UNIVERSITAT AUTÒNOMA DE BARCELONA

DEPARTAMENT D'ECONOMIA I D'HISTÒRIA ECONÒMICA

Essays in International Economics

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

for the degree

Doctor of Philosophy

Field of Economics

By

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Barcelona, Spain

June 2009

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Tesis elaborada bajo la dirección del

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para optar al grado de Doctor en Economía

por la Universidad Autónoma de Barcelona

en el programa de Doctorado Internacional en Análisis Económico

Barcelona, España

June 2009

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ABSTRACT

Essays in International Economics

IVO KRZNAR

This doctoral thesis consists of three self-contained essays in International Economics.

Essay 1. "International business cycles with real rigidities in goods and factors markets"

This paper explores the impact of real rigidities in the market for final goods and factors of production on international transmission of business cycles. In particular, I analyze the role of habits in consumption, capital adjustment costs and labor market frictions in the form of habits in leisure or labor adjustment costs, in a standard international real business cycles model with complete markets. Overall, these rigidities that help explain many salient facts of a closed-economy have less success in resolving international comovement puzzles. Specifically, I find that capital adjustment costs together with consumption habits help explain positive investment comovement only - in combination with capital adjustment costs, consumption habits provide a channel through which capital adjustment costs become larger than the opportunity costs of not investing in a more productive country. However, resolving the investment puzzle comes at the expense of aggravating other comovement problems. In addition, I find that rigidities in labor market do not help to explain factor comovements such as the employment and investment puzzle. Furthermore, while both labor adjustment costs and leisure habits increase the output correlation, only the effects of the latter present forces toward resolving the consumption cross-correlation puzzle (although not actually resolving it). This mainly comes as a result of leisure habits reducing the consumption correlation through amplified effects on the nonseparability of consumption and leisure. (JEL E32, G12, G15, D90)

Essay 2. "Optimal Foreign Reserves: The Case of Croatia" (joint with Ana Maria Čeh)

This paper develops a simple model of precautionary foreign reserves in a dollarized economy subject to a sudden stop shock that occurs in hand with a bank run. By including specific features of the Croatian economy in our model we extend the framework of Goncalves (2007). An analytical expression of optimal reserves is derived and calibrated for Croatia in order to evaluate the adequacy of the Croatian National Bank foreign reserves. We show that the precautionary demand for reserves is consistent with the trend of strong accumulation of foreign reserves over the last 10 years. Whether this trend was too strong or whether the actual reserves were lower than the optimal reserves depends on the possible reaction of the parent banks during a crisis. We show that for plausible values of parameters, the Croatian National Bank has enough reserves to fight a possible crisis of magnitude of the 1998/1999 sudden stop with banking crisis episode. This result holds in a "more favourable" scenario only, in which parent banks assume the role of lenders of last resort. We also show how using the two standard indicators of "optimal" reserves, the Greenspan-Guidotti and the 3-months-of-imports rules, might lead to an unrealistic assessment of the foreign reserves optimality in the case of Croatia. (JEL F31, F32, F37, F41)

Essay 3. "The Impact of the USD/EUR Exchange Rate on Inflation in CEE Countries" (joint with Ljubinko Jankov, Davor Kunovac and Maroje Lang)

This paper explores the impact of the USD/EUR exchange rate on inflation in the Central and East European countries (CEEC). In particular, we analyze which portion of the variation in inflation in the CEEC can be attributed to the USD/EUR exchange rate, as an external shock. In addition, we study to what extent USD/EUR exchange rate shocks influence inflation in the CEEC. A VAR model with block exogeneity restrictions is employed to trace the impact of the USD/EUR exchange rate fluctuations on inflation at each stage along the distribution chain. We find that the USD/EUR exchange rate has different impact on inflation among the CEEC with different exchange rate regimes. Our empirical exercise shows that the USD/EUR exchange rate accounts for the largest share of inflation volatility in the CEEC with stable exchange rates of the domestic currency against the euro. Furthermore, the extent of the USD/EUR exchange rate influence on inflation in the CEEC is the largest in the economies with stable exchange rate regimes. This results might be important in the context of the price stability requirement of the Maastricht Criteria: in addition to the internal challenge of keeping low inflation and dealing with the difficulties of the price convergence process, the applicant countries could face problems beyond their influence. (JEL F41, E3, O11, P2)

Acknowledgements

There are so many people who have contributed to this thesis and many require special acknowledgement and appreciation. Above all, I would like to thank Margareta for her personal support and great patience at all times. Without Margareta's continuous care finishing my studies at the UAB would be impossible. I am also thankful to my parents who have been a constant source of love and support when it was tough.

I want to thank my supervision Juan Carlos Conesa. Our endless discussion on economics, research and the "right" way to go have been life-time experience. His criticism of my work and support and encouragement at the same time has sustained me on more than one occasion. I appreciate his understanding for my decision to leave Barcelona on the third year and get a job outside academia. I would also like to thank Jordi Caballé for his kindness, his comments and support. I will always remember Jordi as the best teacher that I ever had.

I am particularly indebted to Vojmir Franičević for his overwhelming support and encouragement throughout the years. Had I not met him I would not have go studying abroad. The good advice, support and friendship of Vojmir has been invaluable on both an academic and a personal level, for which I am extremely grateful. I thank my colleagues at the Croatian National Bank Gordi, Maroje, Vedran, Tomislav, Tihomir and Evan for their encouragement in decision to go Barcelona.

I cherish the friendships that accompanied my studies here at the UAB. Dolors, Alexandre, Joan, Nadia, Isabel, Brindusa, Aida, Marta, Danijela and Ivana made the whole graduate school experience less stressful. Alexandre streached friendship beyond the call of duty. I thank him for his support, encouragement and stimulating discussion throughout our studies.

I appreciate financial support from the Spanish Ministry of Education. Without this funding my studying at the UAB would not have been possible.

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Introduction

This thesis consists of three self-contained essays. Although united under one title they differ in both the topics considered and approaches chosen. The first essay presents an international real business cycles model with real rigidities which today constitute a large part of closed-economy RBC theory in a complete markets setting. The second essay offers a useful tool for central bankers in dollarized countries for analyzing foreign reserves adequacy. The third essay explores the impact of the USD/EUR exchange rate on inflation in the Central and East European countries (CEEC). In the lines which follow I give a brief overview of the three essays included into this thesis.

Chapter 1, *International business cycles with real rigidities in goods and factors markets,* considers the importance of different types of rigidities, which today constitute a large part of closed-economy RBC theory, on international transmission of business cycles. In particular, I analyze the role of habits in consumption, capital adjustment costs and labor market frictions in form of habits in leisure or labor adjustment costs, in a standard international real business cycles (IRBC) model with complete markets. In this setting individuals have complete access to international risk-sharing (perfect risk sharing). The setup of my framework is similar to earlier two-country (two agents) IRBC models with complete markets in Backus, Kehoe and Kydland (1992) or Baxter and Crucini (1995)) except here a number of rigidities in goods and factors markets are incorporated. Because of complete markets setup the equilibrium allocation in this economy is computed as a solution to the social planner's problem. The social planner's problem was solved numerically using the parametrized expectations approach introduced by Marcet (1989).

The main message of this paper is that the real rigidities that help explain many closed-economy features resolve only the investment comovement puzzle. In particular, I find that capital adjustment costs together with consumption habits help to resolve the investment comovement puzzle by impairing capital flows. Rigidities on the labor market do not help explain factor comovements like the employment and investment puzzle. On the other hand, both labor adjustment costs and leisure habits increase the output correlation. However, only the effects of the latter work towards resolution of the consumption cross-correlation puzzle (although not actually resolving it). This mainly comes as a result of leisure habits reducing consumption correlation through amplified effects on nonseparability between consumption and leisure. On the whole, real rigidities, either when resolving the investment puzzle or trying to resolve the consumption puzzle, accentuate problems in explaining other international comovements.

Overall, Chapter 1 shows that real rigidities that help explain many closed-economy salient facts have less success in resolving international comovement puzzles. This conclusion supports the results of Kehoe and Perri (2002) or Yakhin (2007) that demonstrate the importance of financial and contractual frictions but also of some nominal frictions in explaining the international transmission of business cycles.

In Chapter 2, *Optimal Foreign Reserves: The Case of Croatia* we analyze whether international reserves of the Croatian National bank (CNB) are sufficient to mitigate negative effects of potential sudden stop of capital inflows and banking crisis. The need for reserves act as a protection against a sudden stop. This reserves requirement is even more pronounced in dollarized economies, like Croatian, where the central bank is exposed to a double drain risk (Obstfeld, Shambaugh and Taylor (2008)). This twofold risk exists given that financial account reversals (an external drain risk) may be accompanied by a loss of confidence in the banking system that would result in a large withdrawal of foreign currency deposits (an internal drain risk). Therefore, in dollarized economy reserves are not only an insurance against negative effects of a sudden stop but also a key tool for managing domestic financial instability.

Our framework builds on analytical models trying to characterize and quantify the optimal level of reserves from a prudential perspective similar to those ones in Goncalves (2007) and Ranciere and Jeanne (2006). In our welfare-based model, precautionary motives for accumulating reserves pertain to the crisis management ability of the government to finance underlying foreign payments imbalances in the event of a sudden stop and provide foreign exchange liquidity in the face of a bank run. At the same time the government is trying to maximize the welfare of the economy. In the model economy there are two main opposite forces driving optimal reserves accumulation. On one hand, reserves are expensive to hold. The cost of holding reserves might be interpreted as the opportunity cost that comes from substituting high yielding domestic assets for lower yielding foreign ones. On the other hand, reserves absorb fluctuations in external payment imbalances, ease the credit crunch and allow a country to smooth consumption in the event of a sudden stop with banking crisis.

An analytical expression of optimal reserves is derived and calibrated for Croatia in order to evaluate whether the CNB holds more reserves than the model suggests are necessary. We find that for plausible values of the parameters the model accounts for the recent buildup of foreign reserves in Croatia. However, quantitative implications of the model imply that the accumulation of reserves was too strong. In other words, recent upsurge of reserves observed in Croatia over the past decade seems in excess of what would be implied by an insurance motive against sudden stop and banking crises. This result crucially depends on the assumed behavior of parent banks during a sudden stop. In working with data, we assume two possible reactions of parent banks during the crisis. parent banks might withdraw deposits and cut credit lines to banks in their ownership. On the other hand, they might act as a lender of last resort by prolonging short-term loans and providing extra liquidity. In the benchmark calibration we study optimal reserves in the economy that is hit by the sudden stop with banking crisis of the 1998/1999 crisis scale. We find that the CNB is holding enough reserves to mitigate negative effects of a possible crisis similar to the one that took place during 1998/1999 only if parent banks assume the role of lenders of last resort. Finally, we compare our formula of optimal reserves with two standard indicators of "optimal" reserves for Croatian economy, namely Greenspan-Guidotti and 3-months-of-imports rules. We also show how using the two standard indicators of "optimal" reserves, the Greenspan-Guidotti and the 3-months-of-imports rules, might lead to an unrealistic assessment of the foreign reserves optimality in the case of Croatia. This result stems from the elements that determine optimal reserves and that Greenspan-Guidotti and 3-months-of-imports rules do not take into account.

In Chapter 3, *The Impact of the USD/EUR Exchange Rate on Inflation in CEE Countries* we explore the impact of the USD/EUR exchange rate on inflation in the Central and

East European countries (CEEC). The decision to analyze the USD/EUR exchange rate as a separate external factor is motivated by the monetary and exchange rate regimes in the CEEC. These countries are primarily concerned with fluctuations of their exchange rate against the euro: while all countries (will) have to participate in the ERM-II, some countries use the exchange rate against the euro (previously the Deutsche Mark) to reduce imported inflation and anchor inflation expectations. Since the USD/EUR exchange rate is determined on the global financial market, an individual country is unable to influence it. Nor can it influence world prices. Hence, it cannot simultaneously *manage* both its bilateral exchange rate against the euro and against the dollar. Therefore, for countries with heavily managed exchange rates to the euro, the USD/EUR exchange rate in fact represents an external shock. By focusing on the stability of their domestic currencies against the euro, the CEEC effectively reduce the exchange rate pass-through of goods priced in euros to domestic inflation. However, since a number of commodities are priced in dollars, there is still a pass-through from the dollar, which is amplified by the USD/EUR exchange rate fluctuations.

We distinguish between the exchange rate of the domestic currency against the euro and the USD/EUR exchange rate and analyze which portion of the variation in inflation in the CEEC can be attributed to the USD/EUR exchange rate, as an external shock. In addition, we study to what extent USD/EUR exchange rate shocks influence inflation. Finally, we attribute the different impact of the USD/EUR exchange rate on inflation among the CEEC to the different exchange rate regimes.

To measure the impact of the USD/EUR exchange rate on domestic producers and consumer inflation across countries we employ the empirical model of pricing along a distribution chain, as in McCarthy (2008). The advantage of this model is that it has a Vector Autoregression (VAR) representation that allows us to trace the impact of exchange rate fluctuations on inflation at each stage along the distribution chain (importers, producers, consumers). While McCarthy (2008) studies a large open economy that can influence external factors, we adopt a small country assumption where domestic variables cannot influence external variables. In other words, we represent the model of pricing along the distribution chain in the CEEC with a VAR model with block exogeneity restrictions (for external variables) in the spirit of Cushman and Zha (1997). The imposition of block exogeneity seems a reasonable way to identify foreign shocks from the perspective of the small open economy.

Our empirical exercise shows that the USD/EUR exchange rate accounts for the largest share of inflation volatility in the CEEC with stable exchange rates of the domestic currency against the euro. Furthermore, the extent of the USD/EUR exchange rate influence on inflation in the CEEC is the largest in the economies with stable exchange rate regimes. This result might be important in the context of the price stability requirement of the Maastricht Criteria: in addition to the internal challenge of keeping low inflation and dealing with the difficulties of the price convergence process, the applicant countries could face problems beyond their influence. Given that most of the CEEC peg their currencies to the euro, either because of the conditions of the Exchange Rate Mechanism II (ERM-II) or because of their domestic issues (eurozation in particular), and taking into account the high volatility of the USD/EUR exchange rate, our findings suggest that the CEEC under a fixed or heavily managed exchange rate might face substantial problems in achieving a high degree of price stability.

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CHAPTER 1

International business cycles with real rigidities in goods and factors markets

1.1. Introduction

In a closed economy environment, real business cycle (RBC) theory has enjoyed a measure of success in accounting for many business cycle features. However, most of the poor matching performance of the standard RBC model came from the weakness of its internal propagation mechanism. During the past decade, several studies extended the standard RBC model to address this difficulty. The extensions were made via the introduction of different real rigidities in domestic markets for goods and factors of production. In particular, labor market rigidities such as labor adjustment costs (Cogley and Nason (1995), Janko (2008) and Chang, Doh and Schorfheide (2006)), habit preferences over leisure (Bouakez and Kano (2006), Wen (1998), Hotz, Kydland and Sedlacek (1988) and Eichenbaum, Hansen and Singleton (1988)) or the combination of habit preferences over consumption and capital adjustment costs (Boldrin, Christiano and Fisher (2001), Beaubrun-Diant and Tripier (2005) and Christiano, Eichenbaum and Evans (2005)) turned out to be important in magnifying the propagation of shocks in the economy. More recently Schmitt-Grohe and Uribe (2008) bring fresh news from the business cycles literature. By using the RBC model with real rigidities in terms of consumption habit preferences, leisure habit preferences together with capital adjustment costs they show importance of anticipated shocks as a source of economic fluctuations. Not only do all of these rigidities improve the matching performance of the standard RBC model, but they are now being used to understand a wide range of issues in asset pricing, growth, monetary and international economics[1].

[1]Several papers are worth mentioning. Carroll, Overland and Weil (2000) suggest that consumption habits may be able to explain the relationship between savings and growth across the countries. Fuhrer (2000) argues that consumption habits can induce hump-shaped responses of consumption and inflation to monetary shocks. Mendoza (1991) finds that introducing leisure habits in a small open-economy RBC model improves the fit of consumption and trade balance. Boldrin, Christiano and Fisher (2001) show that the combination

However, closed-economy models abstract from the fact that countries participate in international markets. In particular, they ignore that countries can have the opportunity to share country-specific risks with other countries through the exchange of goods and financial assets. An early open-economy version of the standard RBC model (international real business cycles models, henceforth IRBC models) that incorporated international linkages has been less successful than its closed-economy counterpart in replicating the basic characteristics of international comovements of output, consumption, investment and employment[2]. This model assumes the existence of complete markets that in turn implies perfect risk sharing among agents in the world economy. Perfect risk sharing has implications that are far away from the data. First, empirical cross-correlation of consumption is generally similar to cross-country correlation of output, whereas the standard IRBC model with complete markets produces consumption correlation that is much higher than that of output (consumption puzzle). And second, investment and employment tend to be positively correlated across the countries, whereas the model predicts a negative correlation (investment and employment puzzle).

To reconcile data and theory models were developed in which risk-sharing is limited because of domestic or international financial frictions[3]. While much of the IRBC literature focuses on financial frictions for resolving international comovement puzzles, this paper explores the role of rigidities on markets for domestic goods and factors, which today present an important part of the closed-economy RBC model, on international comovements. In other words, I am asking the same question that Backus, Kehoe and Kydland (1992) put

of consumption habits, capital adjustment costs and labor adjustment costs helps to account for equity premium puzzle in the full-blown general equilibrium model. Janko (2008) finds that labor adjustment costs are one of the factors that are crucial in explaining business cycle properties of real as well as nominal variables.

[2]See, for example, Backus, Kehoe and Kydland (1992).

[3]Baxter and Crucini (1995) and Kollmann (1996) investigated the quantitative impact of elimination of trade in state-contingent assets on the properties of international real business cycles. They found that the exogenous limit on the assets, that may be traded, was not severe enough in terms of risk sharing, investment flows and working effort to resolve correlation puzzles. Kehoe and Perri (2002) examined the model in which limited risk sharing arises endogenously from the limited ability to enforce international credit arrangements between the countries. They find that this contract enforcement friction goes a long way in reconciling the IRBC theory and data (although not all the way in terms of the consumption puzzle). Recently, Yakhin (2007) show that exogenous market incompleteness can also generate positive employment and investment cross-correlations once additional nominal rigidities are introduced (staggered wages and monopolistic behavior of households with respect to supply of labor).

forward: what are the effects of extending the standard RBC model to an open-economy environment. However, since from the time that the Backus, Kehoe and Kydland (1992) paper was published, much effort has been devoted to extending the standard RBC model and trying to replicate salient features of the closed-economy business cycle. In order to explore the effect of goods and factors market rigidities that represented those extensions on international comovements, I build a two-country IRBC model with habit formation preferences over consumption and adjustment costs on capital change in a complete markets environment. In this setting individuals have complete access to international risk-sharing (perfect risk sharing). In addition to consumption habits and capital adjustment costs, I analyze the impact of two labor market rigidities- demand-side rigidity in the form of habit formation preferences over leisure and supply-side rigidity in the form of labor adjustment costs.

The main message of this paper is that the real rigidities that help explain many closed-economy features resolve only the investment comovement puzzle. In particular, I find that capital adjustment costs together with consumption habits help to resolve the investment comovement puzzle by impairing capital flows. Rigidities on the labor market do not help explain factor comovements like the employment and investment puzzle. On the other hand, both labor adjustment costs and leisure habits increase the output correlation. However, only the effects of the latter work towards resolution of the consumption cross-correlation puzzle (although not actually resolving it). This mainly comes as a result of leisure habits reducing consumption correlation through amplified effects on nonseparability between consumption and leisure. On the whole, real rigidities, either when resolving the investment puzzle or trying to resolve the consumption puzzle, accentuate problems in explaining other international comovements.

The rest of the paper is organized as follows. In section 1.2 I present a two-country IRBC model where habits and adjustment costs are incorporated in a complete markets environment. Simulation results together with interpretation of the results in terms of domestic and international (co)movements are presented in Section 1.3. Section 1.4 concludes.

1.2. The model economy

The model considered here follows closely the structure of earlier two-country IRBC models with complete markets (see, in particular, the models by Backus, Kehoe and Kydland (1992) or Baxter and Crucini (1995)) except here a number of rigidities in goods and factors markets are incorporated: habit formation preferences over consumption and leisure and adjustment costs on change of capital and on change of labor. In this section, I first describe the international environment of the model. Then I present a model as social planner's problem. In the same subsection I provide and interpret the optimality conditions the solution of which the social planner has to satisfy and that I will use in order to simulate the same solution in the next section.

1.2.1. The environment

The world economy consists of two countries indexed by $j = 1, 2$, each populated with a continuum of identical households. Households in country j have preferences over consumption, c_{jt}, past consumption incorporated in consumption habit stock, h^c_{jt},[4] and labor, l_{jt}, represented by the Von-Neumann Morgenstern expected utility function. Consumption habit stock evolves through standard law of motion characterized by a persistency parameter, λ^c.

I also allow for two labor market rigidities and I analyze their impact separately− demand-side rigidity in the form of leisure habits and supply-side rigidity in the form of labor adjustment costs. However, for the sake of compactness I will present the model as if both labor market rigidities are being analyzed at the same time. By shutting down the parameter characterizing each labor market rigidity, the model could be rewritten to incorporate each labor market rigidity separately.

When I allow for demand-side rigidity in the labor market, households also have preferences over past labor incorporated in leisure habit stock, h^l_{jt}. Leisure habit stock evolves through standard law of motion characterized by persistency parameters, λ^l. In this case, firms decide on labor they want to hire, l_{jt}, and investment, i_{jt}. Firm's capital accumulation technology is subject to capital adjustment costs governed by the function $\phi(\cdot)$.

[4]The particular specification of preferences that I adopt links the household's habits to its own past consumption ("internal habit"), rather than aggregate, economy-wide consumption ("external habit").

On the other hand, when I introduce supply-side rigidity in the labor market, firms decide on new hirings, m_{jt}, in addition to the investment decision, which is subject to adjustment costs. Productive employment at time $t+1$ is hired at time t. In deciding about new hirings, firms take into account that on each occasion labor hours differ across periods they will face labor adjustment costs, governed by the function $g(\cdot)$. Furthermore, in each period exogenous destruction of hours worked occurs by the "quit" rate $\psi \in (0,1)$. Hence, changing employment within the firm is costly, but it is costless to hire or replace the amount of employment that was exogenously wiped out.

There is a single homogeneous good produced, consumed and used for investment by both countries. A country's j output is produced using the technology that exhibits constant return to scale using capital, k_{jt} and labor, l_{jt} and is subject to country-specific labor augmenting total factor productivity shock, z_{jt}. The countries are symmetric i.e. they share the same structure of economy in terms of preference, technology forms and parameters. Countries differ in two important aspects. In the first, labor input consists only of domestic labor (labor does not move across the borders). And in the second, production is subject to a country-specific (labor augmenting) technology shock.

1.2.2. The Social Planner problem

I characterize the equilibrium in the world economy by exploiting the equivalence between competitive equilibrium and Pareto optimum with reference to the second welfare theorem[5] (in Appendix 2 I show how to decentralize the social planner's problem). Consequently, the equilibrium allocation in this economy can be computed as the solution to the social planner's problem. The social planner chooses contingency plans for $\{c_{jt}, x_{jt}, i_{jt}\}_{t=0}^{\infty}$ in order to maximize the expected discounted sum of weighted utilities of the two countries $j = \{1, 2\}$. The control variable, x_{jt}, denotes new hirings, m_{jt}, in the case of analyzing supply-side labor market rigidity- labor adjustment costs, or just labor decision, l_{jt}, in the case of examining demand-side labor market rigidity- leisure habits. The expectation is taken over the sequence of the shocks $\{z_t\}_{t=0}^{\infty}$ where $z_t = (z_{1t}, z_{2t})$.

[5]Note that this is possible since, among other things, I am dealing with internal habits that, in comparison to external, do not exert any externality. For details see Alvarez-Cuadrado, Monteiro and Turnovsky (2004) or Alonso-Carrera, Caballe and Raurich (2004).

I will present the model in "continuous" formulations in order to be consistent with the algorithm I use to solve the model- the algorithm utilizes a shock process that has continuous support. To do this, I first introduce some technicalities concerning the formal representation of uncertainty .

Let $(Z, \mathcal{Z})$ be a measurable space, where $\mathcal{Z}$ is a $\sigma-$algebra of the Borel subsets of Z. Then the transition function can be defined as $Q : Z \times \mathcal{Z} \to [0, 1]$ on $(Z, \mathcal{Z})$. It is assumed that the transition function satisfies the Feller property. The sequence of the exogenous random vector $\{z_t\}$ is a Markov process generated by Q. Then, for a given point $z \in Z$ and a set $A \subset \mathcal{Z}$, $Q(z, A)$ can be interpreted as a probability that the next period's shock lies in A, given that the current shock is z.

Next, I define the spaces for the partial histories of shocks $z^t = (z_1, z_2, ..., z_t)$, for $t = 1, 2, ...$ Given a measurable space $(Z, \mathcal{Z})$ a $t-$fold product space $(Z^t, \mathcal{Z}^t)$ can be defined as

$$(1.1) \qquad \left(Z^t, \mathcal{Z}^t\right) = (Z \times ... \times Z, \sigma(\mathcal{Z}\times ... \times \mathcal{Z})), \qquad (t \text{ times})$$

where $\sigma(\mathcal{Z}\times ... \times \mathcal{Z})$ denotes $\sigma-$algebra generated by the product $\sigma-$algebras, for any finite $t = 1, 2, ...$ It follows that, for any given initial value of the shock $z_0 \in Z$, and the transition function Q on $(Z, \mathcal{Z})$, the probability measures $\mu^t (z_0, \cdot) : \mathcal{Z}^t \to [0, 1]$ can be defined on these spaces[6]. For any rectangle $B = A_1 \times ... \times A_t \in \mathcal{Z}^t$, let

$$(1.2) \qquad \mu^t (z_0, B) = \int_{A_1} ... \int_{A_{t-1}} \int_{A_t} Q(z_{t-1}, dz_t)Q(z_{t-2}, dz_{t-1})...Q(z_0, dz_1).$$

In this economy, a consumption allocation, for both $j = \{1, 2\}$, is then defined as a sequence of $\{c_{jt}\}_{t=0}^{\infty}$, where $c_{jt} : Z^t \to \mathbb{R}_+$ is a $\mathcal{Z}^t$ - measurable function, for all t. In a similar way, allocations of investment and labor supply, or new hirings are defined as sequences of $\{i_{jt}\}_{t=0}^{\infty}$, $\{l_{jt}\}_{t=0}^{\infty}$ or $\{m_{jt}\}_{t=0}^{\infty}$ respectively, where $i_{jt} : Z^t \to \mathbb{R}_+$, $l_{jt} : Z^t \to (0, 1)$ and $m_{jt} : Z^t \to (0, 1)$ are $\mathcal{Z}^t$ - measurable functions, for all t.

