.9833
Rule 5	Fminsearch	0.975484	–	–	0.0222794	2.22138	1.3389	0.4708	1.2942
	Grid search	1	–	–	0.05	2.23029	1.3931	0.4753	1.1992
Rule 6	Fminsearch	–	0.936282	–	0.0580603	2.10596	1.0055	0.5617	1.6393
	Grid search	–	1.05	–	0.15	2.10948	1.0482	0.5441	1.5785
Rule 7	Fminsearch	0.887574	–	0.288784	0.0970124	2.24154	1.3328	0.4619	1.3555
	Grid search	1	–	0.1	0.1	2.24232	1.3547	0.4645	1.3108
Rule 8	Fminsearch	–	0.935602	0.00232331	0.0584814	2.10590	1.0045	0.5610	1.6418
	Grid search	–	1	0	0.1	2.11069	0.9604	0.5437	1.7569

Table A7: Optimal Simple Rules, Substitutes, Home Bias, Loss CB

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss CB	Variance	
							π^A	Y^A
Rule 1	Fminsearch	5.03317e+006	–	–	–	0.0528229	0.0040	0.1016
Rule 2	Fminsearch	–	7.91617e+012	–	–	0.0381636	0.0000	0.0763
Rule 3	Fminsearch	31.1817	–	11.8537	–	0.0463182	0.0123	0.0803
	Grid search	1.3	–	0.5	–	0.0463182	0.0123	0.0803
Rule 4	Fminsearch	–	3.48621e+009	2.16309e+006	–	0.0381575	0.0000	0.0763
	Grid search	–	3	0.95	–	0.0389490	0.0050	0.0729
Rule 5	Fminsearch	2.70357e+008	–	–	-1.06894e+006	0.0528167	0.0041	0.1015
	Grid search	3	–	–	0	0.0593840	0.0075	0.1112
Rule 6	Fminsearch	–	2.07149e+008	–	-1.30764e+007	0.0353397	0.0046	0.0661
	Grid search	–	3	–	0	0.0465716	0.0035	0.0896
Rule 7	Fminsearch	1.03753	–	0.22828	-0.0427491	0.0474732	0.0124	0.0825
	Grid search	1	–	1.5	0.3	0.0437715	0.0076	0.0799
Rule 8	Fminsearch	–	2.67328e+007	1.1226e+006	-1.36116e+006	0.0357505	0.0042	0.0673
	Grid search	–	3	1	0	0.0389605	0.0058	0.0721

Table A8: Optimal Simple Rules, Substitutes, Home Bias, Loss ERM 2

Rule	Method	$\varphi_{\pi_i^i}$	φ_{π^i}	φ_Y	φ_S	Loss ERM 2	Variance		
							π^A	Y^A	ΔS_C^A
Rule 1	Fminsearch	1.2197	–	–	–	0.312806	0.0894	0.1673	0.2795
Rule 2	Fminsearch	–	1.25255	–	–	0.312953	0.0958	0.1477	0.2866
Rule 3	Fminsearch	1.21923	–	0.000315802	–	0.312806	0.0894	0.1673	0.2795
	Grid search	1.15	–	0.05	–	0.312846	0.0868	0.1661	0.2859
Rule 4	Fminsearch	–	0.99447	0.184219	–	0.310872	0.0930	0.1521	0.2837
	Grid search	–	1.05	0.15	–	0.311291	0.0886	0.1492	0.2962
Rule 5	Fminsearch	2.40439	–	–	0.61751	0.309497	0.0916	0.1575	0.2783
	Grid search	2.45	–	–	0.65	0.309506	0.0927	0.1578	0.2758
Rule 6	Fminsearch	–	1.12256	–	-0.0719897	0.312789	0.0949	0.1477	0.2880
	Grid search	–	1.25	–	0	0.312962	0.0971	0.1482	0.2836
Rule 7	Fminsearch	2.52512	–	-0.149392	0.569528	0.309497	0.0916	0.1575	0.2783
	Grid search	1.9	–	0.6	0.8	0.309497	0.0916	0.1576	0.2782
Rule 8	Fminsearch	–	-5.30875	16.5453	8.96801	0.309433	0.0913	0.1587	0.2776
	Grid search	–	1	1.5	1	0.310027	0.0946	0.1555	0.2754

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