Then the objective of the planner is to solve the following problem:

[6] As shown in Stokey, Lucas and Prescott (1989) (Section 7.5) it is sufficient to define $\mu^t (z_0, \cdot)$ over the measurable rectangles in Z^t.

$$\max_{\{c_{jt},x_{jt},i_{jt}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \int_{Z^t} \left[\sum_{j=1}^{2} \lambda_j u(c_{jt}, h_{jt}^c, l_{jt}, h_{jt}^l) \right] \mu^t \left(z_0, dz^t\right)$$

subject to:

$$\sum_{j=1}^{2} c_{jt} + \sum_{j=1}^{2} i_{jt} = \sum_{j=1}^{2} \left[f(k_{jt}, l_{jt}, z_{jt}) - g(m_{jt}, l_{jt}) \right], \tag{1.3}$$

$$k_{jt+1} = (1-\delta)k_{jt} + \phi \left(\frac{i_{jt}}{k_{jt}} \right) k_{jt}, \qquad 0 \le \delta \le 1 \tag{1.4}$$

$$h_{jt+1}^c = h_{jt}^c + \lambda^c (c_{jt} - h_{jt}^c), \qquad 0 \le \lambda^c \le 1 \tag{1.5}$$

in the case of labor adjustment cost:

$$l_{jt+1} = (1-\psi) l_{jt} + m_{jt}, \qquad 0 \le \psi \le 1 \tag{1.6}$$

with

$$k_{j0}, h_{j0}^c, z_{j0}, \text{and } l_{j0} \text{ given, for } j = \{1, 2\}$$

or in the case of leisure habits:

$$h_{jt+1}^l = h_{jt}^l + \lambda^l (1 - l_{jt} - h_{jt}^l), \quad 0 \le \lambda^l \le 1 \tag{1.7}$$

with

$$k_{j0}, h_{j0}^c, z_{j0} \text{ and } h_{j0}^l \text{ given, for } j = \{1, 2\}$$

Parameters λ_j for $j = \{1, 2\}$ represent the weights that the planner attaches to each country. Furthermore, $u(\cdot)$ represents a utility function that is assumed to be bounded, continuos, strictly concave, strictly increasing and satisfies Inada conditions. $f(\cdot)$ is a production function satisfying concavity and differentiability properties.

To find first order conditions corresponding to the planner's problem, I rewrite the consumption habit stock as a function of all past consumptions:

$$h_{jt+1}^c = h_{jt}^c + \lambda^c (c_{jt} - h_{jt}^c) = \lambda^c \sum_{i=0}^{\infty} (1-\lambda^c)^i c_{jt-i} \tag{1.8}$$

and the leisure habit stock as a function of all past leisure hours:

$$h_{jt+1}^l = h_{jt}^l + \lambda^l (1 - l_{jt} - h_{jt}^l) = \lambda^l \sum_{i=0}^{\infty} (1-\lambda^l)^i (1 - l_{jt-i}) \tag{1.9}$$

Furthermore, I implicitly define the investment function as

$$I(k_{jt+1}, k_{jt}) = \phi_i^{-1}\left(\frac{k_{jt+1} - (1-\delta)k_{jt}}{k_{jt}}\right) k_{jt} \tag{1.10}$$

Then the optimality conditions that a solution of the planner's problem has to satisfy are the following.

The Euler equation for $j = \{1, 2\}$ reads as:

(1.11)

$$\left\{u_1(c_{jt}, h^c_{jt}, l_{jt}, h^l_{jt}) + \beta\lambda^c \int_Z \left[\sum_{i=0}^{\infty} \beta^i (1-\lambda^c)^i u_2(c_{jt+i+1}, h^c_{jt+i+1}, l_{jt+i+1}, h^l_{jt+i+1})\right] Q\left(z_t, dz_{t+1}\right)\right\} \times$$

$$\times\, I_1(k_{jt+1}, k_{jt}) = \beta \int_Z \Bigg[(f_1(k_{jt+1}, l_{jt+1}, z_{jt+1}) + I_2(k_{jt+2}, k_{jt+1})) \times \Bigg(u_1(c_{jt+1}, h^c_{jt+1}, l_{jt+1}, h^l_{jt+1})$$

$$+\beta\lambda^c \sum_{i=0}^{\infty} \beta^i (1-\lambda^c)^i u_2(c_{jt+i+2}, h^c_{jt+i+2}, l_{jt+i+2}, h^l_{jt+i+2})\Bigg)\Bigg] Q\left(z_t, dz_{t+1}\right)$$

The labor supply equation is given by:

(1.12)

$$g_m(m_{jt}, l_{jt}) \times$$

$$\left\{u_1(c_{jt}, h^c_{jt}, l_{jt}, h^l_{jt}) + \beta\lambda^c \int_Z \left[\sum_{i=0}^{\infty} \beta^i (1-\lambda^c)^i u_2(c_{jt+i+1}, h^c_{jt+i+1}, l_{jt+i+1}, h^l_{jt+i+1})\right] Q\left(z_t, dz_{t+1}\right)\right\} =$$

$$\beta \Bigg\{ \int_Z \Bigg[u_3(c_{jt+1}, h_{jt+1}, l_{jt+1}) + \beta\lambda^l \sum_{i=0}^{\infty} \beta^i (1-\lambda^l)^i u_4(c_{jt+i+2}, h^c_{jt+i+2}, l_{jt+i+2}, h^l_{jt+i+2}) +$$

$$\left[u_1(c_{jt+1}, h^c_{jt+1}, l_{jt+1}, h^l_{jt+1}) + \beta\lambda^c \sum_{i=0}^{\infty} \beta^i (1-\lambda^c)^i u_2(c_{jt+i+2}, h^c_{jt+i+2}, l_{jt+i+2}, h^l_{jt+i+2})\right] \times$$

$$\left[f_2(k_{jt+1}, l_{jt+1}, z_{jt+1}) - g_l(m_{jt+1}, l_{jt+1}) + (1-\psi) g_m(m_{jt+1}, l_{jt+1})\right]\Bigg] Q\left(z_t, dz_{t+1}\right) \Bigg\}$$

Finally, the risk sharing condition reads as:

(1.13)

$$\frac{\left(u_1(c_{1t}, h^c_{1t}, l_{1t}, h^l_{1t}) + \beta\lambda^c \int_Z \left[\sum_{i=0}^{\infty} \beta^i (1-\lambda^c)^i u_2(c_{1t+i+1}, h^c_{1t+i+1}, l_{1t+i+1}, h^l_{1t+i+1})\right] Q\left(z_t, dz_{t+1}\right)\right)}{\left(u_1(c_{2t}, h_{2t}, l_{2t}, h^l_{2t}) + \beta\lambda^c \int_Z \left[\sum_{i=0}^{\infty} \beta^i (1-\lambda^c)^i u_2(c_{2t+i+1}, h^c_{2t+i+1}, l_{2t+i+1},, h^l_{2t+i+1})\right] Q\left(z_t, dz_{t+1}\right)\right)} = \frac{\lambda_2}{\lambda_1}$$

In those conditions $u_i(c_{jt}, h^c_{jt}, l_{jt}, h^l_{jt})$, $f_i(k_{jt}, l_{jt}, z_{jt})$, $I_i(k_{jt+1}, k_{jt}), g_i(m_{jt}, l_{jt})$ denote the partial derivative of the function $u(\cdot)$, $f(\cdot)$, $I(\cdot)$ and $g(\cdot)$ respectively, with the respect to the $i-$th component variable.

To sum up, in the optimum the world economy can be described by the following optimality conditions: Euler equations (1.11) and labor supply equations (1.12) for both countries $j = \{1, 2\}$ and risk sharing condition (1.13) together with the budget constraint (1.3), laws of motion for capital, consumption habit stock, leisure habit stock (in case of examining demand-side rigidity in the labor market) or hours worked (in case of analyzing supply-side rigidity in the labor market) given in (1.4), (1.5), (1.6) and (1.7) respectively in each country.

The optimality conditions that match up to the social planner's problem help shed some light on the planner's intratemporal and intertemporal allocation decisions. They demonstrate the dynamic characteristics of consumption, employment and capital in a framework with rigidities in labor, capital and goods market. In particular, for each country the Euler equation represents the planner's intertemporal consumption trade-off: if the planner saves and invests one additional unit of the final good instead of consuming it today, she will consume more tomorrow as a result of higher capital stock to work with. But since the present utility of the planner is derived from past consumption also, which means that agents dislike variations in habit-adjusted consumption, rather than in consumption itself, reducing consumption today will come at the utility cost of $u_1(c_{jt}, h^c_{jt}, l_{jt}, h^l_{jt})$, but also at the expected discounted utility benefit of $\beta\lambda^c \int_Z \left[\sum_{i=0}^{\infty} \beta^i (1-\lambda^c)^i u_2(c_{jt+i+1}, h^c_{jt+i+1}, l_{jt+i+1}, h^l_{jt+i+1})\right] Q\left(z_t, dz_{t+1}\right)$. Furthermore, one unit of final good saved today will not translate to a proportional increase of capital stock because capital is subject to capital adjustment costs (having a cost of $I_1(k_{jt+1}, k_{jt})$) and to depreciation (represented by the cost of $I_2(k_{jt+2}, k_{jt+1})$). Each additional unit of production tomorrow, when used for consumption will yield utility benefit coming from decreased consumption today but also utility loss because of habit forming preferences. The labor-supply equation shows planner's intratemporal and intertemporal decisions on labor supply (leisure) and consumption in the general model with consumption and leisure habits and labor and capital adjustment costs. Since I am analyzing supply-side rigidity (leisure habits) and demand-side rigidity (labor adjustment costs) separately I will interpret the labor-supply equation by assuming that just one of the rigidity is present. Hence, if I allow only for labor adjustment costs (implying that utility is not derived from past leisure decisions), reducing new hirings today will come at the expense of labor adjustment costs, which will have both utility benefit and utility cost. This opposite effect on utility is the result of consumption habits, as in the Euler equation. Since labor hired today becomes productive only tomorrow, a fall in new hirings today will result in an expected discounted utility gain from increased leisure tomorrow. On the other hand, less hiring today will decrease productive labor stock tomorrow, part of which will be destroyed. A smaller labor stock tomorrow will produce less. This will again have a utility loss from present consumption and discounted expected utility benefit from the future stream of consumption. If only leisure habits are present (and I neglect labor adjustment costs i.e. $g(m_{jt}, l_{jt}) = 0$) then labor employed today becomes productive immediately. Hence, reducing labor supply today will create a utility gain coming from increasing leisure activities today. On the other hand, this will come at the expected discounted utility loss coming from the future stream of leisure. Furthermore, a reduced labor force will produce fewer final goods which, when used for consumption, have again a utility loss from present consumption and a utility benefit coming from the future stream of consumption. Finally, the risk-sharing equation requires that the ratio of marginal utilities of consumption in both countries has to be equal to the ratio of weights that the planner assigns to each country.

1.3. Quantitative model prediction

To explore the quantitative impact of different rigidities for international comovements, the model has to be calibrated and functional forms have to be chosen. Before analyzing economies with rigidities, it is useful to review the mechanics of frictionless model (benchmark perfect risk sharing model) in order to understand the puzzles in the first place. I start by choosing the benchmark economy that is essentially a version of Backus, Kehoe and Kydland (1992), which has become the standard in the literature as a perfect risk-sharing case plagued with international comovement puzzles. I describe the calibration of the benchmark model in subsection 3.1. and that of the model with different rigidities in subsection 3.2. For the sake of comparability, when calibrating the model I build on the existing IRBC studies that take parameter values from growth observations or micro studies. If parameter value cannot be pinned down from the data, I choose its value such that the model's second moment of some particular variable matches its empirical counterpart. If this is not possible, I adapt the parameter's value from existing studies and then run the sensitivity analysis by varying the value of this particular parameter. The calibration procedure is summarized in Table 1.1.

[insert Table 1.1 about here.]

In this section I also briefly discuss the numerical algorithm that I construct for simulating the solution that satisfies the optimality conditions given in the previous section. In the end I provide the model's findings and sensitivity analyses results from a simulation exercise.

1.3.1. Functional forms and Calibration of the benchmark model

As mentioned before, the world in my model is composed of two equally sized countries with identical preferences and technology and the same initial endowments so that the planner's weights are the same, $\lambda_1 = \lambda_2$. Following the previous IRBC literature I choose the functional forms of preferences and technology (and the set of parameters values associated with these forms) to match the characteristics of the long-run behavior of aggregates observed in the U.S. data (for both $j = \{1, 2\}$).

1.3.1.1. Technology parameters. I use Cobb-Douglas production function

$$F(k_{jt}, l_{jt}, z_{jt}) = k_{jt}^{\alpha}(z_{jt}l_{jt})^{1-\alpha} \tag{1.14}$$

which is consistent with the stability of labor share in output despite secular increases in the real wage. The parameter α represents the share of capital in output and z_{jt} denotes country-specific, labor augmenting total factor productivity (TFP) shock.

The stochastic fluctuations of the TFP shocks of the two countries $z_t = (z_{1t}, z_{2t})$ are assumed to follow a first order vector-autoregressive process, $VAR(1)$, in logs. Letting $Z_{t+1} = (\log(z_{1t+1}), \log(z_{2t+1}))'$ the $VAR(1)$ reads as:[7]

$$Z_{t+1} = RZ_t + \varepsilon_{t+1}, \tag{1.15}$$

[7]The transition function Q on $(Z, \mathcal{Z})$ can be then defined implicitly by the assumption that the random shocks follow the stochastic difference equation (1.15). See Theorem 8.9 in Stokey, Lucas and Prescott (1989) which insures that a first order stochastic difference equation can be used to define a transition function.

where $\{\varepsilon_t\}_{t=0}^{\infty}$ is a sequence of bivariate normal random variables with zero mean and variance-covariance matrix Ω and where R is a autoregressive coefficient matrix .

In general, TFP shocks can be related through the non-zero off-diagonal coefficient of the matrix R and non-zero off-diagonal element of the covariance matrix Ω. In parametrizing the coefficient matrix R, I follow Baxter and Crucini (1995), Kollmann (1996) and Heathcote and Perri (2002) who found little evidence of spillovers between the United States and some European countries. Furthermore, as is common in the real business cycle literature I assume that each shock is highly auto-correlated. I summarize the parameters of the process given in (1.15) by:

$$R = \begin{bmatrix} 0.95 & 0 \\ 0 & 0.95 \end{bmatrix}, \quad \Omega = 0.007^2 \begin{bmatrix} 1 & 0.25 \\ 0.25 & 1 \end{bmatrix} \tag{1.16}$$

The later is consistent with the estimation results of TFP shock-processes for the United States and Europe[8].

The law of motion of the capital stock (1.4) in the steady state was used to calibrate the depreciation rate, δ, which depends on the investment/capital ratio that I restrict from observed data to take the value of 0.025 (as in Cooley (1995) I assume that the investment/output share in the US data is roughly 0.25, and that capital output ratio on a quarterly basis is around 10)

$$k_{ss} = \delta i_{ss} \tag{1.17}$$

where subscript ss denotes the value of the corresponding variable in the steady state[9]. Hence $\delta = 0.025$.

The range of estimates for the capital share in the literature is $\alpha \in [0.25, 4]$. I choose a compromise and set $\alpha = 0.36$ reflecting a long-run labor share in national income accounts of 2/3.

[8] See Backus, Kehoe and Kydland (1992), Baxter and Crucini (1995), Kollmann (1996) and Heathcote and Perri (2002).

[9] Since I choose the same parametrization for both countries, they have the same deterministic steady state.

1.3.1.2. Preference parameters. In the benchmark model economy, the preferences are of constant relative risk aversion form:

$$u(c_{jt}, l_{jt}) = \frac{[{c_{jt}}^{\gamma}(1-l_{jt})^{1-\gamma}]^{1-\sigma} - 1}{1-\sigma} \tag{1.18}$$

where σ represents the curvature on utility, while γ denotes the share of consumption (relative to leisure) in a composite consumer good.

The discount rate, β, was set so as to match the net average interest rate, $(r - \delta)$ in the US data of 6,5% (annual base). Using the Euler equation (1.11) in the deterministic steady state and shutting down all rigidities I have

$$\frac{1}{\beta} = \left[1 + (\alpha k_{ss}^{\alpha-1} l_{ss}^{1-\alpha} - \delta)\right]^{\frac{1}{4}} = [1 + (r - \delta)]^{\frac{1}{4}} \tag{1.19}$$

so that $\beta = 0.984$.

The share of consumption good in the composite good, γ, was pinned down from the labor supply equation (1.12) in the deterministic steady state by shutting down all the rigidities and assuming that time devoted to market activities is equal to 1/3 and that the investment/output share is equal to 0.25. In the steady state the labor supply equation (1.12) reads as:

$$c_{ss} = \frac{\gamma(1-l_{ss})(1-\alpha)k_{ss}^{\alpha} l_{ss}^{-\alpha}}{(1-\gamma)} \tag{1.20}$$

or by defining $c_{ss} = y_{ss} - i_{ss}$ and dividing by y I have

$$1 - \frac{i_{ss}}{y_{ss}} = \frac{\gamma(1-l_{ss})(1-\alpha)}{l_{ss}(1-\gamma)} \tag{1.21}$$

from which I get $\gamma = 0.369$.

I calibrate the utility curvature parameter, σ, such that the intertemporal elasticity of consumption, $IES(c_{jt}, c_{jt+1})$ in a deterministic model without any rigidities given as

$$IES(c_{jt}, c_{jt+1}) = \frac{1}{1-\gamma(1-\sigma)} \tag{1.22}$$

is equal to 1/2. This value corresponds to the value of the curvature equal to 2, which is usually assumed in RBC and IRBC literature concerned with models without endogenous labor supply. Holding constant intertemporal elasticity of substitution and having calculated γ, I can pin down the curvature parameter, $\sigma = 3.7$, corresponding to intertemporal elasticity of substitution of consumption equal to 1/2.

1.3.2. Calibration of the model with rigidities

Once I have calibrated a benchmark model economy that does not include any rigidity, I present the calibration of a model with four different rigidities. Unfortunately, it was only possible to calibrate the capital adjustment costs parameter "properly" (such that the model's investment volatility is equal to its empirical counterpart). In calibrating the parameters corresponding to other rigidities, I adapt their values from studies related to mine. In the sensitivity analysis I allow for these parameters to take different values in exploring how changes of these values affect international comovements.

1.3.2.1. Capital adjustment costs. I use the specification in Jermann (1998) to deal with adjustment costs to change of capital. Adjustment costs are governed by the function $\phi\left(\frac{i_{jt}}{k_{jt}}\right)$ where $\phi(\cdot)$ is a positive, convex function given by:

$$\phi\left(\frac{i_{jt}}{k_{jt}}\right) = \frac{d_1}{1-\frac{1}{\xi}}\left(\frac{i_{jt}}{k_{jt}}\right)^{1-\frac{1}{\xi}} + d_2 \tag{1.23}$$

Parameter ξ represents the elasticity of investment with respect to Tobin's q (ratio of the price of a newly installed unit of capital to the price of investment good[10]). This parameter determines the magnitude of capital adjustment costs. Values for d_1 and d_2 are chosen so that the deterministic steady state is invariant to ξ[11] i.e. so that the steady state value of Tobin's q is equal to one. If $\xi \to \infty$ the capital accumulation formula reduces to the

[10]Note that in the model without adjustment cost the Tobin's q is equal to one.

[11]The formulas are

$$\begin{aligned} g_1 &= \delta^{\frac{1}{\xi}} \\ g_2 &= \frac{1}{1-\xi}(1-\delta) \end{aligned}$$

standard law of motion of capital without adjustment costs. I set the value for ξ so that the investment volatility in the model is similar to that in the data.

1.3.2.2. Labor adjustment costs. In the case of analyzing supply-side rigidity on labor market , labor adjustment costs follow the standard quadratic specification as suggested by Cogley and Nason (1995), Cooper, Haltiwanger and Willis (2003) and Shapiro (1986):

$$g(l_{jt}, m_{jt}) = \frac{\varphi}{2l_{jt}} \Delta l_{jt+1}^2 = \frac{\varphi}{2l_{jt}} (m_{jt} - \psi l_{jt})^2 \tag{1.24}$$

where $\varphi \geq 0$ denotes labor adjustment costs parameter. When $\varphi > 0$ firms incur positive labor adjustment costs in terms of loss of their production if aggregate hours worked differ across periods. There will be no labor adjustment costs if $\varphi = 0$ or if hours worked do not fluctuate across periods (for example, in the deterministic steady state).A functional form of labor adjustment costs is homogeneous of degree one. Hence, decision on hirings does not depend on the number of firms, i.e. the assumption of a single representative firm holds. Furthermore, the labor adjustment cost function is convex and symmetric. Convexity of the labor adjustment cost function has the same interpretation as convexity of capital adjustment cost function - changing labor stock rapidly is more costly than changing it slowly. Furthermore, symmetric property of labor adjustment costs could be interpreted as it is as easy to hire workers as it is to fire them[12]. The micro foundation of this kind of rigidity on the labor market stems from the fact that labor adjustment costs are just a particular case of a two sided search-and-matching process in the labor market. In particular, my model with convex labor adjustment cost, if put in a closed-economy environment, would be a particular case of the RBC model with two sided search and matching in Merz (1995) if the elasticity of job matches with respect to total search effort were equal to zero, if a cost per unemployed worker is not incurred by varying search intensity and if posting a vacancy comes to an advertising cost that is governed by convex function[13].

As is usual in the RBC literature, my model yields employment volatility lower than in the data. Hence, no calibration of the labor adjustment costs parameter as in the case

[12] I also experimented with the natural assumption of being able to hire workers more easily than to fire them. Overall, the effect of asymmetric labor adjustment costs were very small. Furthermore, notice that there is no actual firing decision taking place. Employment is subject to continual exogenous depletion.

[13] I am thankful for this comment to Thijs van Rens.

of the capital adjustment cost parameter, ξ was possible. I set the labor adjustment costs parameter by referring to the labor adjustment costs literature. Cogley and Nason (1995) and Shapiro (1986) estimated a quadratic labor adjustment costs function similar to the one used here. Their findings correspond to the value of φ equal to 0.36. In a recent paper, Cooper, Haltiwanger and Willis (2003) estimated a similar quadratic labor adjustment costs function, obtaining a value of φ which is around 2. Given that the study of Cooper, Haltiwanger and Willis (2003)) is more recent, I use this parameter value in simulating the model and in reporting my results. However, in order clearly to evaluate the impact of labor adjustment costs on international comovement, I conduct a sensitivity analysis with respect to φ, and consider values of $\varphi \in \{1, 20\}$ as much smaller and much bigger value of labor adjustment cost parameter than the parameter value in the mail simulation exercise.

The value of the quarterly exogenous quit rate is set to $\psi = 0.15$, based on micro evidence reported in Andolfatto (1996).

1.3.2.3. Consumption and leisure habits. I assume simple time additive non-persistent habit-in-consumption specification in the non-separable utility function[14] (between consumption and leisure) proposed by Constantinides (1990). Then $\lambda^c = 1$ in law of motion of consumption habit stock(1.5). In this case, consumption habit stock at period t is simply represented by the level of consumption at period $t-1$.

In dealing with leisure habits ($b^l \neq 0$, see below) I assume the same habit-in-leisure specification as for habit-in-consumption specification. Then $\lambda^l = 1$ in law of motion of leisure habit stock(1.7). This non-persistent specification of leisure habits found some support in empirical studies like Eichenbaum, Hansen and Singleton (1988), Yun (1996), Hotz, Kydland and Sedlacek (1988) and more recently in Schmitt-Grohe and Uribe (2008).

Consequently, consumption and leisure habit stocks at period t are simply the levels of consumption and leisure at period $t-1$. Then the utility function reads as:

(1.25)

$$u(c_{jt}, h^c_{jt}, l_{jt}, h^l_{jt}) = u(c_{jt}, c_{jt-1}, l_{jt}, l_{jt-1}) = \frac{\left[(c_{jt} - b^c c_{jt-1})^\gamma (1 - l_{jt} - b^l(1 - l_{jt-1}))^{1-\gamma}\right]^{1-\sigma} - 1}{1-\sigma}$$

[14]With additive habits the objective function of the planner preserves concavity property, whereas this might not be true in a model with multiplicative habits (see Alonso-Carrera, Caballe and Raurich (2005) for details).

where b^c and b^l are consumption and leisure habit importance parameters. Now γ denotes the share of (habit adjusted) consumption (relative to (habit adjusted) leisure) in a composite consumer good.

Again, the share of consumption good in a composite good, γ, was pinned down from the labor supply equation (1.12) by assuming that time devoted to market activities is equal to 1/3 and that investment/output share is equal to 0.25. But now in the deterministic steady state the labor supply equation (1.12) with additive non-persistent consumption and leisure habits reads as:

$$1-\frac{i_{ss}}{y_{ss}}=\frac{\gamma(1-l_{ss}-b^l(1-l_{ss}))(1-\alpha)}{l_{ss}(1-\gamma)(1-b^c)(1-\beta b^l)}\times(1-\beta b^c) \tag{1.26}$$

from which I get the value for γ depending on values for the habit importance parameters b^c and b^l.

Calibration of the habit model economy requires choosing a value for the habit importance parameter in consumption, b^c, and, in the case of analyzing the rigidity on the demand-side of labor market , a value for the habit importance parameter in leisure, b^l. There are several studies that try to estimate the parameter of consumption and leisure habits (see Diaz, Pijoan-Mas and Rios-Rull (2003) and Wen (1998) for an overview of the estimation of the consumption and leisure habit parameter, respectively). The conclusion of all these studies is that heterogeneity of data, techniques and goals in research rises to a very wide range of possible values for parameters b^c and b^l. Ideally, I would be looking for an estimator consistent with my model in functional forms and length of period, which does not exist. The range of estimated or calibrated values of b^c and b^l in the literature is very wide. Studies of asset pricing[15], found that consumption habits characterized by values in the range of 0.69 to 0.9 can help to explain the equity premium puzzle. Since those models are close to mine, in reporting my results I use the a compromise between those values and set $b^c = 0.8$. Finally, as far as leisure habits are concerned I follow empirical literature[16] in parametrizing their importance parameter, $b^l = 0.7$. In sensitivity analysis I report the results from simulation

[15]See Boldrin, Christiano and Fisher (2001), Constantinides (1990) or Jermann (1998).
[16]See Wen (1998), Hotz, Kydland and Sedlacek (1988) and Eichenbaum, Hansen and Singleton (1988).

of the model with different combinations of two values of habit importance parameters (with the values that should correspond to low and high values of the parameter), $b^c = \{0.4, 0.8\}$ and $b^l \in \{0.4, 0.8\}$.

In the model with habits, again I calibrate the utility curvature parameter, σ, such that the intertemporal elasticity of consumption, $IES(c_{jt}, c_{jt+1})$[17] is equal to 1/2. In other words, I compare the benchmark economy and the economy with consumption and leisure habits but adjusted to have the same $IES(c_{jt}, c_{jt+1})$. This is achieved by changing the curvature parameter, σ. Holding the intertemporal elasticity of substitution constant and having calculated γ (depending on different values for b^c and b^l) I can pin down the curvature parameter, σ, which will now take different values for different values of b^c and b^l. Notice that in this way the steady state of the particular variable will be the same across different models and that simulated moments across different models will be comparable.

1.3.3. Numerical solution of the model

The social planner's problem was solved numerically using the parametrized expectations approach (PEA henceforth) introduced by Marcet (1989). The idea of PEA is to replace the expectation functions in (1.11), (1.12) and (1.13) by smooth parametric approximation functions of the current state variables[18] and a vector of parameters and then iterate on the values of parameters until rational expectation equilibrium is achieved. I choose PEA as a solution algorithm for two reasons. First, PEA circumvent the curse of dimensionality by avoiding the discretization of state space. And second, it has proven difficult to compute a solution of models that incorporate additive consumption habits by value function iteration algorithm, for example. Diaz, Pijoan-Mas and Rios-Rull (2003) show that solving a simple growth model with exogenous incomplete markets and additive habits in consumption is not feasible. This is because the algorithm that relies on value function iteration cannot rule

[17]Notice that since I deal with additive consumption habits recalibration of the coefficient of relative risk aversion in the model with habits is not needed since intertemporal elasticity of substitution of consumption in the model with habits is the same as in the setting without habits and it does not depend (in the deterministic steady state) on habit parameters b^c and λ^c. See Lemma 2 in Diaz, Pijoan-Mas and Rios-Rull (2003) that establishes this result in the environment without labor. It is straightforward to show that the same lemma applies to my model with endogenous labor supply decision and leisure habits.

[18]In my model the vector of states is given by $[k_{1t}\ h^c_{1t}\ y_{1t}\ z_{1t}\ k_{2t}\ h^c_{2t}\ y_{2t}\ z_{2t}]$ where $h^c_{jt} = c_{jt-1}$ for $j = \{1, 2\}$ and $y_{jt} = h^l_{jt} = 1 - l_{jt-1}$ in case of leisure habits or $y_{jt} = l_{jt}$ in case of studying labor adjustment costs.

out ex ante the values of decision variables that the agent would try very hard to avoid (so that actually agents end up consuming negative habit adjusted consumption!). By the endogenous oversampling feature, PEA solves this problem. The endogenous oversampling feature implies that PEA only pays attention to those points that actually happen in the solution (for details see Marcet and Marshall (1994)) - only the economically relevant region of the state space is explored. For algorithm details see the Appendix.

1.3.4. Findings

In this section I compare the quantitative properties of the theoretical world economy with those of the data. I start with a brief discussion of international comovement puzzles by comparing simulation results of a standard, complete markets IRBC model without any rigidity on goods or factors markets (the benchmark, perfect risk sharing model) with the moments calculated from the data (Table 1.2). Then, I explore the quantitative effect of different rigidities on international comovements. In particular, I analyze the simulation results of two models: a model with consumption habits, capital adjustment costs and labor adjustment costs and a model that instead of labor adjustment costs incorporates a different type of labor market rigidity, namely leisure habits.

First, I interpret the effects of introducing capital adjustment costs and consumption habits both separately and jointly on international comovements in comparison to results of the benchmark model and data. Then, I investigate separate consequences on international correlations of introducing labor adjustment costs, on the one hand, and leisure habits on the other in the model with consumption habits and capital adjustment costs. Table 1.2 shows simulation results of the model that incorporates consumption habits (represented by parameter b^c), capital adjustment costs and labor adjustment costs (represented by parameter φ). Table 1.3 shows the simulation results of the model that incorporates consumption habits (represented by parameter b^c), capital adjustment costs and leisure habits (represented by parameter b^l). By shutting down a particular parameter in two models, it is possible to explore separate effects of a particular rigidity on international comovements.

The statistics reported in all the tables in the first nine rows of the Data column are taken from Kehoe and Perri (2002) and pertain to the U.S. quarterly time series (logged and HP filtered with smoothing parameter 1600). International correlations in those tables are also taken from the same source and refer to the correlations between U.S. aggregate variables and the same variables for the aggregate of 15 European countries. The capital flow statistic was computed from the U.S. national accounts (NIPA) and pertains to the quarterly time series of net exports/GDP. To be consistent with the statistics computed from the data, the relevant model statistics are calculated from logged and HP filtered data with smoothing parameter 1600. Instead of simulating each model many times to obtain many samples of artificially generated short time series and then calculating the average throughout the samples and its standard deviations, I simulated each model just once using however a long time series of each variable (10,000 periods)[19].

1.3.4.1. The benchmark, perfect risk sharing model. In comparing the benchmark model and the data in the second and third column of Table 1.2, we can see three international comovement puzzles documented in the literature. In the model, consumption cross-country correlation is substantially higher than that of output (0.65 vs. -0.02), while in the data the opposite is true (0.32 vs. 0.51). And both investment and employment correlations are negative in the model (-0.78 and -0.37 respectively) whereas in the data they are positive (0.29 and 0.43 respectively). In addition, there is one major discrepancy in the domestic economy- both net exports and investments are much more volatile in the model than in the data (0.81 vs. 0.15 and 6.04 vs. 3.24 respectively).

[insert Table 1.2 about here.]

In order to get some intuition for the pattern of (co)movements of the model's aggregates and the dynamics of the model. I study impulse responses of a world economy to a 1% increase in total factor productivity in the home country[20] (pictured in Figure 1.1 and Figure 1.2).

[insert Figure 1.1 and Figure 1.2 about here.]

All the impulse responses of the aggregates are measured as percentage deviations from their steady state values. Figure 1.1 and Figure 1.2 illustrates what happens in the home and foreign country following a positive shock in the home country, which slowly dies out

[19]The two procedures should be equivalent assuming that number of simulations in the first and the sample size in the second procedure are large enough.

[20]Notice that since there are no spillovers ($a_2 = 0$) the productivity in the foreign country does not change.

after the first period. Home investment and labor hours increase (resulting in an increase in domestic output) while foreign investment and employment fall (resulting in a fall in foreign output) - positive domestic productivity shock increases the productivity of capital and labor which results in a shift of resources to the home country. The capital stock in the home country increases both by domestic agents saving more and by more capital inflows from abroad taking advantage of higher return on capital in the home country. This will result in a negative cross-country correlation of investment. For our calibration of the model, investment rises much more than consumption and output together, leading to net exports deficit and negative correlation of net-exports and GDP. With regard to employment, the temporarily high productivity of labor induces home country agents to supply more labor since the substitution effect prevails over the wealth effect, while in the foreign country the stronger wealth effect of the shock generates a reduction in labor supply. This will result in a negative cross-country correlation of employment. Next, since country-specific risk is perfectly insured, agents in the home country agree to "share" some of the additional output generated by the increase in productivity in exchange for a similar deal when the other country receives a positive productivity shock. This will result in a positive cross-country correlation of consumption[21]. Finally, large volatility of investment and net exports reflects the ability of agents in the model costlessly to shift investments across the countries (to a country which is more productive).

1.3.4.2. Adding capital adjustment costs. To account for variability of investment and net exports in the data I add capital adjustment costs into a benchmark model. Capital adjustment costs have been incorporated to slow the response of investment to a country-specific shock. Without the capital adjustment costs, capital owners have a strong incentive to locate new investment in the more productive country making investment and then net exports excessively volatile.

Here I compare the statistics of a benchmark model with those of the model where capital adjustment costs are incorporated. Table 1.3 presents simulation results of the model that

[21]Note that consumption sharing between countries is not 1:1 because preferences are nonseparable in consumption and leisure making cross-country correlation of consumption smaller than 1. Actually, since consumption and labor are complements in utility function, consumption increases by more at home than abroad.

incorporates consumption habits, leisure habits and capital adjustment costs. To explore the relevant effects of capital adjustment costs I shut down consumption habits ($b^c = 0$) and labor adjustment costs ($b^l = 0$). The fourth and third columns of Table 1.3 show than when compared to a benchmark model, introduction of capital adjustment costs substantially affects investment cross-correlation only. Still this correlation is far from the one we observe in the data (-0.32 in the model with capital adjustment costs vs. 0.29 in the data). Moreover, while impairing capital flows (0.93 vs. 1.38), capital adjustment costs make correlation of net export and GDP positive (0.15 vs. -0.26). With regard to domestic comovements, investment and net exports volatilities fall considerably (3.24 vs. 6.04 and 0.18 vs. 0.81 respectively) as consumption volatility rises (0.42 vs. 0.37).

[insert Table 1.2 about here.]

The fact that capital adjustment costs bring volatility of investment and net exports in line with the data follows from our calibration procedure. Capital adjustment costs reduce volatility of investment since convexity of the adjustment cost function $\phi(\cdot)$ implies that changing capital stock rapidly is more costly than changing it slowly. This is the reason why investment (net exports) volatility falls. Furthermore, volatility of consumption rises as a result of not having an investment change opportunity to shield consumption against a shock as in the benchmark model. This effect can be also seen from the impulse responses pictured in Figure 1.3 and Figure 1.4 (impulse responses denoted by $b^c = 0$, $\varphi = 0$).

[insert Figure 1.3 and Figure 1.4 about here.]

The impulse response to a 1% increase in total factor productivity in the home country leads to much smaller investment response than in a no-capital adjustment cost case. Moreover, this presents a main force behind the reversal (and a fall) of capital flows - with small investment response (relative to response of consumption and output which are almost the same as in the no capital adjustment costs case) the home country will experience capital outflow (net exports surplus) during the "good" times. Positive output response in the home country together with a net exports surplus generates a positive correlation of net exports and GDP. With regard to international correlations, capital adjustment costs make a sizeable change in investment cross-correlation only. This is because the costs imposed by adjustment on change of capital impair incentives to move investment to a more productive country - cross-correlation gets smaller. However this cost is still smaller that the return on investment in a more productive country- cross-correlation is still negative.

1.3.4.3. Adding Consumption habits. Now I consider the economy in which agents form preferences over past consumption and where change of capital is subject to adjustment costs[22]. I compare the statistics of benchmark model with those of the model where consumption habits are characterized by habit importance parameter, $b^c = 0.8$.

The most important results of introducing consumption habits into a IRBC model with capital adjustment costs can be summarized as follows (comparing the results of the benchmark model in the third column of Table 1.3 and the results of the model with consumption habits and capital adjustment costs in the fifth column of Table 1.3, where I shut down leisure habits, $b^c = 0.8$, $b^l = 0$). The variability of both investments and net exports is reduced substantially- the standard deviation of the net exports falls from 0.81 to 0.20 and standard deviation of investment from 6.04 to 3.24. In addition, even though consumption habits alone generate more capital flows, in combination with capital adjustment costs the latter has much stronger effect on impairing capital flows (they fall from 1.38 to 0.84). In connection to this, the correlation of net exports and GDP gets positive (0.72 vs. -0.26). Finally, employment variability falls from 0.45 to 0.38. With regard to international statistics, capital adjustment costs and consumption habits have the largest effect on cross-correlation of investment and employment. While they generate large negative cross-correlation of employment (-0.78 vs. -0.37) both rigidities help to resolve the investment puzzle - cross country investment correlation is now positive (0.31 vs. -0.78) and in the range as is observed in the data.

[insert Table 1.3 about here.]

As far as the fall of investment and net exports volatility is concerned, the same logic applies as in the previous subsection. Furthermore, capital adjustment costs act as a tax

[22]Incorporating consumption habits into the model without adjustment costs had its standard effect of increasing volatility of investment and net exports even further, and decreasing volatility of consumption. Consumption habits make the agents (locally) very risk averse since now they want to smooth changes in consumption instead of consumption itself, which implies extreme consumption smoothing (in levels). This then gives rise to more volatile investment which serves as a buffer against productivity shock. With regard to international comovements, consumption habits do not make much difference with respect to the benchmark model. This result stems from the fact that habits do not change the "structure" of the economy in terms of changing the pattern of behavior of aggregates in both countries.

on labor- labor volatility falls since the substitution effect coming from higher productivity (wage) becomes lower than in a benchmark case (but still dominates over wealth effect)- agents are not willing to increase their labor supply as much as without the "tax". This is the reason why employment volatility falls. In connection to international comovements, the cross-correlation of investment is positive whereas that of employment is negative and much larger than in the benchmark model. International comovements can be explained in the following way. Consumption habits make investment volatility larger than in a model without consumption habits and with capital adjustment costs implying that a magnitude of adjustment costs, now, has to be larger to make investment volatility in line with the data. From Figure 1.3 and Figure 1.4 we can see that the investment impulse response of foreign country is now small but more important, it is positive (denoted by $b^c = 0.8$, $\varphi = 0$), for our calibration procedure. This is because the effect of capital adjustment costs prevails over the opportunity cost of not shifting the investment to a more productive country. In other words, the cost (stemming from transforming investment to capital) that agents have to "pay" if they invested abroad are bigger than the return on capital in the more productive country. This in turn, gives a rise to a positive cross-correlation of investment, fewer capital flows (in comparison to both benchmark model and model without habits and with adjustment costs) and positive correlation between net exports and GDP. Although capital adjustment costs and habits together help explain investment puzzle, they aggravate the employment puzzle – the negative cross-correlation of employment is much stronger that in the benchmark model. Because of the lower substitution effect, discussed above, capital adjustment costs bring the response of labor supply in the home country more in line with that in the foreign country (with the opposite sign) making cross-correlation stronger[23].

1.3.4.4. Leisure habits vs. Labor adjustment costs. Now I will separately explore the effects of introducing two labor market rigidities, demand-side rigidity- labor adjustment costs and supply-side rigidity- leisure habits, into the model with consumption habits and capital adjustment costs. I compare simulation results of the model with consumption habits, capital and labor adjustment costs (or leisure habits), where labor adjustment costs (or

[23]Notice that this did not happen in the model without habits and with adjustment costs since the substitution effect coming from "lower" adjustment costs i.e. the "lower tax" of that model did not induce agents in home country to decrease (relatively) their labor effort as much as in the model with both elements.

leisure habits) are characterized by $\varphi = 2$ (or $b^l = 0.7$) (the sixth column of Table 1.2 or the sixth column of Table 1.3, respectively) with the results of the model with consumption habits and capital adjustment costs (the fourth column of Table 1.2, where I shut down labor adjustment costs, $\varphi = 0$).

Introducing labor adjustment costs has the following main effects. In domestic terms, once labor adjustment costs are included in a model with consumption habits and capital adjustment costs, employment and output volatility and correlation of employment with GDP naturally go down. However, for our parametrization this change is small (0.36 vs. 0.38, 0.71 vs. 0.77 and 0.69 vs. 0.90 respectively). All these come as a result of the employment-smoothing effect - firms are reluctant to change the employment level as they are facing labor adjustment costs. With regard to international comovements, all cross correlations rise, which from the perspective of matching the data is favorable from the perspective of output cross-correlation only. As we have seen before, the main forces behind positive investment comovement include consumption habits and capital adjustment costs. Labor adjustment costs just accentuate the effect of two rigidities by acting as a tax on investment. When a home country experiences a positive shock, the response of investment will be lower than in the case of no labor adjustment costs (see Figure 1.5 and Figure 1.6) (but still positive) making investment correlation stronger. Even though the responses of employment are reduced substantially in "good times" once the labor adjustment costs are introduced (see Figure 1.5 and Figure 1.6), the employment correlation becomes even stronger. Positive correlation of investment and of TFP shock together with small responses of employment in both countries will induce positive correlation of output across the countries.

[insert Figure 1.5 and Figure 1.6 about here.]

Now consider an economy in which instead of firms facing adjustment costs if they change the level of employment, agents have preference over past leisure as well as over past consumption. Because of leisure habits, agents will not be willing to change their labor supply decisions too much. The main effects of this kind of labor market rigidity in a model with consumption habits and capital adjustment costs on domestic and international comovements are different from those coming from labor adjustment costs (the last column of Table 1.3 shows the simulation results). In particular, employment volatility is lower than in the model without leisure habits (0.34 vs. 0.38). Furthermore, correlation of employment with

GDP is higher and it is in line with the data (0.85 vs. 0.69), but lower than in the model without any labor market rigidities (0.85 vs. 0.90). Moreover, while labor adjustment costs increase the correlation of net exports and GDP, leisure habits will result in smaller correlation of net exports and GDP, although still too far from the negative correlation that we observe in the data. In an international environment, favorable effects of leisure habits include the increase in output cross-correlations (0.07 vs. 0.00) and a fall in consumption cross-correlation (0.69 vs. 0.80). On the other hand, employment and investment correlations move in the opposite direction from what is needed to account for the correlations that we observe in the data (-0.83 vs. -0.78 and 0.22 vs. 0.31 respectively). The explanations for output, investment and employment comovements with leisure habits is similar to that with labor adjustment costs. The only difference between the two labor market rigidities, in terms of international comovements, pertains to consumption correlation. The decline of consumption correlation can be traced from the risk sharing equation (1.13). This equation requires that marginal utilities for both countries should be the same in any period[24]. Since in the labor adjustment costs case labor is a quasi-fixed factor of production, this equality is driven solely by consumption comovements. With leisure habits, an agent will be able to influence the equality of marginal utilities by changing not only the level of labor supply decision but also by changing the habit-adjusted labor supply. This magnifies the effect of nonseparability in the utility between consumption and leisure and therefore lowers consumption correlation across countries.

1.3.4.5. Sensitivity analysis. The results discussed in the previous section are conditional on parameter values that I could not calibrate from the data. To address this issue, I repeat the analysis carried out in previous section using different values of habit importance parameters, $b^c = \{0, 0.4, 0.8\}$ and $b^l = \{0, 0.4, 0.8\}$, and different values of labor adjustment costs, $\varphi = \{0, 1, 20\}$. Table 1.4 reports simulation results for different values of b^c and φ corresponding to analysis the results of which are summarized in Table 1.2. Table 1.5 shows the results of sensitivity analysis of different values of b^c and b^l corresponding to

[24]Notice that the expectation terms will cancel each other out since the expectation is taken with respect to the same joint distribution of the shock process vector.

simulation exercise which results are summarized in Table 1.3. Other parameter values in both sensitivity analyses are the same as in the baseline analyses.

[insert Table 1.4 about here.]

Increasing the importance of consumption habits, b^c, given the labor adjustment cost parameter, has an important effect on investment and employment cross-correlations and on correlation between output and net exports (see Table 1.4). Only the first effect of positive investment cross-correlation positive coming from high importance of consumption habits is desirable as far the data is concerned. It seems that "intermediate" values of $b^c = 0.4$ do not have much quantitative relevance for any domestic or international statistics. The results indicate that only a high importance of consumption habits is sufficient for generating positive comovement in investment.

Increasing the value of labor adjustment costs, φ, given the consumption importance parameter, is not quantitatively important for any statistics. It seems that φ taking higher values than 20 would not help in resolving international puzzles since higher labor adjustment costs bring about even stronger cross-correlations of consumption, investment and employment which is not in line with the data.

Making leisure habits more important in consumers utility function (see Table 1.5), given the value for consumption habits, magnifies the effects of nonseparability in utility between consumption and leisure and therefore lower consumption cross-corelation. Together with rising output cross-correlation higher b^l brings about forces that lower the gap a bit between output and consumption cross-correlations (but not nearly closing the gap that represents the consumption puzzle). However, effects of higher b^l on investment and employment cross-correlations do not work towards resolving factor comovements puzzles.

[insert Table 1.5 about here.]

1.4. Conclusion

The main goal of this paper was to explore the importance of different types of rigidities in the market for goods and factors, which today constitute a large part of closed-economy RBC theory, for the character of international business cycles. First, I show that the IRBC model with consumption habits and a capital adjustment cost can resolve the investment cross-correlation puzzle - the combination of two rigidities provides a channel through which the adjustment costs become larger than the opportunity costs of not investing in a more productive country. However, solving the investment puzzle comes at the expense of too low capital flows, positive correlation of net export and GDP and even more puzzling cross-correlation of employment. Second, rigidities on the labor market do not help to explain factor comovements (employment and investment puzzles), neither introduced alone in the IRBC model nor in combination with other rigidities. While both labor adjustment costs and leisure habits increase the output correlation, only the effects of the latter present forces toward resolving the consumption cross-correlation puzzle (although not actually resolving it). This mainly comes as a result of leisure habits reducing consumption correlation through amplified effects on nonseparability between consumption and leisure.

Overall, this paper shows that real rigidities that help explain many closed-economy salient facts have less success in resolving international comovement puzzles. Given that only a complete markets environment was considered here, the conclusion of this paper supports the results of Kehoe and Perri (2002) or Yakhin (2007), which show the importance of financial and contractual frictions in explaining the international transmission of business cycles.

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1.5. Appendix

In the first part of the appendix I show one way to decentralize the social planner's problem presented in the main text. In the second part of the appendix, I describe the algorithm that was constructed to solve the model numerically.

1.5.1. Competitive equilibrium

There exists an alternative formulation of the social planner's economy that views households and firms as interacting in the perfectly competitive markets for goods, capital and labor. Below I present a decentralized market mechanism that corresponds to the planner's optimal allocation from the main text.

1.5.1.1. Endowments. Each household has an endowment of one unit of time that can be allocated to leisure or work. The world economy has an initial stocks (identical for the two countries $j = \{1, 2\}$) of capital, k_{j0}, consumption habits, h^c_{j0}, labor-augmenting technology, z_{j0} and initial amount of state contingent assets, a_{j0}. In the case of analyzing leisure habits, a world economy also starts with an initial stock of leisure stock, h^l_{j0}, or with an initial stock of labor, l_{j0}, in the case of examining labor adjustment costs. Notice that in the case of labor adjustment costs, labor hired in period t becomes productive only in period $t+1$. This can be interpreted as "time to build labor stock" or necessity to train workers before they get productive. Anyway, the decision about labor supply in $t+1$ is made in period t, or in other words, the labor supply decision is made before realization of the shock process in $t+1$. After the state of technology is realized, the labor market clears (subject to predetermined labor supply) at a competitive wage.

1.5.1.2. Households. In each period, in both home and foreign country, $j = \{1, 2\}$ a representative household supplies labor to the firm in exchange for the wage w_{jt} that represents its labor income. From the total income it decides how much to consume and how much to save. Since markets are complete, asset trading opportunities consist of a full set of one-period Arrow securities representing a claim for consumption in $t+1$ and whose payment is contingent on realization of z_{t+1}. Let $a_{jt}(z_t)$ denotes the one-period Arrow security that a household brings into period t. Furthermore, $q(z_{t+1})$ is a price of a state-contingent bond that (loosely speaking[25]) gives the price of one unit of period $t+1$ consumption, contingent on the realization of z_{t+1} at $t+1$. The decisions to consume, save and supply labor are made so as to maximize the expected discounted lifetime utility function which represents preferences over consumption, c_{jt}, labor, l^s_{jt}, and consumption habit stock, h^c_{jt} (in the case of examining demand-side labor market rigidity households also have preferences over leisure habit stock, h^l_{jt}):

$$\max_{\{c_{jt}, l^s_{jt}, a_{jt+1}(z_{t+1})\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \int_{Z^t} u(c_{jt}, h^c_{jt}, l^s_{jt}, h^l_{jt}) \mu^t \left(z_0, dz^t\right) \tag{1.27}$$

subject to

$$c_{jt} + \int_Z q(z_{t+1}) a_{jt+1}(z_{t+1}) dz_{t+1} = w_{jt} l^s_{jt} + a_{jt}(z_t) \tag{1.28}$$

$$h^c_{jt+1} = h^c_{jt} + \lambda^c (c_{jt} - h^c_{jt}) \tag{1.29}$$

in the case of leisure habits:

$$h^l_{jt+1} = h^l_{jt} + \lambda^l (1 - l_{jt} - h^l_{jt}) \tag{1.30}$$

$$a_{j0}(z_0), h^c_{j0}, h^l_{j0}, z_{j0} \text{ given for } j = \{1, 2\}$$

with discount factor $0 < \beta < 1$.

To rule out the Ponzi schemes, I impose state-by-state borrowing constraint

$$-a_{jt+1}(z_{t+1}) \leq A_{jt+1} \tag{1.31}$$

where A_{jt+1} is natural debt limit.

1.5.1.3. Firms. In each country there is a representative firm that operates the technology $f(k_{jt}, l_{jt}, z_{jt})$. In each period, the firm decides how much labor to hire, l^d_{jt} and how much to invest, i_{jt} taking into account capital adjustment costs. In the case of labor adjustment costs, instead of deciding on labor demand, the firm decides on new employment, m_{jt} so as to maximize expected, present values of discounted profits (current and future cash flow) to

[25]See Lucas (1978) for rigorous treatment and notation of the price of the state contingent bond.

its owners (a representative household):

$$\max_{\{i_{it},x_{it}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} v_{jt,0} \int_{Z^t} \left[f(k_{jt},l_{jt},z_{jt}) - g(m_{jt},l_{jt}) - w_{jt}l_{jt} - i_{jt}\right] \mu^t \left(z_0, dz^t\right) \tag{1.32}$$

subject to

$$k_{jt+1} = (1-\delta)k_{jt} + \phi\left(\frac{i_{jt}}{k_{jt}}\right)k_{jt} \tag{1.33}$$

in the case of labor adjustment costs:

$$l_{jt+1} = (1-\psi)l_{jt} + m_{jt} \tag{1.34}$$

$$k_{j0}, l_{j0}, z_{j0} \text{ given for } j = \{1,2\}$$

where $x_{jt} = \{l_{jt}^d, m_{jt}\}$, depending on the presence of particular labor market rigidity. Furthermore, $v_{jt,0}$ is the firm's stochastic discount factor representing a marginal rate of substitution of consumption between the time period t and period 0 of the firms owners in country $j = \{1,2\}$ given by

(1.35)

$$v_{jt,0} = \frac{\beta^t\left(u_1(c_{jt},h_{jt}^c,l_{jt},h_{jt}^l) + \beta\lambda\int_Z\left[\sum_{i=0}^{\infty}\beta^i(1-\lambda)^i u_2(c_{jt+i+1},h_{jt+i+1}^c,l_{jt+i+1},h_{jt+i+1}^l)\right]Q\left(z_t,dz_{t+1}\right)\right)}{\left(u_1(c_{j0},h_{j0}^c,l_{j0},h_{j0}^l) + \beta\lambda\int_Z\left[\sum_{i=0}^{\infty}\beta^i(1-\lambda)^i u_2(c_{j0+i+1},h_{j0+i+1}^c,l_{j0+i+1},h_{j0+i+1}^l)\right]Q\left(z_t,dz_{t+1}\right)\right)}$$

and $\phi(\cdot)$ and $g(\cdot)$ are capital and labor adjustment cost functions given in (1.23) and (1.24) respectively.

1.5.1.4. Market equilibrium. In this economy, a competitive equilibrium consists of, for $j = 1,2$, a list of stochastic processes for allocations for the households, $\left\{c_{jt}, l_{jt}^s\right\}_{t=0}^{\infty}$, and for the firm $\{x_{jt}, i_{jt}\}_{t=0}^{\infty}$, assets $\{a_{it+1}(z_{t+1})\}_{t=0}^{\infty}$, and prices $\{q_t(z_{t+1}), w_{jt}\}_{t=0}^{\infty}$, such that

(1) given prices, and initial assets, consumption habit stock, $\{a_{j0}, h_{j0}^c\}_{i=1,2}$ (in the case of leisure habits initial stocks read as $\{a_{j0}, h_{j0}^c, h_{j0}^l\}_{i=1,2}$), $\left\{c_{jt}, l_{jt}^s\right\}_{t=0}^{\infty}$ solves the consumer problem for each $j = \{1,2\}$,

(2) given prices and initial capital $\{k_{j0}\}_{i=1,2}$, (in the case of labor adjustment costs there is also an initial stock of labor $\{l_{j0}\}_{i=1,2}$) the allocation $\{x_{jt}, i_{jt}\}_{t=0}^{\infty}$ solves the

representative firm problem for each $j = \{1, 2\}$ where $x_{jt} = \{l^d_{jt}, m_{jt}\}$ depending on the presence of particular labor market rigidity.

(3) markets clear

$$a_{1t+1}(z_{t+1}) + a_{2t+1}(z_{t+1}) = 0 \tag{1.36}$$

$$l^s_{jt} = l^d_{jt} \tag{1.37}$$

$$\sum_{j=1}^{2} c_{jt} + \sum_{j=1}^{2} i_{jt} = \sum_{j=1}^{2} [f(k_{jt}, l_{jt}, z_{jt}) - g(m_{jt}, l_{jt})] \tag{1.38}$$

1.5.2. The algorithm

I rely on log-linear polynomials in a parametrization of conditional expectations so that each conditional expectation is approximated by the following functional form (for each country $j = \{1, 2\}$) as a function of states:

$$\begin{aligned}\psi_j(\theta_j; k_{1t}(\theta), h^c_{1t}(\theta), y_{1t}(\theta), z_{1t}, k_{2t}(\theta), y_{2t}(\theta), z_{2t}) &= \exp(\theta_{j1} + \theta_{j2}k_{1t}(\theta) + \theta_{j3}h^c_{1t}(\theta) + \\ &\quad +\theta_{j4}y_{1t}(\theta) + \theta_{j5}z_{1t} + \theta_{j6}k_{2t}(\theta) + \\ &\quad +\theta_{j7}h^c_{2t}(\theta) + \theta_{j8}y_{2t}(\theta) + \theta_{j9}z_{2t})\end{aligned}$$

where $\theta = (\theta_1, \theta_2)$, $\theta_j \in \mathbb{R}^9$ and where $y_{jt}(\theta) = h^l_{jt}(\theta)$ in the case of analyzing leisure habits or $y_{jt}(\theta) = l_{jt}(\theta)$ in the case of examining labor adjustment costs. The subscript of functional form, ψ_j and of parameter vector, θ_j denotes the parametrization for specific country $j = \{1, 2\}$. One advantage of using the log-linear polynomial is that it guarantees the simulated series will be non-negative.

If expectation were correctly parametrized i.e. if there existed a θ^*_j such that $\psi_j\left(\theta^*_j; k_{1t}(\theta^*), h^c_{1t}(\theta^*), y_{1t}(\theta^*), z_{1t}, k_{2t}(\theta^*), h^c_{2t}(\theta^*), y_{2t}(\theta^*), z_{2t}\right)$ is a very good approximation to the true conditional expectation, then the decision rules would coincide with the true optimal decision rules and simulations of decision variables would represent realization from the true stochastic process (for the proof see Marcet and Marshall (1994)). Increasing the degree of polynomial would insure that there exist θ^*_j such that $\psi_j\left[\theta^*_j; k_{1t}(\theta^*), h^c_{1t}(\theta^*), y_{1t}(\theta^*), z_{1t}, k_{2t}(\theta^*), h^c_{2t}(\theta^*), y_{2t}(\theta^*), z_{2t}\right)$ is an arbitrary good approximation to the true conditional expectation.

To obtain a numerical solution of the model I parametrize three conditional expectation functions, for each country, which I denote by $E_t^i(\cdot)$ where superscript i denotes the optimality condition ($i = 1$ corresponds to expectation in the Euler equation (1.11), $i = 2$ to expectation in the labor supply equation (1.12) and $i = 3$ to expectation in the risk sharing condition (1.13)). In other words, for our functional forms and calibration, after rearranging the terms and applying the law of iterated expectations I parametrize the expectation in the Euler equation (1.11), $E_t^1(\cdot)$, expectation in labor supply equation (1.12), $E_t^2(\cdot)$, and expectation in risk sharing condition (1.13), $E_t^3(\cdot)$. Each expectation function is denoted by superscript $i = \{1, 2, 3\}$ for both $j = \{1, 2\}$. Also, parameters corresponding to a parametrization of a given expectation will be denoted by the same superscript.

First, I rewrite the Euler equation (1.11) in such a way that I can parametrize its expectation for the quadratic value of investment, i_{jt}^2 for both countries, $j = \{1, 2\}$. Next, I substitute the conditional expectation $E_t^1(\cdot)$ in (1.11) by a first degree log-linear polynomial that depends on state variables and vector of parameters θ_j^1 to get

$$i_{jt}^2 = \beta\psi_j(\theta_j^1; k_{1t}(\theta), h_{1t}^c(\theta), y_{1t}(\theta), z_{1t}, k_{2t}(\theta), h_{2t}^c(\theta), y_{2t}(\theta), z_{2t}) \tag{1.39}$$

where $y_{1t}(\theta)$ represents either leisure habit stock or labor stock depending on the labor market rigidity I am analyzing (as explained before).

Next, for $j = \{1, 2\}$ I also use first degree log-linear polynomial (with parameter vector θ_j^2) to parametrize a conditional expectation $E_t^2(\cdot)$ in the labor supply equation (1.12). I parametrize the resulting conditional expectation for x_{jt} which represents either l_{jt} in case of analyzing leisure habits (where labor adjustment costs parameter $\varphi = 0$) or m_{jt} in the case of examining labor adjustment costs (where leisure habit importance parameter $b^l = 0$), for both countries, $j = \{1, 2\}$. I substitute the conditional expectation $E_t^2(\cdot)$ in (1.11) by a first degree log-linear polynomial that depends on state variables and vector of parameters θ_j^2 to get

$$x_{jt} = \beta\psi_j(\theta_j^2; k_{1t}(\theta), h_{1t}^c(\theta), y_{1t}(\theta), z_{1t}, k_{2t}(\theta), h_{2t}^c(\theta), y_{2t}(\theta), z_{2t}) \tag{1.40}$$

Finally, for $j = \{1, 2\}$ I also use first degree log-linear polynomial (with parameter vector θ_j^3) to parametrize a conditional expectation $E_t^3(\cdot)$ in the risk sharing condition (1.13) to get:

$$(1.41)\quad E_t^3\left[u_2(c_{1t}, h_{1t}^c, l_{1t}, h_{1t}^l)\right] = \beta\psi_j(\theta_j^3; k_{1t}(\theta), h_{1t}^c(\theta), y_{1t}(\theta), z_{1t}, k_{2t}(\theta), h_{2t}^c(\theta), y_{2t}(\theta), z_{2t})$$

Once I have a parametrized expectation forms, the algorithm for solving the model can be described as follows.

- *Step* 1. Fix the initial vector of parameters, $\theta = (\theta_1^1, \theta_2^1, \theta_1^2, \theta_2^2, \theta_1^3, \theta_2^3)$, the stopping criterion (tolerance level) and draw sequences of the TFP shocks $\{z_{1t}, z_{2t}\}_{t=0}^T$ that obey (1.15) with T sufficiently large[26].
- *Step* 2. Given the parametrized expectations and given the parameter vector θ, at time period t, solve for the decision variables$\{c_{jt}(\theta), i_{jt}(\theta), x_{jt}(\theta), k_{jt+1}(\theta), y_{jt+1}(\theta)\}_{j=1}^2$ from the system of risk sharing condition (1.13) and budget constraint (1.3) together with the laws of motion for the capital, consumption, leisure (or labor) stock (1.4), (1.5), (1.7) (or (1.6)), respectively. To do this, given the parametrized expectations in (1.39), (1.40) and (1.41) for both $j = \{1, 2\}$ (hence given $\{i_{jt}\}_{j=1}^2$ and $\{x_{jt}\}_{j=1}^2$) calculate the values for the capital stock next period, k_{jt+1}, which follows from the corresponding equations of motion (1.4) and the values for y_{jt+1}- the values for the habits leisure stock next period, l_{jt}, in the case of analyzing demand-side rigidity on the labor market from (1.7) or labor stock next period, l_{jt+1}, in the case of analyzing supply-side rigidity on the labor market from (1.6). Also, given the parametrized expectations $i = \{1, 2, 3\}$ for both $j = \{1, 2\}$ in (1.39), (1.40) and (1.41) the values of remaining decision variables $\{c_{1t}(\theta), c_{2t}(\theta)\}$ are a solution of the non-linear system of the following two equations in two unknowns: risk sharing condition (1.13) and the budget constraint (1.3).

[26]In order to insure higher accuracy of solution and correct impulse response functions I should choose very large sample size such that the estimated parameter θ does not depend on the realization of the shock process. I manage to experiment with the sample size up to T=100 000. Even tough there was a lot of variation in estimated parameter vector in estimation using sample of T=10 000 and those for the sample size of T=100 000 the model's results did not change much. In addition, because of the computational time problem (for the solution of the model with habits alone the algorithm that used T=100 000 needed more that 10 days to converge to the rational expectation equilibrium) I report the results obtained using the sample size T=10 000.

- *Step* 3. For particular parametrization depending on θ use the realizations for the shocks, $\{z_{1t}, z_{2t}\}_{t=0}^{T}$ to obtain recursively a sequence for the decision variables
  $\{c_{jt}(\theta), i_{jt}(\theta), x_{jt}(\theta), k_{jt+1}(\theta), y_{jt+1}(\theta)\}_{t=1}^{T}$ for $j = \{1, 2\}$ by repeating Step 2.
- *Step* 4. Compute the updated parameter vector $S(\theta) = \big(S(\theta_1^1), S(\theta_2^1), S(\theta_1^2), S(\theta_2^2),$ $S(\theta_1^3), S(\theta_2^3)\big)$ by running six non-linear least square regressions using the simulated realization
  $\{c_{1t}(\theta), i_{1t}(\theta), x_{1t}(\theta), k_{1t+1}(\theta), c_{2t}(\theta), i_{2t}(\theta), x_{2t}(\theta), k_{2t+1}(\theta)\}_{t=1}^{T}$ as data. In other words, for every $j = \{1, 2\}$ and $i = \{1, 2, 3\}$ find $S(\theta_i^j)$ such that
  (1.42)
  $$S(\theta_j^i) = \arg\min_{\theta_i^j \in \mathbb{R}^9} \frac{1}{T}\sum_{t=0}^{T}\left|Y_{jt}^i - \psi_j(\theta_j^i; k_{1t}(\theta), h_{1t}^c(\theta), y_{1t}(\theta), z_{1t}, k_{2t}(\theta), h_{2t}^c(\theta), y_{2t}(\theta), z_{2t})\right|^2$$
  where Y_{jt}^i denotes the dependent variable for country j, as a expression inside the conditional expectation $E_t^i(\cdot)$, for $i = \{1, 2, 3\}$
- *Step* 5. Find a fixed point of the map S by iterating on steps 3 and 4 such that $\theta^* = S(\theta^*)$ (equal up to the tolerance level set in step 1) which gives the solution for the decision variables $\{c_{jt}(\theta^*), i_{jt}(\theta^*), x_{jt}(\theta^*), k_{jt+1}(\theta^*), nx_{jt}(\theta^*)\}_{t=1}^{T}$ for $j = \{1, 2\}$ where nx_{jt} denotes the net exports defined as net absorption in country j.

1.6. Figures and Tables

Figure 1.1. Impulse response functions of home country variables implied by the model without any frictions

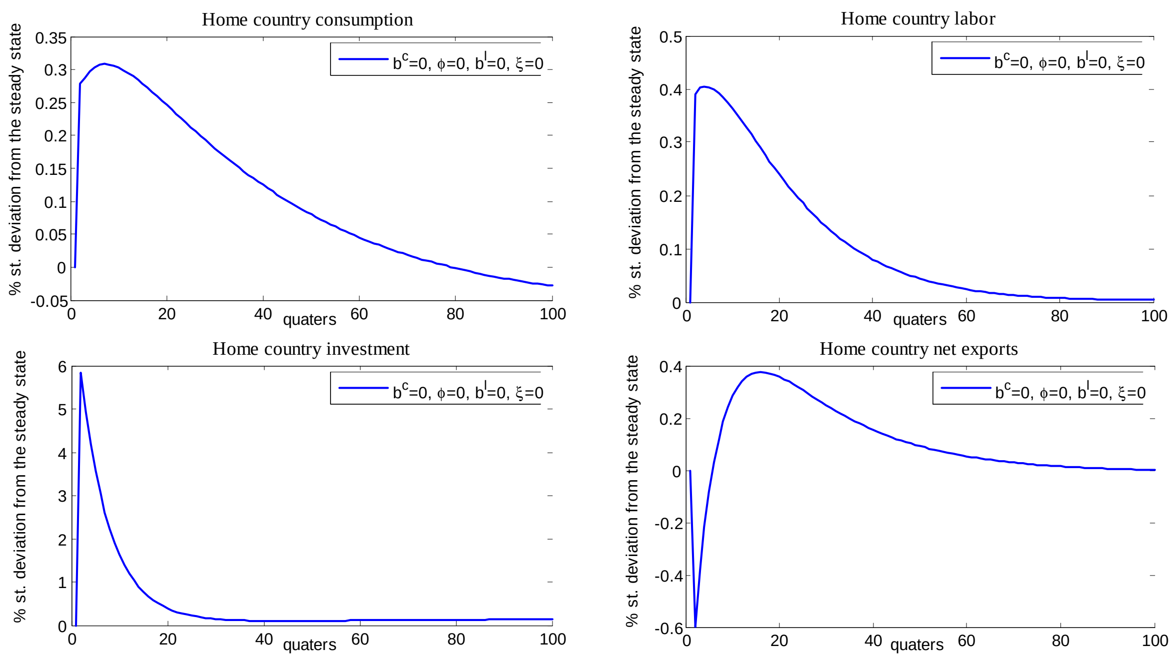


Figure 1.2. Impulse response functions of foreign country variables implied by the model without any frictions

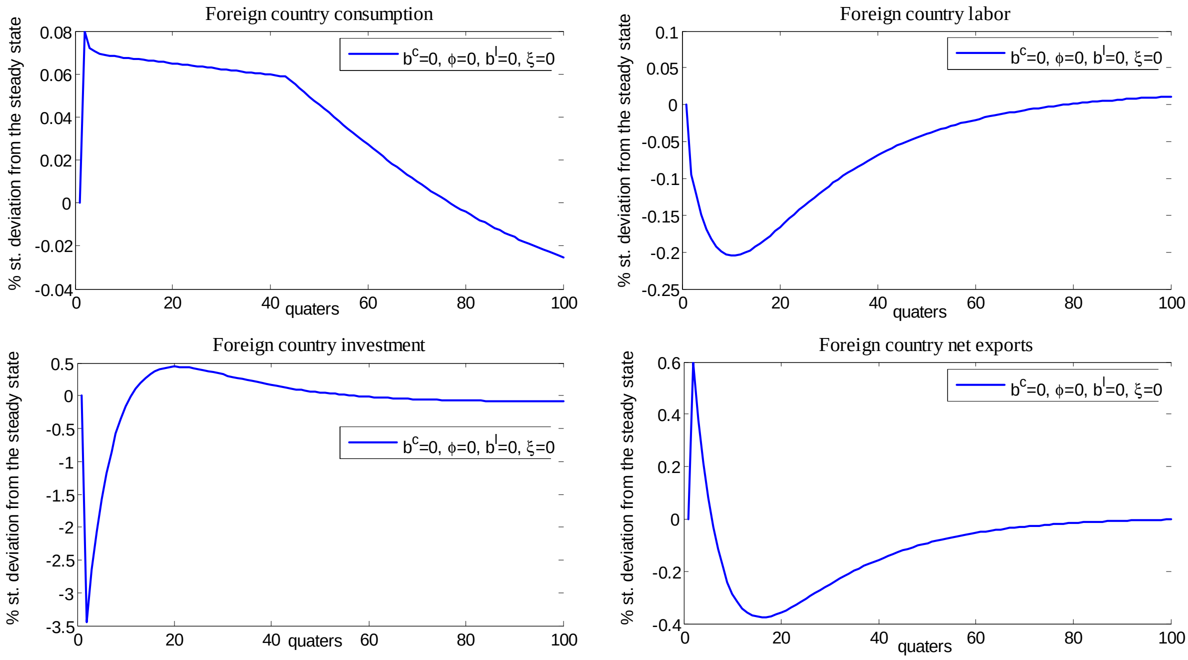
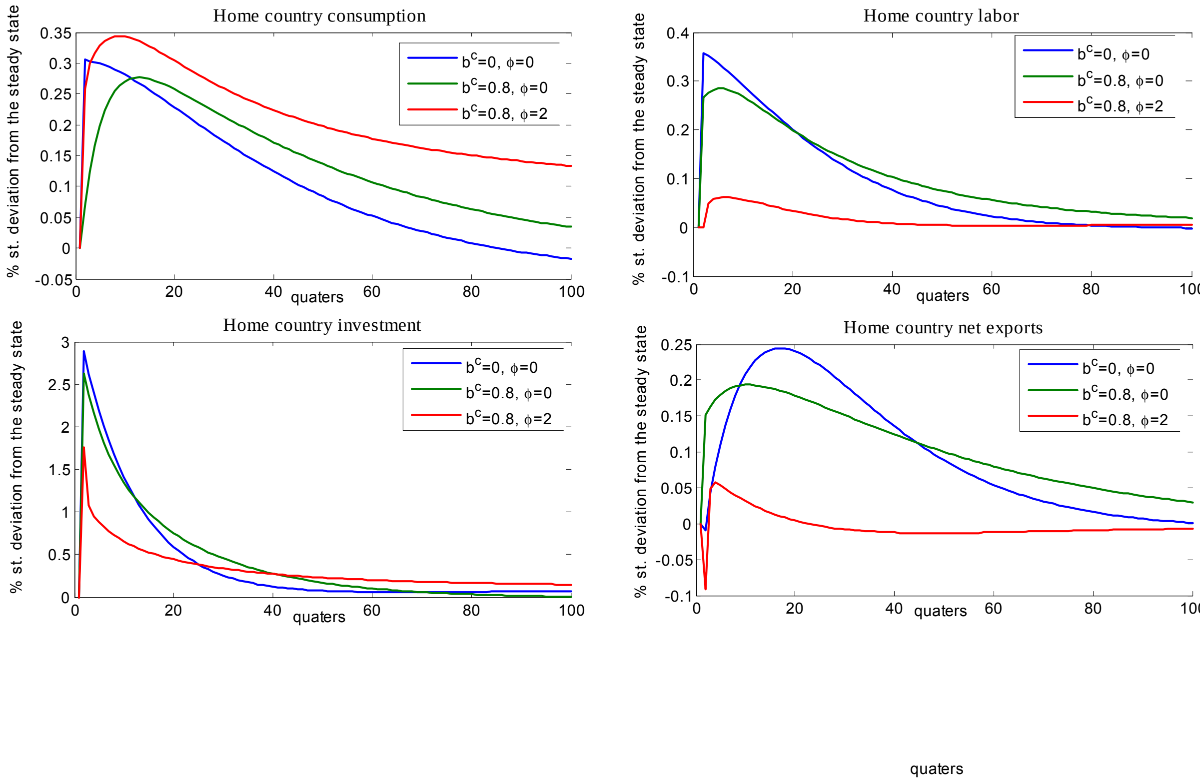


Figure 1.3. Impulse response functions of home country variables implied by the model with capital adjustment costs, model with consumption habits and capital adjustment costs and model with consumption habits, capital and labor adjustment costs

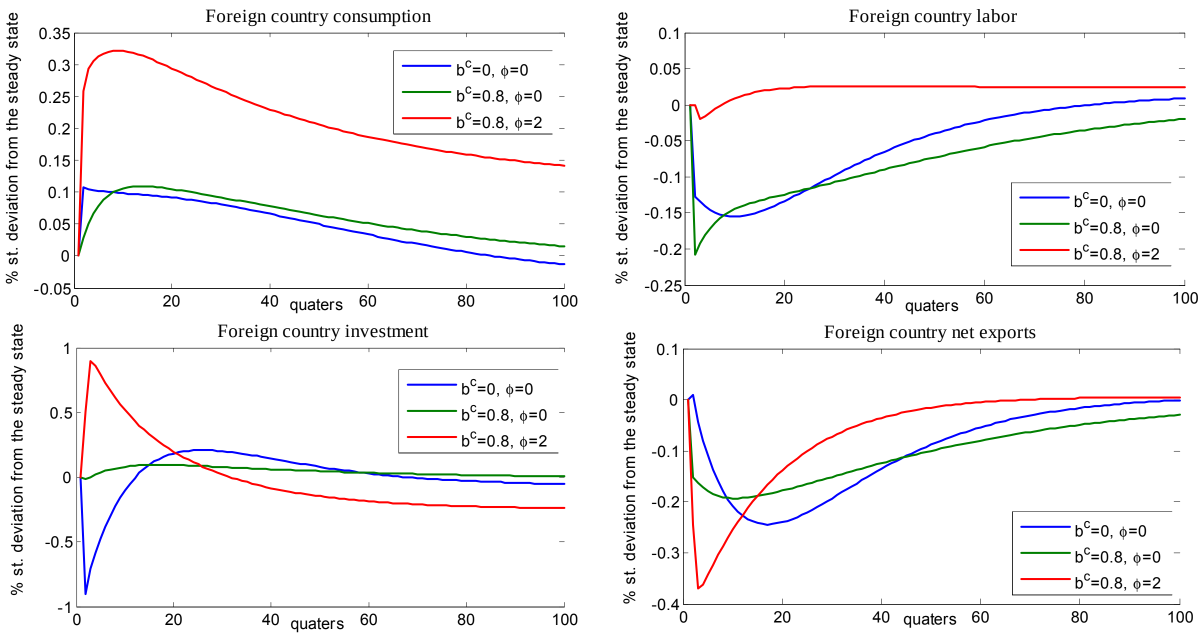


Note: $b^c = 0$, $\varphi = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs (without consumption habits and no labor adjustment costs)

$b^c = 0.8$, $\varphi = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs and consumption habits (and no labor adjustment costs)

$b^c = 0.8$, $\varphi = 2$ represents the impulse response of the corresponding variable of the model with capital adjustment costs, consumption habits and labor adjustment costs

Figure 1.4. Impulse response functions of foreign country variables implied by the model with capital adjustment costs, model with consumption habits and capital adjustment costs and model with consumption habits, capital and labor adjustment costs

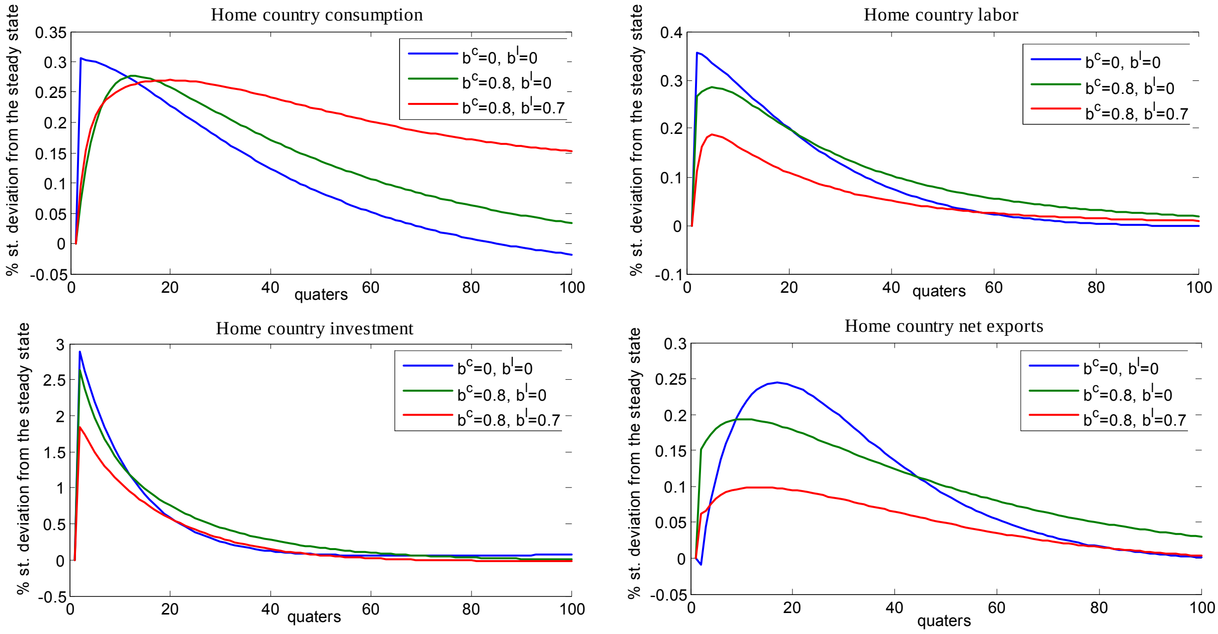


Note: $b^c = 0$, $\varphi = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs (without consumption habits and no labor adjustment costs)

$b^c = 0.8$, $\varphi = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs and consumption habits (and no labor adjustment costs)

$b^c = 0.8$, $\varphi = 2$ represents the impulse response of the corresponding variable of the model with capital adjustment costs, consumption habits and labor adjustment costs

Figure 1.5. Impulse response functions of home country variables implied by the model with capital adjustment costs, model with consumption habits and capital adjustment costs and model with consumption and leisure habits, capital adjustment costs

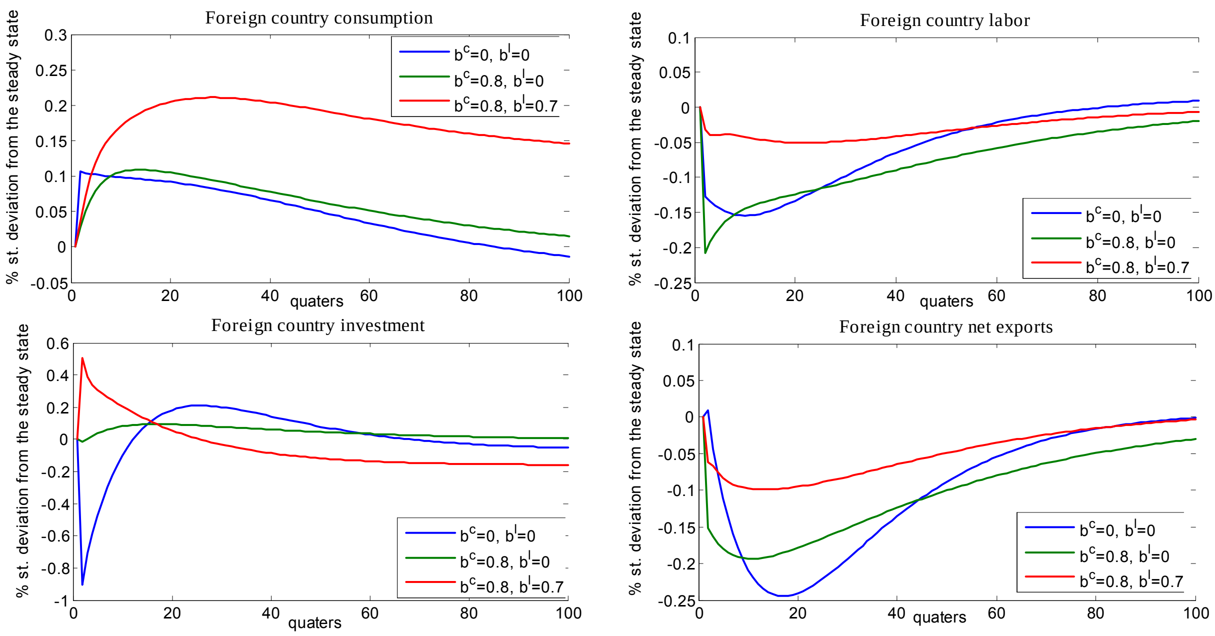


Note: $b^c = 0$, $b^l = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs (without consumption and leisure habits)

$b^c = 0.8$, $b^l = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs and consumption habits (without leisure habits)

$b^c = 0.8$, $b^l = 0.7$ represents the impulse response of the corresponding variable of the model with capital adjustment costs, consumption and leisure habits

Figure 1.6. Impulse response functions of foreing country variables implied by the model with capital adjustment costs, model with consumption habits and capital adjustment costs and model with consumption and leisure habits, capital adjustment costs



Note: $b^c = 0$, $b^l = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs (without consumption and leisure habits)

$b^c = 0.8$, $b^l = 0$ represents the impulse response of the corresponding variable of the model with capital adjustment costs and consumption habits (without leisure habits)

$b^c = 0.8$, $b^l = 0.7$ represents the impulse response of the corresponding variable of the model with capital adjustment costs, consumption and leisure habits

Table 1.1. Parameter values for the benchmark model and the model with frictions

Parameter		Calibrated values/targets: Benchmark model	Calibrated values/targets: Model with frictions
Technology			
Capital share	α	0.36/Labor/output=2/3	
Depreciation rate	δ	0.1/Investment/outpu=0.25	
Quit rate	ψ	0.15/Taken from the literature	
Elasticity of investment (Capital adj. cost parameter)	ξ	∞	Same Inv. volatility of the model and data
Matrix of coefficients in VAR(1) of the shock process	R	$\begin{bmatrix} 0.95 & 0 \\ 0 & 0.95 \end{bmatrix}$/Taken from the literature	
Covariance matrix of the shock process	Ω	$0.007^2 \begin{bmatrix} 1 & 0.25 \\ 0.25 & 1 \end{bmatrix}$/Taken from the literature	
Labor adjustment costs parameter	φ	0	$\{1, 2, 20\}$/Taken from the literature and varies
Preference			
Discount rate	β	0.984/Net average interest rate=6,5%	
Habit importance in consumption	b^c	0	$\{0.4, 0.8\}$/Taken from the literature and varies
Habit importance in leisure	b^l	0	$\{0.4, 0.7, 0.8\}$/Taken from the literature and varies
Share of consumption in composite good	γ	0.369	Depends on b^l and b^c; Investment/output=0.25, labor supply=1/3
Utility curvature	σ	3.7	Depends on γ; Intertemporal elasticity of consumption=1/2

Table 1.2. BUSINESS CYCLE STATISTICS- Perfect Risk Sharing model (benchmark model) and the Model with consumption habits, capital and labor adjustment costs

		Models with different frictions			
Statistic	Data	Perfect risk sharing ($b^c = 0$, $\varphi = 0$, $\xi = \infty$)	Capital adjustment costs ($b^c = 0$, $\varphi = 0$, $\xi < \infty$)	Cons. habits, cap. adj. cost ($b^c = 0.8$, $\varphi = 0$, $\xi < \infty$)	Cons. habits, cap. & labor adj. cost ($b^c = 0.8$, $\varphi = 2$, $\xi < \infty$)
Volatility (% st. dev.)					
GDP	1.72 (0.20)	0.90	0.83	0.77	0.71
Net Exports/GDP	0.15 (0.01)	0.81	0.18	0.20	0.17
% St. dev. relative to GDP					
Consumption	0.79 (0.05)	0.37	0.42	0.28	0.30
Investment	3.24 (0.17)	6.04	3.24	3.24	3.24
Employment	0.63 (0.04)	0.45	0.43	0.38	0.36
Domestic Comovement Correlation with GDP					
Consumption	0.87 (0.03)	0.92	0.93	0.64	0.62
Investment	0.93 (0.02)	0.73	0.94	0.95	0.96
Employment	0.86 (0.03)	0.98	0.97	0.90	0.69
Net Exports/GDP	-0.36 (0.09)	-0.26	0.15	0.72	0.72
International Correlations					
GDP	0.51 (0.13)	-0.02	0.07	0.00	0.06
Consumption	0.32 (0.17)	0.65	0.75	0.80	0.82
Investment	0.29 (0.17)	-0.78	-0.32	0.31	0.32
Employment	0.43 (0.11)	-0.37	-0.42	-0.78	-0.84
Capital Flows (in %)					
Net Exports/GDP	1.1	1.38	0.93	0.84	0.83

Note: Parameters b^c, ξ and φ denote the consumption habit importance parameter in the utility function and the parameter of capital and labor adjustment costs, respectively. Data column contains estimates (standard errors in paranthesis) of the business cycle moments taken from Kehoe and Perri (2002), except for the Capital flow statistic which was calculated from the NIPA. The Volatility, Standard Deviations and Domestic Comovement of the Data column pertain to the U.S. quaterly time series sample 1970:1-1998:4. International comovements statistics are calculated from U.S. data and aggregated data of 15 European countries- all the statistics are based on logged (except for the net exports) and HP filtered data with the smoothing parameter of 1600. The model statistics are computed from a single simulation on a 10 000 periods time series of logged and HP-filtered data (with smoothing parameter 1600).

Table 1.3. BUSINESS CYCLE STATISTICS- Perfect Risk Sharing model (benchmark model) and the Model with consumption and leisure habits and capital adjustment costs

Statistic	Data	Models with different frictions			
		Perfect risk sharing ($b^c = 0$, $b^l = 0$, $\xi = \infty$)	Capital adjustment costs ($b^c = 0$, $b^l = 0$, $\xi < \infty$)	Cons. habits, cap. adj. cost ($b^c = 0.8$, $b^l = 0$, $\xi < \infty$)	Cons. habits, cap. & labor adj. cost ($b^c = 0.8$, $b^l = 0.7$, $\xi < \infty$)
Volatility (% st. dev.)					
GDP	1.72 (0.20)	0.90	0.83	0.77	0.75
Net Exports/GDP	0.15 (0.01)	0.81	0.18	0.20	0.15
% St. dev. relative to GDP					
Consumption	0.79 (0.05)	0.37	0.42	0.28	0.28
Investment	3.24 (0.17)	6.04	3.24	3.24	3.23
Employment	0.63 (0.04)	0.45	0.43	0.38	0.34
Domestic Comovement Correlation with GDP					
Consumption	0.87 (0.03)	0.92	0.93	0.64	0.80
Investment	0.93 (0.02)	0.73	0.94	0.95	0.97
Employment	0.86 (0.03)	0.98	0.97	0.90	0.85
Net Exports/GDP	-0.36 (0.09)	-0.26	0.15	0.72	0.70
International Correlations					
GDP	0.51 (0.13)	-0.02	0.07	0.00	0.07
Consumption	0.32 (0.17)	0.65	0.75	0.80	0.69
Investment	0.29 (0.17)	-0.78	-0.32	0.31	0.22
Employment	0.43 (0.11)	-0.37	-0.42	-0.78	-0.83
Capital Flows (in %)					
Net Exports/GDP	1.1	1.38	0.93	0.84	0.82

Note: Parameters b^c, b^l and ξ denote the consumption and leisure habit importance parameter in the utility function and the parameter of capital adjustment costs respectively. Data column contains estimates (standard errors in paranthesis) of the business cycle moments taken from Kehoe and Perri (2002), except for the Capital flow statistic which was calculated from the NIPA. The Volatility, Standard Deviations and Domestic Comovement of the Data column pertain to the U.S. quaterly time series sample 1970:1-1998:4. International comovements statistics are calculated from U.S. data and aggregated data of 15 European countries- all the statistics are based on logged (except for the net exports) and HP filtered data with the smoothing parameter of 1600. The model statistics are computed from a single simulation on a 10 000 periods time series of logged and HP-filtered data (with smoothing parameter 1600).

Table 1.4. BUSINESS CYCLE STATISTICS- SENSITIVITY ANALYSIS- Economy with consumption habits, capital and labor adjustment costs

		Sensitivity analisys with respect to b^c and φ								
		$b^c = 0$			$b^c = 0.4$			$b^c = 0.8$		
Statistic	Data	$\varphi = 0$	$\varphi = 1$	$\varphi = 20$	$\varphi = 0$	$\varphi = 1$	$\varphi = 20$	$\varphi = 0$	$\varphi = 1$	$\varphi = 20$
Volatility (% st. dev.)										
GDP	1.72 (0.20)	0.83	0.77	0.69	0.82	0.76	0.69	0.77	0.71	0.66
Net Exports/GDP	0.15 (0.01)	0.18	0.19	0.16	0.12	0.14	0.11	0.20	0.17	0.17
% St. dev. relative to GDP										
Consumption	0.79 (0.05)	0.42	0.42	0.41	0.39	0.40	0.40	0.28	0.30	0.31
Investment	3.24 (0.17)	3.24	3.23	3.25	3.23	3.24	3.25	3.24	3.24	3.25
Employment	0.63 (0.04)	0.43	0.42	0.32	0.43	0.42	0.31	0.38	0.37	0.27
Domestic Comovement Correlation with GDP										
Consumption	0.87 (0.03)	0.93	0.90	0.87	0.88	0.86	0.81	0.64	0.62	0.59
Investment	0.93 (0.02)	0.94	0.91	0.91	0.94	0.94	0.95	0.95	0.96	0.95
Employment	0.86 (0.03)	0.97	0.83	0.68	0.97	0.82	0.66	0.90	0.70	0.57
Net Exports/GDP	-0.36 (0.09)	0.15	0.26	0.30	0.35	0.37	0.45	0.72	0.72	0.74
International Correlations										
GDP	0.51 (0.13)	0.07	0.09	0.15	0.07	0.11	0.17	0.00	0.04	0.17
Consumption	0.32 (0.17)	0.75	0.75	0.84	0.78	0.78	0.85	0.80	0.81	0.88
Investment	0.29 (0.17)	-0.32	-0.28	-0.24	-0.14	-0.12	-0.07	0.31	0.32	0.47
Employment	0.43 (0.11)	-0.42	-0.48	-0.55	-0.47	-0.46	-0.60	-0.78	-0.84	-0.85
Capital Flows (in %)										
Net Exports/GDP	1.1	0.93	0.91	0.87	0.91	0.89	0.87	0.84	0.83	0.80

Note: Parameters b^c and φ denote the consumption habit importance parameter in the utility function and parameter of labor adjustment costs respectively. Data column contains estimates (standard errors in paranthesis) of the business cycle moments taken from Kehoe and Perri (2002), except for the Capital flow statistic which was calculated from the NIPA. The Volatility, Standard Deviations and Domestic Comovement of the Data column pertain to the U.S. quaterly time series sample 1970:1-1998:4. International comovements statistics are calculated from U.S. data and aggregated data of 15 European countries- all the statistics are based on logged (except for the net exports) and HP filtered data with the smoothing parameter of 1600. The model statistics are computed from a single simulation on a 10 000 periods time series of logged and HP-filtered data (with smoothing parameter 1600).

Table 1.5. BUSINESS CYCLE STATISTICS- SENSITIVITY ANALYSIS- Economy with consumption and leisure habits and capital adjustment costs

		Sensitivity analisys with respect to b^c and b^l								
		$b^c = 0$			$b^c = 0.4$			$b^c = 0.8$		
Statistic	Data	$b^l = 0$	$b^l = 0.4$	$b^l = 0.8$	$b^l = 0$	$b^l = 0.4$	$b^l = 0.8$	$b^l = 0$	$b^l = 0.4$	$b^l = 0.8$
Volatility (% st. dev.)										
GDP	1.72 (0.20)	0.83	0.81	0.72	0.82	0.81	0.72	0.77	0.77	0.74
Net Exports/GDP	0.15 (0.01)	0.18	0.20	0.23	0.12	0.12	0.16	0.20	0.17	0.14
% St. dev. relative to GDP										
Consumption	0.79 (0.05)	0.42	0.43	0.47	0.39	0.39	0.44	0.28	0.28	0.29
Investment	3.24 (0.17)	3.24	3.25	3.23	3.23	3.23	3.24	3.24	3.24	3.24
Employment	0.63 (0.04)	0.43	0.40	0.30	0.41	0.40	0.31	0.38	0.37	0.32
Domestic Comovement Correlation with GDP										
Consumption	0.87 (0.03)	0.93	0.93	0.94	0.88	0.92	0.94	0.64	0.70	0.83
Investment	0.93 (0.02)	0.94	0.93	0.91	0.96	0.96	0.95	0.95	0.97	0.97
Employment	0.86 (0.03)	0.97	0.96	0.83	0.96	0.96	0.84	0.90	0.86	0.84
Net Exports/GDP	-0.36 (0.09)	0.15	0.09	0.03	0.35	0.23	0.03	0.72	0.72	0.67
International Correlations										
GDP	0.51 (0.13)	0.07	0.07	0.10	0.07	0.09	0.11	0.00	0.03	0.10
Consumption	0.32 (0.17)	0.75	0.71	0.61	0.78	0.74	0.63	0.80	0.78	0.65
Investment	0.29 (0.17)	-0.32	-0.34	-0.36	-0.14	-0.15	-0.23	0.31	0.22	0.20
Employment	0.43 (0.11)	-0.42	-0.48	-0.62	-0.47	-0.44	-0.63	-0.78	-0.83	-0.84
Capital Flows (in %)										
Net Exports/GDP	1.1	0.93	0.93	0.93	0.91	0.91	0.91	0.84	0.83	0.80

Note: Parameters b^c and b^l denote the consumption and leisure habit importance parameter in the utility function respectively. Data column contains estimates (standard errors in paranthesis) of the business cycle moments taken from Kehoe and Perri (2002), except for the Capital flow statistic which was calculated from the NIPA. The Volatility, Standard Deviations and Domestic Comovement of the Data column pertain to the U.S. quaterly time series sample 1970:1-1998:4. International comovements statistics are calculated from U.S. data and aggregated data of 15 European countries- all the statistics are based on logged (except for the net exports) and HP filtered data with the smoothing parameter of 1600. The model statistics are computed from a single simulation on a 10 000 periods time series of logged and HP-filtered data (with smoothing parameter 1600).

CHAPTER 2

Optimal Foreign Reserves: The Case of Croatia

2.1. Introduction

Foreign reserves accumulation is a widespread phenomenon, particularly among emerging economies. Since 1990 emerging markets' foreign reserves have increased by more than five times, from 4 percent to over 20 percent of GDP (Obstfeld, Shambaugh and Taylor (2008)). This practice has raised interesting questions in the literature regarding the reasons for such a behavior. It has been argued that part of the motivation for the reserve accumulation stems from an incarnated mercantilist desire by some governments to maintain undervalued exchange rates and bolster domestic economy. Apart from these exchange rate objectives which have resulted in rapid reserve accumulation as a side effect, some countries have chosen explicitly to build up reserves for precautionary motives or self-insurance against exposure to future sudden stops. Aizenman and Marion (2002) and Aizenman and Lee (2005) suggest that precautionary demand for reserves plays an important role in explaining rising foreign reserves in East Asia following the Asian crisis, which was to a large extent unexpected.

The need for reserves, acting as a protection against a sudden stop, is even more pronounced in dollarized economies, like Croatian, where the central bank is exposed to a double drain risk (Obstfeld, Shambaugh and Taylor (2008)). This twofold risk exists given that financial account reversals (an external drain risk) may be accompanied by a loss of confidence in the banking system that would result in a large withdrawal of foreign currency deposits (an internal drain risk). Therefore, in dollarized economy reserves are not only an insurance against negative effects of a sudden stop but also a key tool for managing domestic financial instability.

Strong accumulation of foreign reserves was also apparent in Croatia. Since 1998 gross foreign reserves (expressed in euros) of the Croatian National Bank (CNB henceforth) have quadrupled. We explore the reasons behind the strong accumulation of CNB reserves. One might say that strong inflow of foreign capital in the situation of dirty management floating of the exchange rate was behind the buildup of foreign reserves. However, the question of foreign reserves adequacy is still relevant regardless of exchange rate regime. Providing that the double drain risk is present in Croatian economy[1] we analyze whether CNB reserves are sufficient to mitigate negative effects of potential sudden stop of capital inflows and banking crisis. To tackle this issue we study precautionary demand for foreign reserves in a stochastic dynamic general equilibrium model, similar to Goncalves (2007), where central bank holds reserves as a self-insurance against a sudden stop and a banking crisis in a dollarized economy. By including specific features of Croatian economy in our model we extend the framework of Goncalves (2007) that develops a model of optimal reserves for Uruguay. In the model economy there are two main opposite forces driving optimal reserves accumulation. On one hand, reserves are expensive to hold. The cost of holding reserves might be interpreted as the opportunity cost that comes from substituting high yielding domestic assets for lower yielding foreign ones. On the other hand, reserves absorb fluctuations in external payment imbalances, ease the credit crunch and allow a country to smooth consumption in the event of a sudden stop with banking crisis.

The model is calibrated using Croatian data and simulated to see whether the CNB holds more reserves than the model suggests are necessary. We find that for plausible values of the parameters the model accounts for the recent buildup of foreign reserves in Croatia. However, quantitative implications of the model imply that the accumulation of reserves was too strong. In other words, recent upsurge of reserves observed in Croatia over the past decade seems in excess of what would be implied by an insurance motive against sudden stop and banking crises. This result crucially depends on the assumed behavior of parent banks during a sudden stop. In working with data, we assume two possible reactions of parent banks during the crisis. Parent banks might withdraw deposits and cut credit lines to banks in their ownership. On the other hand, they might act as a lender of last resort by prolonging short-term loans and providing extra liquidity. In the benchmark calibration we study optimal reserves in the economy that is hit by the sudden stop with banking crisis of the 1998/1999 crisis scale. We find that the CNB is holding enough reserves to mitigate negative effects of a possible crisis similar to the one that took place during 1998/1999. This

[1]In the same period, the short-term foreign debt of the Croatian economy has almost quintupled, while the foreign deposits have more than doubled.

holds in a "more favourable" scenario, in which parent banks assume the role of lenders of last resort. Finally, we compare our formula of optimal reserves with two standard indicators of "optimal" reserves for Croatian economy, namely Greenspan-Guidotti and 3-months-of-imports rules. We present advantages of our optimal reserves formula over the two standard indicators in assessing reserves adequacy.

Our framework builds on analytical models trying to characterize and quantify the optimal level of reserves from a prudential perspective[2] rather than from the cost-benefit perspective of reserve accumulation, pioneered by Heller (1961)[3]. The earlier cost-benefit literature focused on using international reserves as a buffer stock, part of the management of different exchange-rate regimes. In those models optimal reserves balance the macroeconomic adjustment costs that would be incurred in the absence of reserves with the opportunity cost of holding reserves[4]. Although buffer stock model had the capacity to explain behavior of foreign reserves in the 1980s, the greater flexibility of the exchange rates exhibited in recent decades should have reduced reserves hoarding according to the buffer stock model (Aizenman and Lee (2005)). Recent welfare-based models of optimal reserves as a self-insurance had more success in explaining recent hoarding of foreign reserves[5]. In our welfare-based model, precautionary motives for accumulating reserves pertain to the crisis management ability of the government to finance underlying foreign payments imbalances in the event of a sudden stop and provide foreign exchange liquidity in the face of a bank run. At the same time the government is trying to maximize the welfare of the economy.

The rest of the paper is organized as follows. In section 2.2 we discuss how important is the double drain risk for Croatian economy and describe the episode of banking crisis and sudden stop that took place in 1998/1999. In section 2.3 we present a model of optimal reserves together with calibration of the model, discussion of data, quantitative implications of the model and sensitivity analysis. Section 2.5 concludes.

[2]See Goncalves (2007), Ranciere and Jeanne (2006), Jeanne and Ranciere (2008), Aizenman and Marion (2002), Aizenman and Lee (2005), Caballero and Panageas (2004), Jeanne (2007).

[3]See Flood and Marion (2002) for a recent review on the cost-benefit literature.

[4]The buffer stock model predicts that optimal reserves depend negatively on adjustment costs, the opportunity cost of reserves, and exchange rate flexibility; and positively on GDP and on reserve volatility, driven frequently by the underlying volatility of international trade. See Frenkel and Jovanovic (1981) for details.

[5]See Durdu, Mendoza and Terrones (2007) Caballero and Panageas (2004), Ranciere and Jeanne (2006), Jeanne and Ranciere (2008).

2.2. Double drain risk and the Croatian economy

We first present a basic national account identity which shows, in a simple manner, the mechanism of self-insurance against a sudden stop provided by foreign reserves. Note that domestic absorption (of domestic goods), A_t can be decomposed into the sum of the domestic output, Y_t, the financial account, FA_t, the net factor income from abroad, IT_t, and the change in foreign reserves, ΔR_t:

$$A_t = Y_t + FA_t + IT_t - \Delta R_t \tag{2.1}$$

When a sudden stop hits the economy, short-term foreign loans become unavailable. Hence, a sudden stop brings about financial account shortfall that reduces the domestic absorption. If we assume that a bank run (internal drain) also occurs when a sudden stop (external drain) takes place, the negative effect will be magnified by a fall in the domestic output through the reduction of domestic savings[6] and resulting credit crunch. However, by providing enough foreign liquidity to the economy, the central bank can smooth the domestic absorption and diminish the negative effects of a sudden stop and a banking crisis. Because of the double drain risk, the protection role of reserves is more important in dollarized economies. Foreign reserves serve not only as a domestic absorption stabilizer but they also mitigate negative effects on output - they provide insurance against the risk of external loans not being rolled-over during a sudden stop and help lessen credit crunch by providing liquidity in the event of foreign deposit withdrawal.

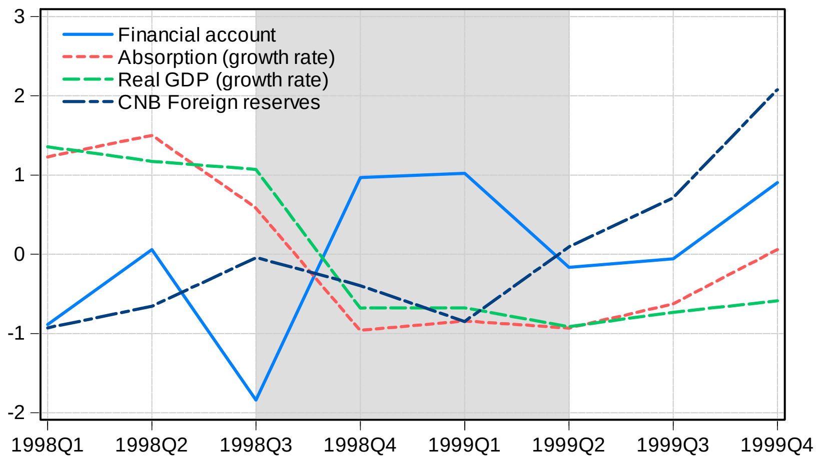
We put emphasis on a double drain risk given that foreign lenders stopped providing credits to Croatian economy in the midst of 1998/1999 banking crisis (see Jankov (2000) for details). Internal drain risk seems to be more important in explaining slowdown of domestic absorption than the financial account reversal during that crisis. Figure 2.1 shows how components of domestic absorption behaved during the banking crisis in Croatia[7]. The crisis began with the failure of Dubrovačka banka and unfolded in parallel with the sudden

[6] To see this, remember that $Y_t = C_t + I_t + G_t + X_t - M_t = C_t + S_t + T_t - FA_t - IT_t + \Delta R_t$ where $C_t, I_t, G_t, X_t, M_t, S_t, T_t$ denote consumption, investment, government spending, export, imports, savings and taxes, respectively.

[7] The series in Figure 1 are standardized. Hence, Figure 1 does not show the actual decomposition of domestic absorption as a sum of its components but provides direction of components behavior.

stop in the third quarter of 1998. Financial account reversal was relatively mild and lasted for one quarter only. The negative effects of the sudden stop were lessened by releasing a part of the foreign reserves.

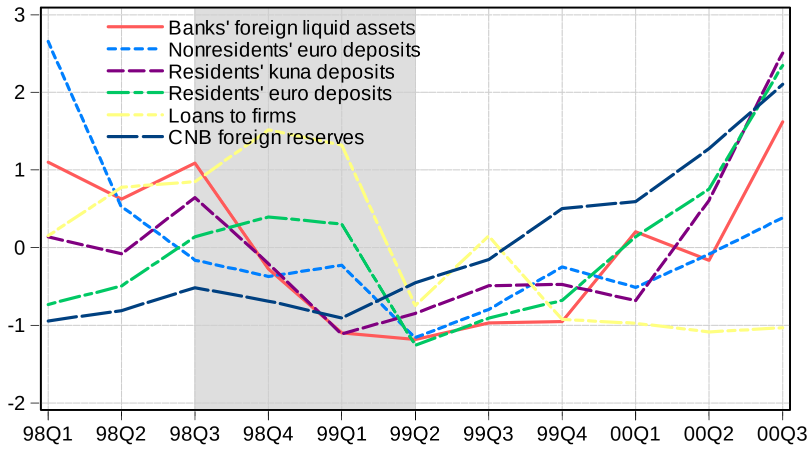
Figure 2.1. Components of domestic absorption (standardized series).



However, output and domestic absorption continued to fall (until the second quarter of 1999- the shaded area in Figure 2.1). Hence, it seems that the banking crisis, the deposit run, and the credit crunch had a dominant role in shaping output and domestic absorption behavior during the 1998/1999 episode. Banks activity peaked in the third quarter of 1998 (at the same time when sudden stop occurred) after it reached its trough in the second quarter of 1999 (shaded area in Figure 2.2) followed by the end of the real activity slowdown in the next quarter.

Besides the foreign reserves, it seems that banks' foreign reserves were also important in absorbing the fall in the euro deposits' withdrawal in the period from August 1998 until May 1999 (Figure 2.3). Yet, the bankruptcy of a number of banks accentuated credit crunch, that could not be mitigated by any foreign liquidity buffer. While this resulted in a recession, the use of foreign assets (both CNBs' and private banks') helped offset a potentially larger fall in economic activity.

Figure 2.2. Banking sector activity during the sudden stop with banking crisis (standardized series).



Euro deposits[8] and short-term external debt[9] give rise to a double drain risk in Croatia. The volatility in these two variables during a crisis could potentially lead to a large foreign liquidity requirement (as they had during the 1998/1999 crisis). Hence, foreign reserves serve the twofold role of stabilizing both the output and the domestic absorption in a dollarized economy faced with a double drain risk. Nowadays, just like during the 1998/1999 episode, euro deposits still represent the main vulnerability for the Croatian economy (Figure 2.4 shows that an internal drain risk might persistently be significant given that on average the foreign reserves were covering only half of the euro deposits during the observed period). On the other hand, short-term external debt does not seem to imply a persistently high external drain risk since on average the foreign reserves were covering little over 100% of the short-term external debt during the same period.

In practice foreign reserves adequacy has often been assessed using simple rules of thumb, such as maintaining reserves equivalent to three months of imports, or the Greenspan-Guidotti rule of full coverage of short-term external debt[10]. According to Łonje (2007)

[8]Euro deposits include euro deposits of households and non-residents of all maturities.

[9]We treat installments on long term debt that are due in period (year) t as short-term debt issued in the previous year. It will not be possible to roll over this principal repayment if sudden stop shock hits the economy. We could not present data on short term debt during the sudden stop with banking crisis since data on short-term debt are available only since the end of 1998.

[10]These two indicators are used given that empirical research show that they appear to be a potent predictors of currency crises and sudden stops.

Figure 2.3. Euro deposits withdrawal and foreign buffers drop (mil. EUR) during the sudden stop with banking crisis.

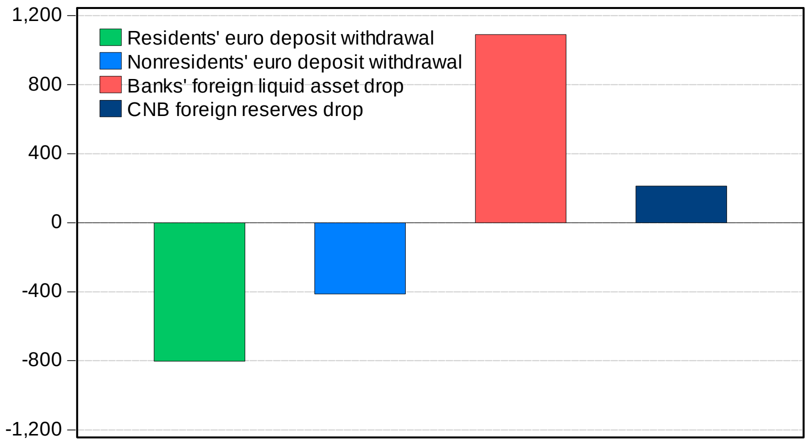
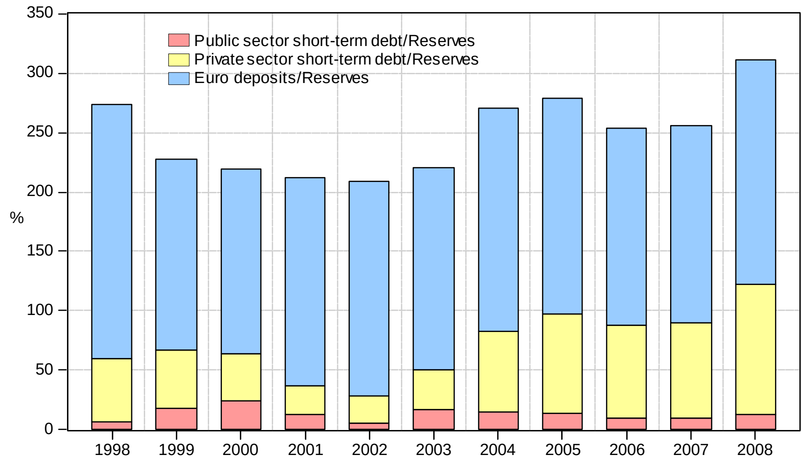
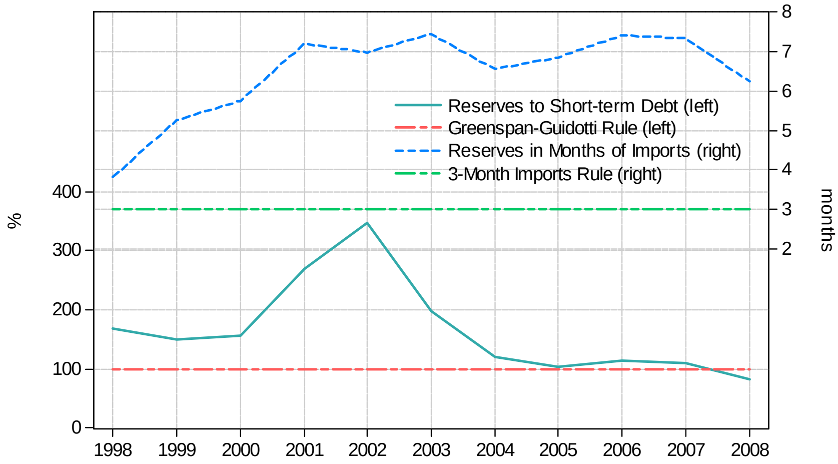


Figure 2.4. Short term foreign currency debt and euro deposits in % of foreign reserves in the period 1998-2008.



Croatia is on safe grounds as far as the second indicator of foreign reserves adequacy is concerned. Even if one considers a situation of extreme shock hitting our economy Šonje shows that foreign reserves are twice as high as our short-term external debt. Although we use a broader definition of short-term external debt (Figure 2.5 shows the behavior of the two standard indicators), Šonje's result still holds (even though short-term external debt is almost equal to foreign reserves in recent years). Moreover, Croatia's (gross) foreign reserves cover

Figure 2.5. Reserves to short-term external debt ratio (%) and Reserves in months of imports.



more than 100%[11] of its short term external debt and more than 5 months of its imports. Thus, one might conclude that Croatia's foreign reserves are adequate. However, these two indicators do not take into account a high degree of deposit dollarization which represents a main vulnerability for the Croatian economy (as Figure 2.4 shows), raising doubts about their appropriateness.

Moreover, using these indicators is not useful in general in assessing whether actual reserves are too high or too low, because they are not based on any optimality criterion. The national accounting equation (2.1) shows that by releasing foreign reserves it is possible to increase domestic absorption. Hence, holding foreign reserves comes at a cost - reserves could be used to repay foreign loans or to invest in assets with higher returns. As much as we are interested in answering the question whether central banks have enough foreign reserves to mitigate negative effects of a possible sudden stop with banking crisis we also have to examine whether we have too much of a good thing. Standard indicators can not help in tackling this issue- neither do they consider the opportunity costs of holding reserves nor do they take into account expected precautionary benefit of holding reserves.

[11]Notice that we are using extended definition of short-term external debt that is usually not used in the literature that discusses the foreign reserves adequacy. Therefore the reader should be careful in interpreting the threshold of 100% as an alarming signal for the crisis since the threshold in our case should be smaller that 100%.

In his previous article Łonje (2005) conjectures correctly that the two standard indicators of reserve adequacy might no longer be valid in the new financial environment. He is calling for a new formula for optimal reserves, arguing against regulation that limits foreign-related risks by maintaining banks' foreign liquid assets, as an additional buffer, at a level that keeps crisis indicators[12] below certain thresholds. However, although he is rightly calling for the missing optimality criterion in determining the desirable level of private foreign liquidity, Šonje makes his argument based on historical thresholds that are by no means founded on an optimality norm. On the other hand, our model offers a formula of optimal reserves that is based on a micro-founded rule of maximizing the welfare of the economy. This norm balances between costs and benefits of holding foreign reserves and thus offers an appropriate benchmark for assessing the foreign reserves adequacy. Using optimal reserves in the cost-benefit analysis of regulation related to foreign risks might be therefore more appropriate than employing crisis indicators and their arbitrary thresholds.

2.3. The model

We construct a simple, discrete time model of self-insurance offered by foreign reserves. Our model follows the structure of the model in Goncalves (2007) and Ranciere and Jeanne (2006). Foreign reserves help mitigate negative domestic consumption effects of a sudden stop that comes in tandem with a bank run in a dollarized economy. Our model is simple in two aspects. First, we do not differentiate between households' and firms' behavior. Second, instead of modeling some elements explicitly, we make many assumptions about actions of the agents during a sudden stop period based on stylized facts of sudden stop with banking crisis events.

The only uncertainty in the model comes from the probability of a sudden stop. There are three sectors in our model economy: households (that also incorporate behavior of firms), banks, and the government that also plays the role of the central bank.

A sudden stop is characterized by the following assumptions. Once the economy is hit by a sudden stop:

- short-term foreign loans of every sector are not rolled over,
- real GDP falls by some fraction,

[12] He is using the short term debt/foreign reserves and the M4/foreign reserves ratios as crisis indicators

- kuna/euro exchange rate depreciates,
- a part of kuna deposits (both household and corporate) is exchanged for euro deposits,
- a bank run occurs - a fraction of overall deposits of non-financial sector is withdrawn from banks,
- a central bank (government) lowers kuna and euro reserve requirements by a fraction of α^k and α^f respectively,
- government stops repaying long-term liabilities that become due,
- banks and households withdraw their foreign liquid assets from abroad to use them as a buffer against a sudden stop.

Except for the richer structure of our model there are couple of important differences between our model and the model in Goncalves (2007). These differences stem from differences between Croatian and Uruguayan economy. A bank run in our model occurs as a result of the loss of households' confidence (in comparison to nonresident deposit withdrawal in Goncalves (2007)). A part of deposits that were pulled out of the banking system are used as a buffer against a lost access to foreign loans market. Furthermore, during the bank run, households exchange part of kuna deposits into euro deposits because of the lost confidence in domestic currency. This feature is not present in Goncalves (2007). Finally, removing dynamics in the formula for optimal reserves (as in Goncalves (2007)) might lead to problematic interpretation of reserves optimality (at least ex-ante). Therefore, our formula preserves the dynamics.

In the next several sections, we first present our model, then we calibrate the model and derive the formula for optimal reserves, and finally, we show and interpret our results and their robustness.

2.3.1. Non-financial sector - Households

There is a continuum of infinitely lived households of measure one. All households have identical preferences over consumption c_t of the single good. Preferences are represented by the Von Neumann-Morgenstern expected utility function that has a constant relative risk aversion form. The price of consumption good is P_t. This good is financed by a deterministic exogenous endowment y_t that is growing over time at the rate of g. In addition to this endowment, the sources of households' funds include: domestic loans, foreign loans, transfer from the government, profits of financial sector, deposits and foreign liquid assets that become due. All loans and deposits of households are assumed to be short-term. Households can borrow from domestic banks or from abroad. If they go for a loan to domestic banks they can choose between euro denominated (or indexed to kuna/euro exchange rate, S_t), l_t^f or kuna denominated loan, l_t^k. Loans from abroad, b_t, are only in euros. In the event of a sudden stop, that comes with probability π, households cannot roll over this foreign loan. A transfer from the government, T_t, is distributed in a lump sum manner. Since households are assumed to be owners of financial sector they receive all their profits, Π_t (if any). For simplicity, we assume that all interest rates, r, are the same and constant[13].

From the overall sources of funds households buy goods, repay their domestic and foreign loans at given interest rates and decide about the structure of funds they will invest as domestic versus foreign bank deposit. They can choose between foreign denominated, d_t^f, and kuna denominated deposits, d_t^k, that are due next period. Moreover, there are also two types of deposits[14]: household deposits, d_t^{kh} and d_t^{fh}, and corporate deposits, d_t^{kc} and d_t^{fc}. Foreign bank deposits (foreign liquid assets) are denoted by FRB_t^h.

The timing of the actions within the period when sudden stop occurs is the following. At the beginning of the period households invest their funds into kuna and euro deposits. Then a sudden stop occurs. Kuna depreciates (against euro) by an absolute change of ΔS. Access of households to foreign loans market is canceled. Households exchange a fraction, η of kuna deposits into euro deposits. At the end of the period households withdraw a fraction of overall deposits, ϕ (that also include newly exchanged deposits from kuna to euro). A fraction of euro household deposits withdrawn will not be used as a substitute for foreign loans that are no longer available. On the other hand, kuna household deposits together with kuna and euro corporate deposits will act as a buffer against sudden stop effects. In other words, only euro household deposits that are withdrawn from banking system will not be used as a buffer against sudden stop effects. In our model withdrawing euro deposits does not have any impact on the budget constraint of households during a sudden stop-

[13]Differentiating between interest rates on deposits and loans would not change our formula of optimal reserves.

[14]This assumption circumvents modeling households and firms behavior separately.

households cannot use these funds to buy goods (since these funds are in euros) and they do not yield any interest rate (since these funds are outside financial sector). This is why they do not appear in the budget constraint- in the model putting euro deposits under the mattress is equal to putting money into a term deposit that is not due during the period of a sudden stop.

Tables 2.1 and 2.2 present balance sheets of households if there is no sudden stop occurs and if sudden stop occurs. These tables summarize actions of households during those two states of the world.

Table 2.1. Balance sheet of households if there is no sudden stop

Assets	Liabilities
Kuna deposits, $d_t^k (= d_t^{kh} + d_t^{kc})$	Short-term Kuna loans, l_t^k
Euro deposits, $S_t\, d_t^f = S_t\, (d_t^{fh} + d_t^{fc})$	Short-term Euro loans, $S_t\, l_t^f$
Foreign liquid assets, $S_t\, FRB_t^h$	Short-term foreign borrowing, $S_t\, b_t$
	Profits, Π_t
	Transfer from the government, T_t

Table 2.2. Balance sheet of households if sudden stop occurs

Assets	Liabilities
Kuna household deposits, $d_t^{kh} - \phi(1-\eta) d_t^{kh}$	Short-term Kuna loans, l_t^k
Euro household deposits, $(S_t + \Delta S) d_t^{fh}$	Short-term Euro loans, $(S_t + \Delta S)\, l_t^f$
Kuna corporate deposits, $d_t^{kc} - \phi(1-\eta) d_t^{kc}$	Short-term foreign borrowing, $(S_t + \Delta S)\, b_t = 0$
Euro corporate deposits, $(S_t + \Delta S) d_t^{fc} - (S_t + \Delta S)\phi(d_t^{fc} + \frac{\eta}{S+\Delta S} d_t^{kc})$	Profits, Π_t
Foreign liquid assets, $S_t\, FRB_t^h = 0$	Transfer from the government, T_t

To make optimal decisions on how much to consume, how much to save and how much to borrow, households maximize the expected discounted value of utility i.e. solve the following problem:

$$\max_{\left\{c_t, l_t^f, l_t^k, b_t, d_t^{fh}, d_t^{fc}, d_t^{kh}, d_t^{kc}, FRB_t^h\right\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_t) \right\}$$

subject to budget constraints
if sudden stop does not occur:

$$\begin{aligned} (2.2)\quad & P_t c_t + S_t(1+r) l_{t-1}^f + (1+r) l_{t-1}^k + S_t(1+r) b_{t-1} + S_t(d_t^{fh} + d_t^{fc}) + (d_t^{kh} + d_t^{kc}) + \\ & S_t\, FRB_t^h = P_t y_t + S_t\, l_t^f + l_t^k + S_t\, b_t + S_t(1+r)(d_{t-1}^{fh} + d_{t-1}^{fc}) + (1+r)(d_{t-1}^{kh} + d_{t-1}^{kc}) + \\ & + S_t(1+r) FRB_{t-1}^h + \Pi_t + T_t \end{aligned}$$

if sudden stop occurs:

$$
\begin{aligned}
(2.3) \qquad & P_t c_t + (S_t + \Delta S)(1+r) l_{t-1}^f + (1+r) l_{t-1}^k + (S_t + \Delta S)(1+r) b_{t-1} + \\
& +(S_t + \Delta S)(d_t^{fh} + d_t^{fc}) + (d_t^{kh} + d_t^{kc}) = \\
& (1-\gamma) P_t y_t + (S_t + \Delta S) l_t^f + l_t^k + (S_t + \Delta S)(1+r)(d_{t-1}^{fh} + d_{t-1}^{fc}) + \\
& +(1+r)(d_{t-1}^{kh} + d_{t-1}^{kc}) + (S_t + \Delta S)\phi(d_t^{fc} + \frac{\eta}{S_t + \Delta S} d_t^{kc}) + \phi(1-\eta)(d_t^{kh} + d_t^{kc}) \\
& +(S_t + \Delta S)(1+r) FRB_{t-1}^h + \Pi_t + T_t
\end{aligned}
$$

where $u(c) = \frac{c_t^{1-\sigma} - 1}{1-\sigma}$ with σ the relative risk aversion parameter and γ the output cost of a sudden stop with banking crisis.

2.3.2. Financial sector - Banks

We consider a simple version of the banking sector where the only role of banks is to take deposits from households, take out loans from abroad and extend loans to households. We are assuming perfect competition in the banking sector so that the whole sector can be represented by a representative bank. Bank's assets consist of kuna credit, l_t^k, euro credit, l_t^f, reserve requirement that monetary authority imposes on bank's sources of funds, RB_t, and private banks' foreign liquid assets, FRB_t^b. Reserve requirement is imposed on both domestic and foreign source of finance (RB_t^k, RB_t^f respectively). However, half of the reserves requirement imposed on foreign liabilities is paid in kunas. Monetary authority pays no interest on these reserves. The source of finance consists of kuna deposits, d_t^k (as a sum of household and corporate kuna deposits), euro deposits, d_t^f (as a sum of household and corporate euro deposits), and short-term foreign borrowings, FB_t.

The bank earns profits by extending kuna and euro denominated loans after they become due. The amount of deposits that the bank has to return to households represents its costs (augmented by nominal deposit interest rate). Furthermore, if the bank takes the loan from abroad ($FB_t > 0$) it will have to return it in the next period with the cost of exogenous nominal interest rate, r.

Tables 2.3 and 2.4 present the balance sheet of the banking sector if there is no sudden stop and if sudden stop hits the economy. During the sudden stop banks access to foreign loans market is stopped. Furthermore, a bank run on deposits occurs. To mitigate the effects on loans, banks liquidate their foreign assets and use them to cover a part of deposit claims. Notice that euro household deposits that are withdrawn from banking system and put under the mattress are visible here in the balance sheet of the banking sector.

Table 2.3. Balance sheet of banking sector if there is no sudden stop

Assets	Liabilities
Short-term kuna loans, l_t^k	Kuna deposits, $d_t^k (= d_t^{kh} + d_t^{kc})$
Short-term euro loans, $S_t\, l_t^f$	Euro deposits, $S_t\, d_t^f = S_t\,(d_t^{fh} + d_t^{fc})$
Reserve requirement, $RB_t^k + S_t\, RB_t^f$	Short-term foreign borrowing, $S_t\, FB_t$
Foreign liquid assets, $S_t\, FRB_t^b$	

Table 2.4. Balance sheet of banking sector if sudden stop occurs

Assets	Liabilities
Short-term kuna loans, l_t^k	Kuna household deposits, $d_t^{kh} - \phi(1-\eta) d_t^{kh}$
Short-term euro loans, $(S_t + \Delta S)\, l_t^f$	Euro household deposits, $(S_t + \Delta S) d_t^{fh} - (S_t + \Delta S)\phi(d_t^{fh} + \frac{\eta}{S_t + \Delta S} d_t^{kh})$
Reserve requirement, $RB_t^k + (S_t + \Delta S)\ RB_t^f$	Kuna corporate deposits, $d_t^{kc} - \phi(1-\eta) d_t^{kc}$
Foreign liquid assets,$(S_t + \Delta S)\, FRB_t^b = 0$	Euro corporate deposits, $(S_t + \Delta S) d_t^{fc} - (S_t + \Delta S)\phi(d_t^{fc} + \frac{\eta}{S_t + \Delta S} d_t^{kc})$
	Short-term foreign borrowing, $(S_t + \Delta S)\, FB_t = 0$

The representative bank is choosing domestic deposit demand, domestic loan supply and international net borrowings optimally i.e. so as to maximize its profit (that is returned to households) taking interest rates and the exchange rate as given:

$$\max_{\left\{d_t^{fh}, d_t^{fc}, d_t^{kh}, d_t^{kc}, l_t^f, l_t^k, FB_t, RB_t^k, RB_t^f, FRB_t^b\right\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} Q_{t,0}\, \Pi_t \right\}$$

subject to
profits if sudden stop does not occur:

$$\begin{aligned} \Pi_t &= S_t(d_t^{fh} + d_t^{fc}) + (d_t^{kh} + d_t^{kc}) + S_t(1+r) l_{t-1}^f + (1+r) l_{t-1}^k + \\ &+ S_t\, FB_t + RB_{t-1}^k + S_t\, RB_{t-1}^f + S_t(1+r) FRB_{t-1}^b - \\ &- S_t(1+r)(d_{t-1}^{fh} + d_{t-1}^{fc}) - (1+r)(d_{t-1}^{kh} + d_{t-1}^{kc}) - S_t\, l_t^f - l_t^k - \\ &- S_t(1+r) FB_{t-1} - RB_t^k - S_t\, RB_t^f - S_t\, FRB_t^b \end{aligned} \tag{2.4}$$

with

$$RB_t^k = \omega^k [d_t^{kh} + d_t^{kc} + 0.5\, S_t(d_t^{fh} + d_t^{fc} + FB_t)] \tag{2.5}$$

$$S_t\, RB_t^f = 0.5\, \omega^f S_t(d_t^{fh} + d_t^{fc} + FB_t) \tag{2.6}$$

profits if sudden stop occur:

$$
\begin{aligned}
(2.7) \qquad \Pi_t \;=\;& (S_t+\Delta S)(d_t^{fh}+d_t^{fc})+(d_t^{kh}+d_t^{kc})+(S_t+\Delta S)(1+r)l_{t-1}^{f}+\\
+\;& (1+r)l_{t-1}^{k}+RB_{t-1}^{k}+(S_t+\Delta S)RB_{t-1}^{f}+(S_t+\Delta S)(1+r)FRB_{t-1}^{b}-\\
-\;& (S_t+\Delta S)(1+r)(d_{t-1}^{fh}+d_{t-1}^{fc})-(S_t+\Delta S)\phi[(d_t^{fh}+d_t^{fc})+\\
+\;& \frac{\eta}{S_t+\Delta S}(d_t^{kh}+d_t^{kc})]-(1+r)(d_{t-1}^{kh}+d_{t-1}^{kc})-\phi(1-\eta)(d_t^{kh}+d_t^{kc})-\\
-\;& (S_t+\Delta S)\,l_t^{f}-l_t^{k}-(S_t+\Delta S)(1+r)FB_{t-1}-RB_t^{k}-(S_t+\Delta S)RB_t^{f}
\end{aligned}
$$

with

$$(2.8) \qquad RB_t^{k} = (\omega^k-\alpha^k)[d_t^{kh}+d_t^{kc}+0.5\,S_t(d_t^{fh}+d_t^{fc})]$$

$$(2.9) \qquad (S_t+\Delta S)\,RB_t^{f} = 0.5\,(\omega^f-\alpha^f)(S_t+\Delta S)(d_t^{fh}+d_t^{fc})$$

where $Q_{t,0}=\left(\frac{\beta^t u'(c_t)}{u'(c_0)}\right)$ is bank's stochastic discount factor (the marginal rate of substitution of consumption in the time period t for consumption in the time period 0 of the bank's owner). Reserve requirement ratio on domestic and foreign liabilities are denoted by ω^k and ω^f, respectively. Parameters α^k and α^f represent central bank relief in terms of releasing part of reserve requirement to mitigate a bank run.

2.3.3. Government - Central bank

The role of the government is simple. The government expenditures consist of international reserves, R_t, transfers to households[15], T_t, repayment of short-term foreign debt, FG_{t-1}, reserve requirement that is due, RB_{t-1} (as a sum of reserve requirement on kuna liabilities, RB_{t-1}^{k},and foreign reserve requirement, RB_{t-1}^{f}), and a long-term debt matured at time t, $P\ N_{t-1}$. The government is assumed to be the only sector that can issue long-term security to finance a stock of international reserves

$$(2.10) \qquad R_t = P\ N_t$$

By selling this security, the government pays term premium, δ that captures the cost of issuing long-term debt instead of short-term debt. This long-term external debt (long-term security) yields one unit of good in every period until a sudden stop occurs. Hence, in period

[15]The government returns to households any seigniorage revenues in form of a lump sum transfer.

t the government has to pay one unit of a good for every unit bond issued (N_t denotes a stock of bonds issued by the time period t). For simplicity, the price of long-term debt, P is not explicitly modeled[16]. We assume that before a sudden stop the price of long-term security is constant and falls to zero when a sudden stop hits the economy. Hence, before the sudden stop the price of long-term security is equal to expected present discounted value of its payoffs next period (equal to 1 for sure) and the expected price of the bond next period:

$$P = \frac{1}{1+(r+\delta)} + \frac{E_t(P_{t+1})}{1+(r+\delta)} = \frac{1+(0\cdot\pi+(1-\pi)\cdot P)}{1+(r+\delta)} \tag{2.11}$$

$$P = \frac{1}{r+\delta+\pi} \tag{2.12}$$

where $r+\delta$ is the interest rate on the long-term security.

The government expenditures are financed by short-term foreign credits, FG_t, long-term borrowing $P\ N_t$, reserve requirement, RB_t and international reserves that are due in period t. During a sudden stop government cannot issue short-debt any more. It also releases part of the reserve requirement (by a fraction of α^k and α^f). Balance sheets of the government before and during a sudden stop, summarizing action of government, are given in Tables 2.5 and 2.6.

Table 2.5. Balance sheet of the government if there is no sudden stop

Assets	Liabilities
International reserves, $S_t\,R_t$	Short-term foreign borrowing, $S_t\,FG_t$
Transfer from the government, T_t	Long-term foreign borrowing, $S_t\,PN_t - S_t\,PN_{t-1}$
	Reserve requirement, $RB_t^k + S_t\,RB_t^f$

Table 2.6. Balance sheet of the government if sudden stop occurs

Assets	Liabilities
International reserves, $(S_t+\Delta S)R_t$	Short-term foreign borrowing, $(S_t+\Delta S)FG_t = 0$
Transfer from the government, T_t	Long-term foreign borrowing, $(S_t+\Delta S)PN_t$
	Reserve requirement, $RB_t^k + (S_t+\Delta S)RB_t^f$

[16]Modeling a price of a bond would require modeling behavior of agents selling bonds i.e. modeling behavior of foreigners. Nevertheless, the price of any bond comes down to a simple formula (e.g. from the Lucas tree model).

Overall, if sudden stop does not occur the government budget constraint is given by:

$$T_t + S_t\, R_t + S_t(1+r)FG_{t-1} + S_t\, N_{t-1} + S_t\, PN_{t-1} + RB^k_{t-1} + S_t\, RB^f_{t-1} = S_t(1+r)R_{t-1} + S_t\, FG_t + S_t\, PN_t + RB^k_t + S_t\, RB^f_t \tag{2.13}$$

where RB^k_t and RB^f_t are given as in (2.5) and (2.6) respectively.

If there is sudden stop hits the economy the government budget constraint reads as:

$$\begin{aligned} &T_t + (S_t + \Delta S)\, R_t + (S_t + \Delta S)(1+r)FG_{t-1} + (S_t + \Delta S)N_{t-1} + \\ &+ RB^k_{t-1} + (S_t + \Delta S)RB^f_{t-1} = (S_t + \Delta S)(1+r)R_{t-1} + \\ &+ (S_t + \Delta S)PN_t + RB^k_t + (S_t + \Delta S)RB^f_t \end{aligned} \tag{2.14}$$

where RB^k_t and RB^f_t are given as in (2.8) and (2.9) respectively.

2.3.4. Optimal reserves

The government chooses consumption and reserves so as to maximize household's welfare (given by household's utility function) taking into account the overall (consolidated) budget constraint[17] of the economy:

$$\max_{\{c_t, R_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_t) \right\}$$

subject to consolidated budget constraint
if there is no sudden stop

$$\begin{aligned} &P_t c^b_t + S_t(1+r)b_{t-1} + S_t(1+r)FB_{t-1} + S_t(1+r)FG_{t-1} + S_t FRB^b_t + S_t\, FRB^h_t = \\ = \; &P_t y_t + S_t\, b_t + S_t(1+r)FRB^h_{t-1} + S_t(1+r)FRB^b_{t-1} + S_t\, FB_t + S_t\, FG_t - \\ &- S_t\, (\delta + \pi)R_{t-1} \end{aligned} \tag{2.15}$$

[17] Derivation of consolidated budget constraint is provided in Appendix.

if sudden stop occurs

$$
\begin{aligned}
(2.16) \qquad & P_t c_t^d + (S_t + \Delta S)(1+r)b_{t-1} + (S_t + \Delta S)(1+r)FB_{t-1} + \\
& +(S_t + \Delta S)(1+r)FG_{t-1} + (S_t + \Delta S)\phi(d_t^{fh} + \frac{\eta}{S_t + \Delta S} d_t^{kh}) \\
= \; & (1-\gamma)P_t y_t + (S_t + \Delta S)(1+r)FRB_{t-1}^h + (S_t + \Delta S)(1+r)FRB_{t-1}^b \\
& +(S_t + \Delta S)(1 - \delta - \pi)R_{t-1}
\end{aligned}
$$

In Appendix we show that the consolidated budget constraint actually correspond to the national accounts identity (2.1). Hence, the budget constraint of the economy represents all maximum possible combinations of consumption which are consistent with national accounts. Welfare maximization principle determines which consumption point the government will actually choose.

Furthermore, consolidated budget constraint shows that holding reserves is equivalent to repaying short-term external debt by issuing more expensive long-term debt. Even though this is costly, there is a benefit which stems from possibility of substitution of short-term with long-term debt during the sudden stop.

It is clear that holding foreign reserves is beneficial. Foreign reserves allow consumption smoothing of non-financial sector by changing transfers to this sector. Counterbalancing these precautionary motives for holding reserves are their opportunity costs which in practice arise from substituting high yielding domestic assets for lower yielding foreign ones. We do not proxy these costs as the difference between the domestic marginal product of capital and the returns obtained on the reserve assets. Instead, we model these costs as in Ranciere and Jeanne (2006)- foreign reserves have opportunity costs since they are financed by issuing long-term debt at a term premium. In other words, opportunity cost of reserves is defined as the difference between the interest rate paid on the country's liabilities $(r + \delta)$ and the lower return received on the reserves (r).

Substituting for consumption before a sudden stop, c_{t+1}^b, and consumption during a sudden stop, c_{t+1}^d, from consolidated budget constraint before and during a sudden stop and deciding about the level of reserves that maximizes the welfare of the economy, the first order condition with respect to R_t is given as

$$
(2.17) \qquad S_{t+1}(1-\pi)(\delta+\pi)u'(c_{t+1}^b) = (S_{t+1} + \Delta S)\pi(1-\delta-\pi)u'(c_{t+1}^d)
$$

This optimality condition balances benefits and costs of holding reserves - expected marginal benefit of holding reserves during the crisis (right-hand side) has to be equal to expected marginal cost of holding reserves before sudden stop (left hand side).

From (2.17) we have that level of optimal reserves reads as[18]

$$\begin{aligned}
(2.18) \qquad R_t \;=\; & \frac{1}{q_{t+1}}\Bigg\{(1+g)(1-\varepsilon^{\gamma}_{t+1})y_t + \left[\lambda^*_{t+1} - \frac{S^r_{t+1}}{P^r_{t+1}}(1+r)(1-\varepsilon^s_{t+1})\lambda^*_t\right] - \\
& - \left[\lambda^A_{t+1} - \frac{S^r_{t+1}}{P^r_{t+1}}(1+r)(1-\varepsilon^s_{t+1})\lambda^A_t\right] + \phi\varepsilon^s_{t+1}\lambda^D_{t+1}\Bigg\}
\end{aligned}$$

with

$$\begin{aligned}
z_{t+1} &= \frac{(1-\pi)(\delta+\pi)}{\pi(1-\delta-\pi)(1+\frac{\Delta S}{S_{t+1}})},\ \varepsilon^{\gamma}_{t+1} = z^{\frac{1}{\sigma}}_{t+1}(1-\gamma),\ \varepsilon^s_{t+1} = z^{\frac{1}{\sigma}}_{t+1}(1+\frac{\Delta S}{S_{t+1}}) \\
y_{t+1} &= (1+g)y_t,\ S^r_{t+1} = \frac{S_{t+1}}{S_t},\ P^r_{t+1} = \frac{P_{t+1}}{P_t} \\
q_{t+1} &= \frac{S_{t+1}}{P_{t+1}}\left[(\delta+\pi)(1-\varepsilon^s_{t+1}) + \varepsilon^s_{t+1}\right] \\
\lambda^*_t &= \frac{S_t}{P_t}(b_t + FB_t + FG_t),\ \lambda^A_t = \frac{S_t}{P_t}(FRB^h_t + FRB^b_t),\ \lambda^D_t = \frac{S_t}{P_t}(d^{fh}_t + \frac{\eta}{S_t+\Delta S}d^{kh}_t)
\end{aligned}$$

where λ^*_t, λ^A_t, λ^D_t denote overall short term external debt, overall foreign buffer and cost of bank run, respectively.

A formula for optimal reserves provides the level of reserves that a central bank needs to hold today if it wants to prevent expected negative effects of a sudden stop with banking crisis that might happen tomorrow. At the same time, by holding optimal reserves, central bank is smoothing consumption that yields maximum possible welfare.

Optimal reserves increase with overall expected short-term external debt, λ^*_{t+1}, possible foreign deposits withdrawal, $\phi\lambda^D_{t+1}$, output loss, γ, probability of sudden stop, π and exchange rate depreciation, ΔS. First two variables pertain to a double drain risk. Central bank is holding reserves so as to step in if an external drain risk is realized (short-term external debt falls to zero) or if an internal drain risk takes in (a bank run occurs). Output loss, exchange rate depreciation and probability of a sudden stop are parameters in our model that have to be calibrated. Output loss affects the optimal level of reserves in that it reduces domestic

[18] Derivation of the optimal reserves formula is provided in Appendix.

absorption. Exchange rate depreciation increases the burden of potential foreign liabilities and forces central bank to hold more reserves.

On the other hand, central bank will hold less reserves if their costs, δ, increase and if its alternative buffer in terms of expected foreign liquid assets of private sector, λ_{t+1}^{A} increases.

Our formula for optimal reserves differs from the one in Goncalves (2007) in that it preserves dynamics[19]. Excluding dynamics from the formula comes at the cost of losing one of the main implications of the model- the model implies that central bank needs to be ready for the potential crisis - to prevent the crisis a central bank needs to hold optimal reserves in the period before the crisis as a precautionary measure.

Ruling out dynamics does not pose a big problem in ex-post interpretation of optimal reserves. To see why, imagine, for example, that one is interpreting a crisis that happened in 2002 (as it did in Uruguay) from todays' perspective. A dynamic formula (like ours) would result in lower optimal reserves in comparison to optimal reserves implied by a static formula (like in Goncalves (2007)). The reason for this is that when calculating optimal reserves ex-post, one is using the past (realized) data and not the expected data. Hence when the crisis is realized the values of the variables that are hit during the crisis fall (for example, the short-term external debt falls since it is not rolled over and the foreign deposits fall because of the bank run). Hence, optimal reserves in 2001 would be lower than the ones one would calculate using a static formula (that would not use 2002 data). Therefore, dynamic formula would underestimate optimal reserves before the crisis. However, static formula would overestimate optimal reserves during the crisis period since it does not take into account the recovery period that comes after the crisis and that implies holding less reserves[20].

Moreover, a static formula might lead to a problematic interpretation of optimal reserves ex-ante. A static formula is not a forward-looking formula. On the other hand, a dynamic formula implies the level of reserves today so as to prevent crisis tomorrow. A forward

[19]Goncalves (2007) make all model variables in period $t+1$ to be equal to the value of corresponding model variable in period t.

[20]On average, static formula in Goncalves (2007) yields different results than dynamic one by 4% of GDP whereas the biggest difference comes in the crisis period. The comparison of results of static and dynamic formula in Goncalves (2007) are available upon request.

looking analysis of current reserves using a static formula does not have anything to say about this issue.

Regarding the comparison of standard indicators of reserves adequacy and optimal reserves, notice that we can restrict a formula of optimal reserves to be equal to the Greenspan-Guidotti rule:

$$R_t = \lambda^*_{t+1} \tag{2.19}$$

This would hold if there is no alternative buffer to protect the economy from potential crisis, no output costs of the crisis, no effects from the bank run, and no depreciation during the crisis. Even though many analysts use this indicator in assessing reserves adequacy, it is clear that the restricted formula does not even reflect the stylized facts of sudden stops with banking crises since it excludes main elements of all sudden stop with banking crisis episodes.

2.3.5. Calibration

To go from the general formula for optimal reserves to quantitative statements about the issues of holding optimal amount of international reserves we have to calibrate the model. In other words, model's ability to say something about optimal reserves depends on model's parameters. Calibrating the model involves finding numerical values for parameters using the model as the basis for restricting the model economy and mapping that economy onto the data. Hence, in calibrating the model we assign numerical values to all the model's parameters, that characterize preferences and technology, so as to make it roughly consistent with some of the empirical regularities that reflect the structure of the Croatian economy. If the parameter value cannot be pinned down from the data, we adapt its value from the existing studies and run some sensitivity analysis to see how optimal reserves change if we change a specific parameter.

We managed to calibrate most of the parameter values based on the sudden stop with banking crisis episode during 1998/1999. In other words, benchmark calibration involves setting parameter values to reflect the 1998/1999 sudden stop with banking crisis episode. Even though we use end-of-period annual data when calculating the optimal reserves (in the next section), in calibrating the model we use quarterly and monthly data so as to determine the date of the crisis and its consequences more precisely. This is because sudden stop happened somewhere in the middle of a year (third quarter 1998). Furthermore, by the end of the next year the most severe effects of that sudden stop with banking crisis disappeared as external credit lines reopened again and the banking crisis culminated somewhere in the middle of 1999. Hence, by using annual data we would probably underestimate the consequences of this sudden stop with banking crisis.

There is no official date when 1998/1999 sudden stop with banking crisis started. It should be the date when issuing new external debt was no longer possible and when bank run occurred. Hence, we would see the beginning of the sudden stop with banking crisis in the data for external debt and banking activity. Unfortunately, data on external debt are available from December 1998 only. However, we have longer time series on non-residential deposits that also count as external debt. Moreover, we have longer time series of financial account that reflects the behavior of external debt. We take the peak and the trough of non-residential deposits as the start and the end of the sudden stop with banking crisis period, respectively. Therefore, the sudden stop with banking crisis began in March 1998 (that correspond to the date of Dubrovačka banka failure) and its consequences were still felt until end-May 1999. These dates somehow correspond to banking and real sector slowdown (and recovery) and financial account reversal discussed in Section 2.2.

We set the parameter value for exchange rate depreciation rate, ΔS, to match the exchange rate increase during the sudden stop with banking crisis period when it went up by 8%.

The growth rate of GDP, g, was calibrated as the average annual growth rate of potential real GDP over the period $1998-2007$ which is equal to 3.9%. Potential GDP was estimated using Hoddrick-Prescott filter. Output loss during the sudden stop with banking crisis, γ, was calibrated as the difference between the average growth rate of potential GDP and the largest (negative) actual GDP growth rate during the sudden stop with banking crisis period (which happened just after the sudden stop with banking crisis started- in the fourth quarter 1998 when real GDP changed by -4.8%). Hence, the output loss during the sudden stop with banking crisis period is set to 8.7% of nominal GDP.

To account for possible "Tequila effect" we define a parameter that characterizes a fraction of kuna deposits exchanged for euro deposits, $\eta(\alpha^k)$, to be a function of kuna reserve requirement relief during a sudden stop

$$\eta(\alpha^k) = s_0 + s_\alpha \alpha^k$$

where s_0 is a parameter of kuna deposit that would be exchanged for euros in any event (even if the central bank would not respond to a sudden stop) and s_α measures the elasticity of deposit withdrawal to a central bank move to decrease reserve requirement ("Tequila effect"). Namely, during a sudden stop with bank run episode in Mexico the Central Bank of Mexico tried to fight credit crunch by lowering reserve requirement. This reaction by the central bank seemed to be a positive move towards stopping the bank run. However, it induced people to exchange even more pesos for dollars when they realized they have a chance to exchange the full amount of their peso savings and put even higher burden at a banking system. Since the Croatian National Bank was not reacting to the sudden stop with banking crisis by lowering reserve requirement in 1998/1999 we set $s_\alpha = 0$ in the benchmark case. This parameter will be relevant in the alternative calibration where we study what amount of optimal international reserve should be held as a precautionary insurance against possible future "Tequila effects". Parameter s_0 was calibrated based on the fact that 19% of kuna deposits were withdrawn from the banking system (starting in August 1998 and ending just one month after the euro deposits withdrawal happened). We assume that those kuna deposits were exchanged for euros[21]. Notice that releasing reserve requirement on banks' foreign liabilities does not have any effect on optimal reserves since we work with gross foreign reserves (that are partially financed by reserve requirement).

A parameter value that characterizes the deposit withdrawal rate during a sudden stop with banking crisis period, ϕ, is set to the value that matches the drop of euro deposits[22] during the 1998/1999 episode. Data show that the peak level of the euro deposits was recorded in February 1999, followed by a 17% drop in the period of three months.

Parameter values that describe reserve requirement ratios on kuna and euro denoted liabilities, ω^k and ω^f, respectively, were set to their actual values at the end of 2007. Parameter ω^k was set to the ratio of kuna reserve requirement and bank's domestic liabilities (deposit

[21]This might be a reason why euro deposits did not decline before February 1999 and were actually rising.
[22]In calibration of ϕ we were not considering kuna deposits since euro deposits account for the largest part of overall deposits.

money, kuna deposits, government deposits, CNB credits) in December 2007 that is equal to 17%. Parameter ω^f was set to the ratio of the euro reserve requirement and the banks' foreign liabilities (euro deposits, euro liabilities and the difference between foreign assets and banks' international reserves to account for the numerator of the CNB prescribed minimum foreign currency liquidity ratio for banks) equal to 17% in December 2007.

Since we experienced only one sudden stop in the last ten years, we cannot use standard probit estimation techniques to estimate a probability of a sudden stop. In the benchmark calibration we set the probability of crisis that implies on average one crisis in every ten years ($\pi = 0.1$). This value corresponds to probit estimation of a sudden stop probability on panel data for 34 middle income countries in Ranciere and Jeanne (2006).

We adapt the standard value for the risk aversion parameter, σ, from the real business cycle literature (equal to 2).

The term premium, δ, was calculated as an average difference between the yield on 10-year German government bond and ECB main refinancing repo rate ($\delta = 1.3$ percentage points).

We assume that the interest rate in the model, r, is the return on reserves (among other things) and is equal to an average foreign risk-free rate, in the Croatian case appropriately set at the six month Euribor rate (3.3%).

Table 2.7 summarizes the values of the calibrated parameters.

Table 2.7. Benchmark calibration

Symbol	Parameter	Benchmark (98/99) Value
π	probability of sudden stop (%)	10
g	growth rate of potential GDP (%)	3.9
r	interest rate (%)	3.3
δ	term premium (pp)	1.3
σ	relative risk aversion	2
ω^k	kuna reserve requirement ratio (%)	17
ω^f	euro reserve requirement ratio (%)	17
α^k	kuna reserve requirement relief during sudden stop (pp)	0
γ	output loss during sudden stop (%)	8.7
ΔS	exchange rate depreciation rate (%)	8
ϕ	fraction of deposit withdrawn (%)	17
s_0	fraction of kuna deposits exchanged for euro deposits (constant) (%)	19
s_α	fraction of kuna deposits exchanged for euro deposits (elasticity)	0

2.3.6. Data

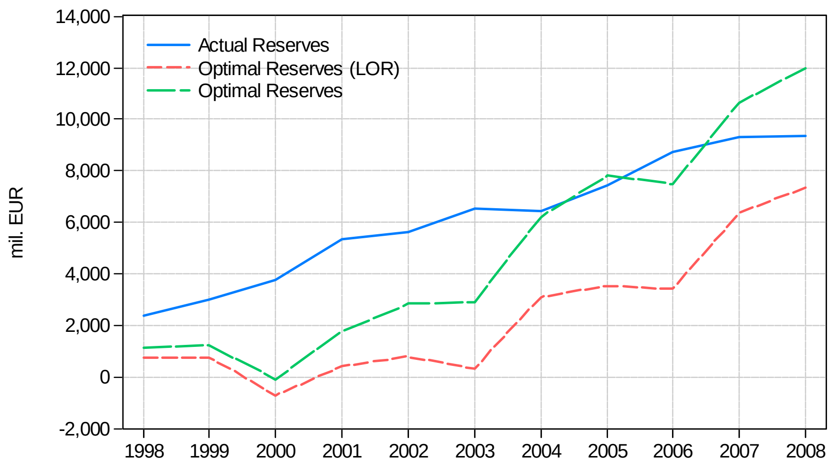
In addition to the parameter values, we need the data to plug into our formula of optimal reserves in order to explore the quantitative implications of the model. There are a couple of things worth mentioning regarding data. First, we augment the short-term external debt of every sector by the principal payments of its long-term debt that are due. These principal payments represent a short-term liability and do not depend on the occurrence of a sudden stop. Second, most deposits, even deposits with long maturities, can be easily withdrawn at any point in time. Therefore, we treat non-residents deposits (mainly deposits of parent banks) of every maturity as short-term external debt of banking sector. Foreign liquid assets of the non-banking sector consist of cash and deposits invested abroad that can be easily withdrawn. Foreign liquid assets of the banking sector comprise mandatory foreign currency reserves that can be used as a buffer against a bank run. Finally, since the model implies that reserves are partly financed with reserve requirement we have to use gross measure of the CNB's foreign reserves.

The presence of foreign banks in the Croatian banking system complicates the story. Namely, foreign banks are at the same time owners and largest lenders to the Croatian banking sector. Therefore, their role in a sudden stop might be different from the role of "ordinary" foreign lenders. During the 1998/1999 episode foreign banks were mostly not present in Croatia. Hence, we do not know how they might behave during a sudden stop, that is, whether they could be expected to act as the lenders of last resort for their Croatian subsidiaries by converting their short-term funding into long-term funding or they would simply „take the money and run". Current literature on parent banks behavior provides evidence that parent banks presence added significantly to the stability of the financial sector as the parent banks have provided liquidity and capital support during banking crises. Gardo, Hildebrandt and Walko (2008) conjecture that parent banks might sustain business activities in Central and Eastern Europe to benefit from the opportunities arising from the region's catching up potential in terms of the scale and scope of banking activities. Hence parent banks might protect their subsidiaries in the event of the crisis. Using panel data on the intra-group ownership structure and the balance sheets of 45 of the largest banking groups in the world de Haas and van Lelyveld (2006) finds that parent banks tend to support weak subsidiaries by providing additional capital when the latter are confronted with adverse financial conditions. Using annual financial statements of individual banks operating in 11 countries in East Asia and Latin America Brei (2007) finds that foreign banks attenuate significantly more the adverse effects of sudden stops on the domestic lending volume playing an important stabilizing role. Moreover, in the event of unexpected loss of Riječka banka in 2002, that provoked the run on its deposits, the parent bank (Bayerische Landesbank) run away immediately as it heard the bad news (by selling Riječka banka to the government for 1 euro). However, it did not claim its money back in terms of deposit withdrawal or cancellation of credit lines probably because the cost of losing reputation would be too large. To account for two possibilities of parent banks behavior we use two definitions of banks' foreign borrowing. When we treat parent banks as lenders of last resort their euro deposits and their short-term loans are excluded from the above definition of augmented short-term external debt.

2.4. Findings

Plugging in the data into the formula for optimal reserves, our benchmark calibration implies that the level of optimal reserves depends mainly on the reaction of parent banks during a potential sudden stop with banking crisis (Figure 2.6).

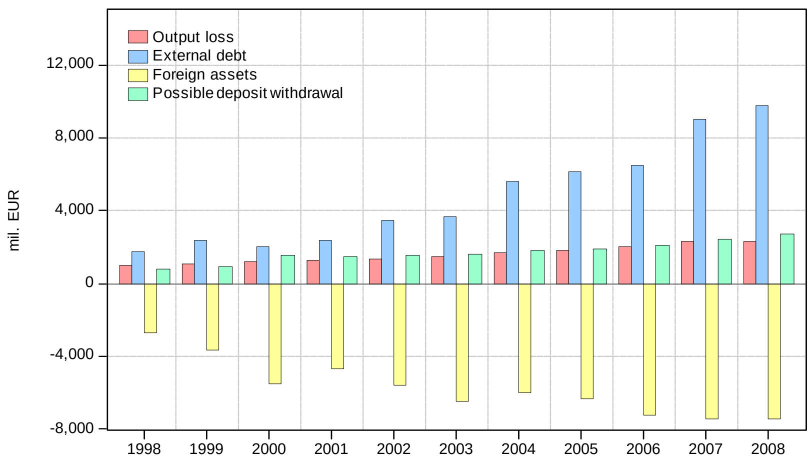
Figure 2.6. Benchmark calibration- Actual reserves, optimal reserves where parent banks act as the lenders of last resort (LOR), optimal reserves where parent banks participate in a crisis (mil. EUR).



If we assume that during the crisis all parent banks play their lender of last resort roles, then the level of the actual reserves was on average three times the optimal level in the period 1998-2007. The large difference between the actual and the optimal levels of the foreign reserves is a consequence of the low calculated level of the optimal reserves (even negative in 2000) and the strong accumulation of the actual reserves until 2003. After 2003, the difference between the actual and the optimal reserve levels falls mainly as a consequence of a big increase in the calculated level of the optimal reserves. At the end of 2008, the foreign reserves of the CNB were still bigger than the optimal reserves. However, the picture is quite different if we assume that parent banks will turn their back on Croatian banks in the event of a sudden stop with banking crisis. Under this assumption, the need for foreign reserves has increased since 2003 from well below to above the actual level at the end of 2008 as domestic lending was fueled by foreign borrowing from parent banks (mostly in the form of foreign deposits). Thus, if during 2009 Croatia experiences a sudden stop with banking crisis of the 1998/1999 magnitude then the CNB has just enough reserves to prevent the financial account reversal and bank run from causing consumption loss. However, this holds in a "more favourable" scenario only, in which parent banks assume the role of lenders of last resort.

Figures 2.7 and 2.8 explain the pattern of the optimal reserves. We decompose the optimal reserves into their four main components of optimal reserves formula (2.18). Optimal reserves are defined as the weighted difference between contributions of the output loss, the short-term external debt change, and the deposit withdrawal on one hand, and the contribution of the change in the foreign liquid assets of firms and banks on the other[23].

Figure 2.7. Decomposition of optimal reserves (mil. EUR) where parent banks act as the lenders of last resort.



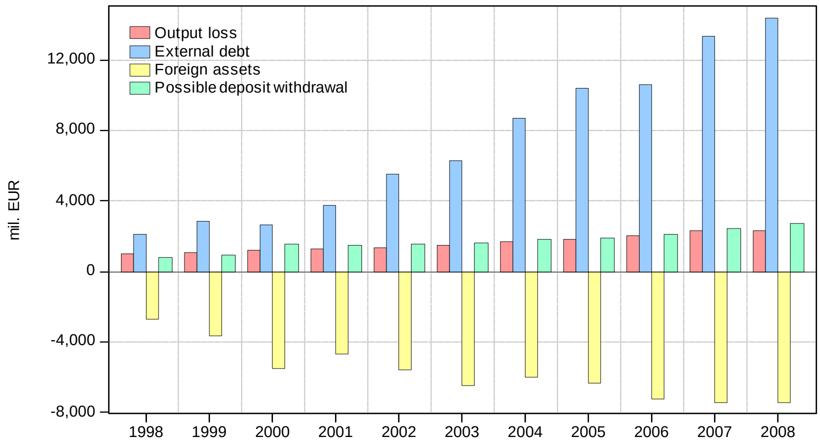
The negative calculated optimal reserve level for 2000 is primarily a consequence of the high growth of foreign liquid assets of the private sector during 2001, due to the German mark-to-Euro conversion at the end of 2001. The model suggests that at the end of 2000 the CNB did not have to hold any reserves since the private sector's buffers were large enough to cope with a possible sudden stop with banking crisis during 2001[24]. A high growth of the calculated optimal reserve level by 2004 is largely the end result of high borrowing of banks

[23]Note that these components do not perfectly correspond to data since they are given weights that come from the Ramsey problem. Components correspond to the four elements of the optimal reserves formula (2.18).

[24]This result would not hold if the probability of sudden stop is a function of optimal reserves.

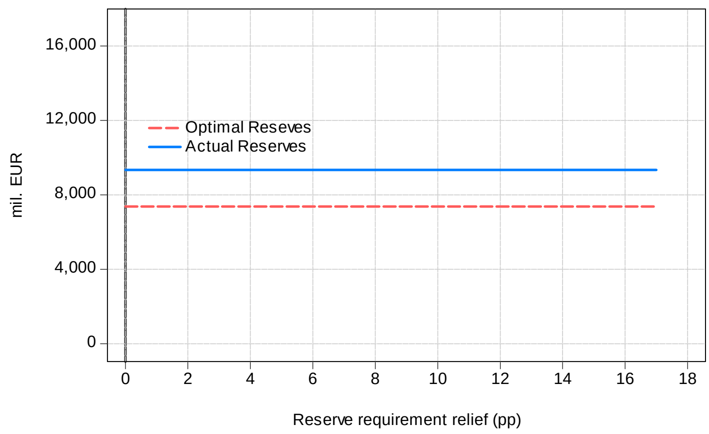
and firms from abroad in the interim period. These trends in the calculated level of the optimal reserves are observed for both scenarios of the parent banks' behavior. The large difference between the optimal reserve levels calculated in the two cases indicates that the major part of the external borrowing used parent-its subsidiary bank credit/deposit lines. The optimal reserves slowdown at the end of 2008 can be for the most part explained by a smaller increase in banks' foreign debt due to the CNB's credit growth ceiling.

Figure 2.8. Decomposition of optimal reserves (mil. EUR) where parent banks participate in sudden stop.



Next, we study if it is wise to release a part of the banks' reserves (by lowering the reserve requirement) to help the banking sector cope with the deposit run assuming that Tequila effect would emerge. Note that if Tequila effect does not exist releasing reserve requirement on foreign liabilities does not have any impact on optimal reserves as it would reduce actual reserves and at the same time increase a buffer of banking sector. For the benchmark calibration with Tequila effect (i.e. with $\alpha^k = 17$ pp, $s_\alpha = 1$) where the parent banks acting as the lenders of last resort, the central bank would fail to help the banking system to overcome the deposit run even if it released a part of the kuna reserve requirement. Figure 2.9 shows how the optimal reserves level in 2008 depends on the kuna reserve requirement reduction in this hypothetical scenario with the parent banks acting as the lenders of last resort (perpendicular line indicates zero benchmark value of kuna reserve requirement relief). The upshot is that due to the Tequila effect, the central bank would actually have to hold more (!) reserves to help tackle the deposit run. By removing the reserve requirement the central bank would actually be adding oil to the fire. However, Figure 2.9 shows that in our model the level of the optimal reserves is not sensitive to a change in the reserve requirement. Nevertheless, the model suggests that it would not be wise to reduce the reserve requirement when a crisis occurs if Tequila effect would appear.

Figure 2.9. Optimal reserves (mil. EUR) and kuna reserve requirenment relief (pp).



Finally, we investigate how our measure of optimal reserves (for a benchmark calibration and the parent banks acting as the lenders of last resort) corresponds to the rule-of-thumb measures of reserves adequacy. All three measures of reserves adequacy suggest that the CNB had enough reserves as an insurance against a potential crisis during the last ten years (Figure 2.10). However, it is important to notice that the two standard measures of reserves adequacy behave differently from our optimal reserves measure. For example, in 2000 the optimal reserve level was shown to be negative, but since the two standard measures of reserves adequacy do not take into account the private sector's liquid foreign assets' buffer they suggest that the optimal reserves should have been positive.

While the optimal reserves level depends on many parameters reflecting common features of sudden stops with banking crisis, the short-term external debt and the 3-months-of-imports measures do not take into account these features. Figures 2.11 and 2.12 show the optimal reserves level when the output loss and the fraction of deposits withdrawn are different from the benchmark calibration (perpendicular lines indicates benchmark values of the two parameters).

Figure 2.10. Actual and optimal reserves with Greenspan-Guidotti and 3-months-of-imports rules (mil. EUR).

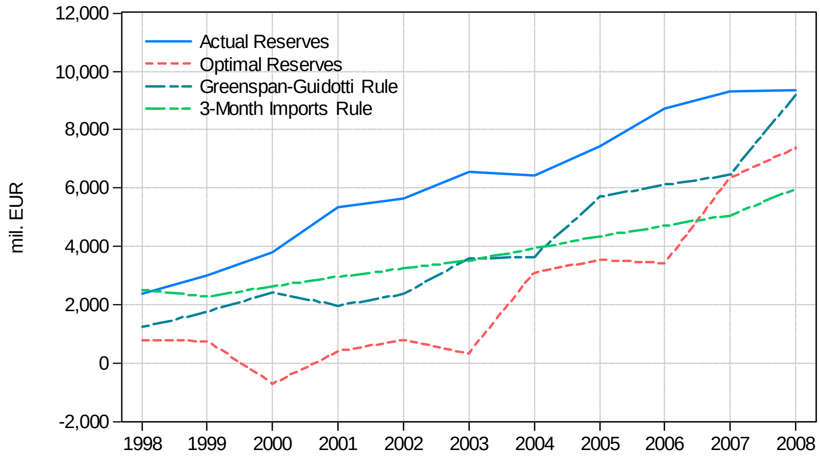
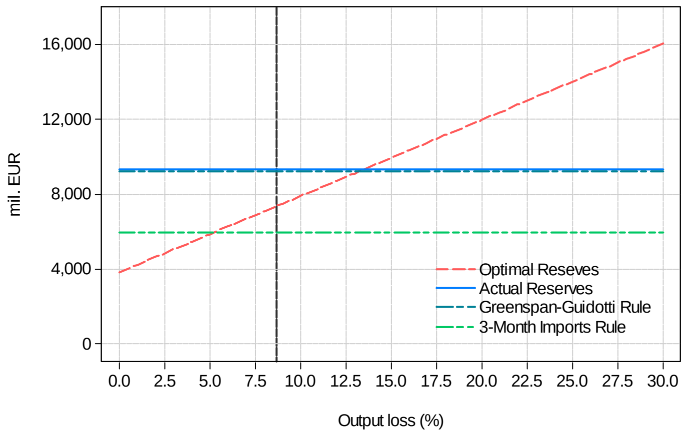
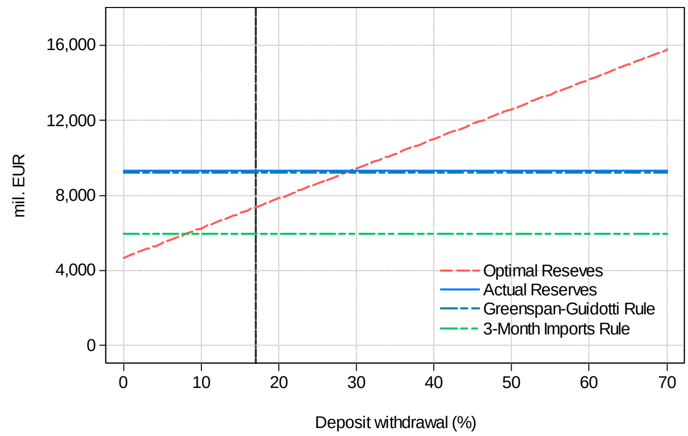


Figure 2.11. Optimal reserves, Greenspan-Guidotti rule and 3-months-of-imports rule (mil. EUR) with different values of output loss (%).



The error that one would make by using only the two standard measures of reserves adequacy in assessing the optimality of those reserves might be quite large. For example, if the Croatian economy is hit by a sudden stop with banking crisis of the 1998/99 magnitude, then the Greenspan-Guidotti rule implies the "optimal" reserves level higher than that implied by our measure by more than 2 billion euros (perpendicular line denoting the benchmark calibration of the output loss parameter). Actually, for the Greenspan-Guidotti rule and our optimal reserves measure to be equal we should be expecting either about 13%

Figure 2.12. Optimal reserves, Greenspan-Guidotti rule and 3-months-of-imports rule (mil. EUR) with different values of fraction of deposit withdrawal (%).



(instead of 8,7%) of output loss or about 30% deposit withdrawal (instead of 19%) during the hypothetical 2009 crisis. The Greenspan-Guidotti rule does a good job in terms of assessing reserves optimality in 2007 in the baseline scenario. However, even though the two measures are almost equal in 2007, Figures 2.11 and 2.12 show that they might yield very different results for the optimal reserves level, depending on the assumed output loss and deposit withdrawal parameters. For example, if one expects a crisis of the size about two times larger than during 1998/1999 than the Greenspan-Guidotti rule would be closer to our measure of optimal reserves than the 3-months-of-import rule.

2.4.1. Sensitivity analysis

The results discussed in the previous section are conditional on parameter values. In this section we check if our results are robust to changes in those parameter values. Table 2.8 shows the examined intervals of parameter values and their benchmark calibration. We solve for the optimal reserves level for every discrete point in the interval, for each individual parameter, and compare this level with the actual reserves level at the end of 2008. Furthermore, in Figure 13 we indicate the benchmark value of the corresponding parameter (using the perpendicular line). In our sensitivity analysis we assume that the parent banks act as the lenders of last resort in the event of a sudden stop with bank run[25].

Table 2.8. Benchmark calibration and intervals for the sensitivity analysis

Symbol	Parameter	Benchmark (98/99) Value	Sensitivity analysis interval
π	probability of sudden stop (%)	10	$2 - 30$
ΔS	exchange rate depreciation rate (%)	8	$0 - 30$
g	growth rate of potential GDP (%)	3.9	$0 - 10$
γ	output loss during sudden stop (%)	8.7	$0 - 30$
r	interest rate (%)	3.3	$3 - 7$
δ	term premium (pp)	1.3	$0 - 5$
ϕ	fraction of deposit withdrawn (%)	17	$0 - 70$
s_0	fraction of kuna deposits exchanged for euro deposits (constant) (%)	19	$0 - 70$

Figure 13 shows how the optimal level of the reserves depends on the size of the eight parameters from Table 2.8. The optimal level of reserves is particularly sensitive to the probability of sudden stop, exchange rate depreciation, output loss, the term premium and the fraction of deposit that will be withdrawn during the banking crisis[26]. The relation between the probability of a sudden stop and the optimal reserves level is nonlinear and positive. Hence, the actual probability of a sudden stop is relevant for the optimal reserves level only for small probability values. In the benchmark case, even if one doubles the probability (from 10% to 20%) the optimal reserves level would increase by only 15%. Increasing the exchange rate depreciation from 8% (in the benchmark case) to 20% increases the optimal reserve level by 23%. Doubling the output loss (from 8.7% to 17.4%) has an even larger impact (35%). Increasing the assumed deposit withdrawal rate from 17% to 30% increases the optimal reserves level from 5.130 million euros to 6.924 million euros. It is interesting that increasing the term premium by just a little (say 1 percentage point) has a large impact on the cost of holding reserves[27]. Increasing the term premium from 1.3 percentage points

[25] We also run sensitivity analysis when parent banks participate in sudden stop (available upon request). Overall, sensitivity analysis results did not change by much. We do not provide sensitivity analysis for kuna reserve requirement relief during a sudden stop and a fraction of kuna deposits exchanged for euro deposits (elasticity) since in the benchmark calibration we assume they are both zero.

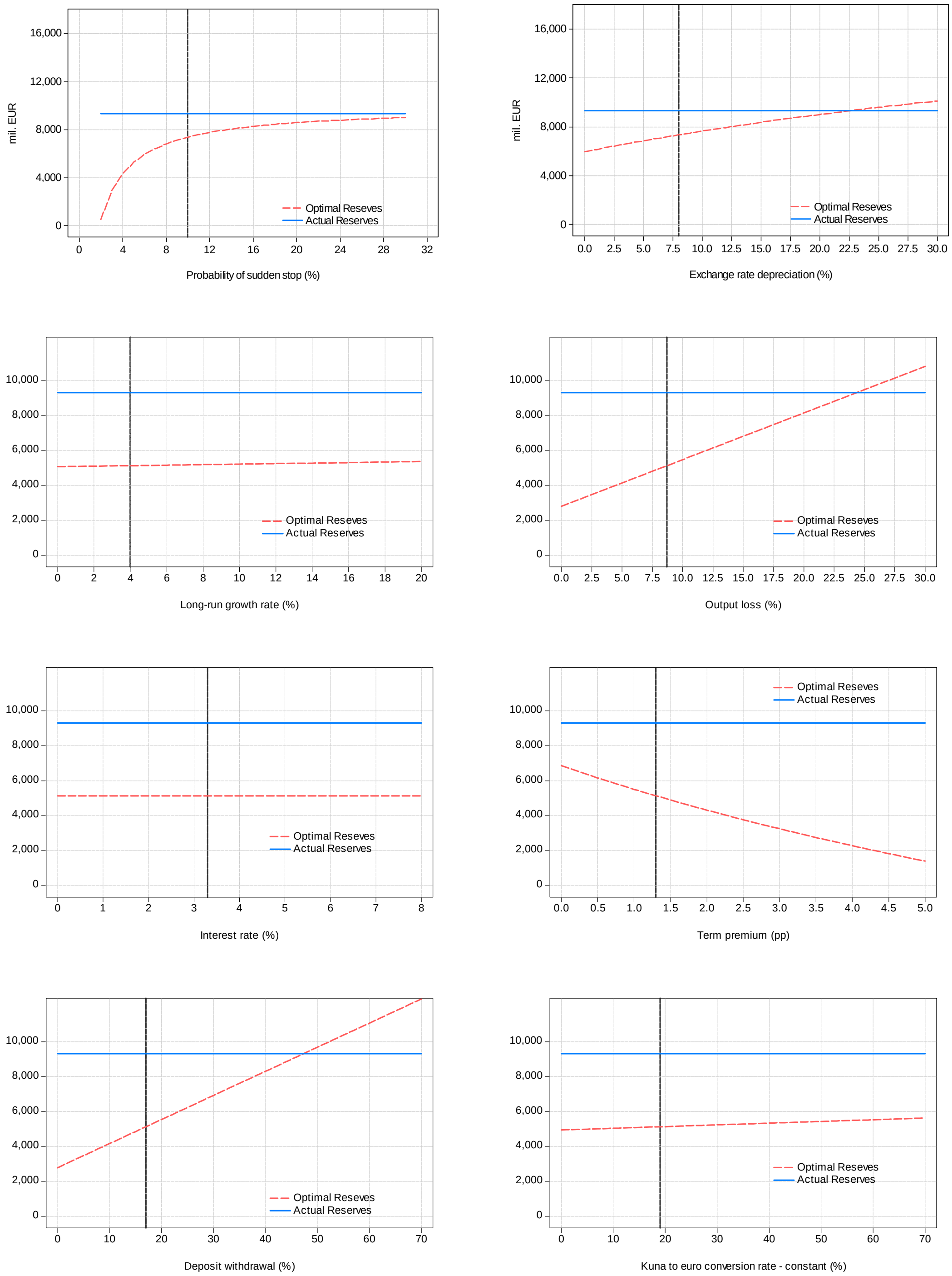
[26] Note that this is in strike contrast with the Greenspan-Guidotti and 3-months-of imports rules, which do not depend on these parameters.

[27] This might be the biggest weakness of the model then.

(in the benchmark case) to 2.3 would decrease the optimal level of the foreign reserves by 22%.

Figure 13 also shows that, assuming that the parent banks act as the lenders of last resort, the actual reserves are still above their optimal level under a range of shocks that do not assume their extreme values at the same time. For example, providing that the magnitude of other shocks is at the benchmark level, the CNB has enough reserves for fighting off the crisis with the probability of its occurrence larger than 30%. Alternatively, even if kuna depreciates during the crisis by more than 20%, the CNB is holding reserves for overcoming the higher burden of potential foreign liabilities. Finally, actual foreign reserves can be thought of as an insurance against maximum 25% output loss or about 50% deposit withdrawal as long as scale of other effects of crisis is at the benchmark level.

Figure 13: Sensitivity analysis of optimal reserves (mil. EUR).



2.5. Conclusion

This paper has explored the main issues related to the trend of strong foreign reserves accumulation in Croatia during the last decade within a context of a simple analytical model. We show that this trend is consistent with the precautionary demand for foreign reserves. Whether this trend has been too strong or whether the actual reserves have been lower than optimal depends on the expected reaction of the parent banks during the crisis. Our study reveals that for plausible values of parameters, related to the 1998/1999 sudden stop/banking crisis, the CNB is holding enough foreign reserves to fight the possible crisis in the near future. This result holds in a "more favourable" scenario only, in which parent banks assume the role of lenders of last resort. Moreover, we show that the CNB reserves present an insurance asset against a crisis of the magnitude larger than that during the 1998/1999 episode, provided that not all shocks assume their extreme values at the same time and that the parent banks act as the lenders of last resort. We also show how using the two standard indicators of foreign reserves adequacy might be misleading in assessing foreign reserves optimality. This result stems from the elements that determine optimal reserves and that Greenspan-Guidotti and 3-months-of-imports rules do not take into account.

Our model could be extended in many directions. In particular, it would be worth exploring the elements of the models by Ranciere and Jeanne (2006) and Jeanne and Ranciere (2008) like crisis prevention (where the probability of a crisis depends on the level of reserves) and endogenous agents' behavior during a sudden stop. An interesting issue to tackle would be to analyze the relation between profits of parent banks, their behavior during crisis and the probability of crisis. These extensions would endogeneize some of the assumptions in our model. Other extensions of the model could include introducing parameters related to regulation: optimality of reserves models provide a natural setting for comparing the costs and the benefits of regulation, at least from the prudential perspective. For example, it would be possible to introduce a parameter representing the CNB's „minimum required liquid foreign assets“ instrument and find its optimal value, in a sense that any value of this parameter that would yield the optimal reserves level below their actual level would be considered costly. All those extensions constitute a task for future research.

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2.6. Appendix

In the first part of Appendix we show how to derive the consolidated budget constraint (2.15) and (2.16). In the second part of Appendix, we show how to derive the formula for the optimal reserves (2.18). In the end we show how the consolidated budget constraint relates to the national accounts identity (2.1) and present a table with our data sources.

2.6.1. Consolidated budget constraint

Substituting for profits of banking sectors as well as transfers into the budget constraint of household if there is no sudden stop we have:

$$
\begin{aligned}
(2.20)\qquad & P_t c_t + S_t(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + S_t(1+r)b_{t-1} + S_t(d^{fh}_t + d^{fc}_t) + \\
& +(d^{kh}_t + d^{kc}_t) + S_t\, FRB^h_t = P_t y_t + S_t\, l^f_t + l^k_t + S_t\, b_t + S_t(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) + \\
& +(1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) + S_t(1+r)FRB^h_{t-1} + S_t(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) + \\
& +S_t(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + S_t\, FB_t + RB^k_{t-1} + S_t\, RB^f_{t-1} + \\
& +S_t(1+r)FRB^b_{t-1} - S_t(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) - (1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) - \\
& -S_t\, l^f_t - l^k_t - S_t(1+r)FB_{t-1} - RB^k_t - S_t\, RB^f_t - S_t\, FRB^b_t + \\
& -S_t\, R_t - S_t(1+r)FG_{t-1} - S_t\, N_{t-1} - S_t\, PN_{t-1} - RB^k_{t-1} - S_t\, RB^f_{t-1} + \\
& +S_t(1+r)R_{t-1} + S_t\, FG_t + S_t\, PN_t + RB^k_t + S_t\, RB^f_t
\end{aligned}
$$

where

$$
\begin{aligned}
(2.21)\qquad RB^k_t &= \omega^k[d^{kh}_t + d^{kc}_t + 0.5\, S_t(d^{fh}_t + d^{fc}_t + FB_t)] \\
(2.22)\qquad S_t\, RB^f_t &= 0.5\,\omega^f S_t(d^{fh}_t + d^{fc}_t + FB_t) \\
(2.23)\qquad R_t &= PN_t
\end{aligned}
$$

Canceling out most of the terms and substituting for reserves equation (2.23) we get consolidated budget constraint given in (2.15).

If there is sudden stop the augmented households budget constraint reads as:

$$
\begin{aligned}
(2.24)\ & P_t c_t + (S_t+\Delta S)(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + (S_t+\Delta S)(1+r)b_{t-1} + \\
& +(S_t+\Delta S)(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) = \\
& (1-\gamma)P_t y_t + (S_t+\Delta S)l^f_t + l^k_t + (S_t+\Delta S)(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) + \\
& +(1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) + (S_t+\Delta S)\phi(d^{fc}_t + \frac{\eta}{S_t+\Delta S}d^{kc}_t) + \phi(1-\eta)(d^{kh}_t + d^{kc}_t) \\
& +(S_t+\Delta S)(1+r)FRB^h_{t-1} + \\
& +(S_t+\Delta S)(d^{fh}_t + d^{fc}_t) + (d^{kh}_t + d^{kc}_t) + (S_t+\Delta S)(1+r)l^f_{t-1} + (1+r)l^k_{t-1} + \\
& +RB^k_{t-1} + (S_t+\Delta S)RB^f_{t-1} + (S_t+\Delta S)(1+r)FRB^b_{t-1} - \\
& -(S_t+\Delta S)(1+r)(d^{fh}_{t-1} + d^{fc}_{t-1}) - (S_t+\Delta S)\phi[(d^{fh}_t + d^{fc}_t) + \frac{\eta}{S_t+\Delta S}(d^{kh}_t + d^{kc}_t)] - \\
& -(1+r)(d^{kh}_{t-1} + d^{kc}_{t-1}) - \phi(1-\eta)(d^{kh}_t + d^{kc}_t) - (S_t+\Delta S)\, l^f_t - l^k_t - \\
& -(S_t+\Delta S)(1+r)FB_{t-1} - RB^k_t - (S_t+\Delta S)RB^f_t + \\
& -(S_t+\Delta S)\, R_t - (S_t+\Delta S)(1+r)FG_{t-1} - (S_t+\Delta S)N_{t-1} - RB^k_{t-1} - \\
& -(S_t+\Delta S)RB^f_{t-1} + (S_t+\Delta S)(1+r)R_{t-1} + (S_t+\Delta S)PN_t + RB^k_t + \\
& +(S_t+\Delta S)RB^f_t
\end{aligned}
$$

where

$$
\begin{aligned}
(2.25)\qquad RB^k_t &= (\omega^k - \alpha^k)[d^{kh}_t + d^{kc}_t + 0.5\, S_t(d^{fh}_t + d^{fc}_t)] \\
(2.26)\qquad (S_t+\Delta S)\, RB^f_t &= 0.5\,(\omega^f - \alpha^f)(S_t+\Delta S)(d^{fh}_t + d^{fc}_t) \\
(2.27)\qquad R_t &= PN_t
\end{aligned}
$$

2.6.2. Optimal reserves

Optimal reserves formula is derived in the following way. First order condition (2.17) can be rewritten as

$$
(2.28)\qquad \frac{u'(c^d_{t+1})}{u'(c^b_{t+1})} = \left(\frac{c^b_{t+1}}{c^d_{t+1}}\right)^{\sigma} = \frac{S_{t+1}(1-\pi)(\delta+\pi)}{(S_{t+1}+\Delta S)\pi(1-\delta-\pi)} = \frac{(1-\pi)(\delta+\pi)}{\pi(1-\delta-\pi)(1+\frac{\Delta S}{S_{t+1}})} = z_{t+1}
$$

where (from consolidated budget constraints (2.15) and (2.16))

$$
\begin{aligned}
(2.29) \qquad P_{t+1}c_{t+1}^{b} &= P_{t+1}y_{t+1} + S_{t+1}\left[(b_{t+1} + FB_{t+1} + FG_{t+1}) - \right. \\
&\left. -(1+r)(b_t + FB_t + FG_t)\right] - S_{t+1}\left[(FRB_{t+1}^{h} + FRB_{t+1}^{b}) - \right. \\
&\left. -(1+r)(FRB_t^{h} + FRB_t^{b})\right] - S_{t+1}(\delta + \pi)R_t \\
(2.30) \qquad P_{t+1}c_{t+1}^{d} &= (1-\gamma)P_{t+1}y_{t+1} - (S_{t+1} + \Delta S)(1+r)(b_t + FB_t + FG_t) + \\
&+(S_{t+1} + \Delta S)(1+r)(FRB_t^{h} + FRB_t^{b}) - \\
&-(S_{t+1} + \Delta S)\phi(d_{t+1}^{fh} + \frac{\eta}{S_{t+1} + \Delta S}d_{t+1}^{kh}) + \\
&+(S_{t+1} + \Delta S)(1 - \delta - \pi)R_t
\end{aligned}
$$

After substituting (2.29) and (2.30) into (2.17) and after some manipulation we get (2.18) with optimal level of foreign reserves given in equation (2.18).

2.6.3. National accounts identity and consolidated budget constraint

Here we show how consolidated budget constraint corresponds to national accounts identity. If there is sudden stop consolidated budget constraint reads as:

$$
\begin{aligned}
&\underbrace{S_t[(b_t - b_{t-1}) + (FB_t - FB_{t-1}) + (FG_t - FG_{t-1})] -}_{FA_t} \\
&- \underbrace{[(FRB_t^{h} - FRB_{t-1}^{h}) + (FRB_t^{b} - FRB_{t-1}^{b})] + (PN_t - PN_{t-1} - N_{t-1})}_{FA_t} + \underbrace{S_t(R_t - R_{t-1})}_{\Delta R_t} \\
= \; &\underbrace{P_t(y_t - c_t^{b})}_{Y_t - A_t} + \underbrace{S_t r[(b_{t-1} + FG_{t-1} + FB_{t-1}) - (FRB_{t-1}^{h} + FRB_{t-1}^{b} + R_{t-1})]}_{IA_t}
\end{aligned}
$$

The first term on the left hand side corresponds to financial account since it involves foreign borrowing, the second term represents foreign reserves change as an element of financial account. On the right-hand side we have the difference between domestic output and domestic absorption (consumption in our model) and the elements of current account that are related to interest rate payments and are therefore stated in the income account.

If there is sudden stop we have:

$$
\begin{aligned}
& \underbrace{S_t\{[(-\,b_{t-1}) + (-\,FB_{t-1}) + (-FG_{t-1})] - [(-FRB^h_{t-1}) + (-FRB^b_{t-1})]\} + (PN_t - N_{t-1})}_{FA_t} + \\
& + \underbrace{S_t(R_t - R_{t-1})}_{\Delta R_t} \\
= \;& \underbrace{P_t(y_t - c^d_t)}_{Y_t - A_t} + \underbrace{S_t r[(b_{t-1} + FG_{t-1} + FB_{t-1}) - (FRB^h_{t-1} + FRB^b_{t-1} + R_{t-1})]}_{IA_t}
\end{aligned}
$$

2.6.4. Data description and data sources

The Table 2.9 below matches model variables with their data counterpart (the source of data is given in parenthesis, where most of the data come from CNB bulletin's table).

Table 2.9. Model variables and their data counterpart

Symbol	Model variable	Data counterpart
y_t	Exogenous endowment	Gross domestic product (constant prices, DZS)
S_t	Nominal kuna/euro exchange rate	Nominal kuna/euro exchange rate (H10)
P_t	Price index	GDP deflator (DZS)
d_t^{fh}	Household euro deposits	Household euro deposits (D8)
d_t^{kh}	Household kuna deposits	Household kuna deposits (D6 and D7)
b_t	Foreign borrowing by non-banking sector	Short term foreign debt by firms (including FDI debt, H12) + principal payment by firms of long-term debt (H14)
FB_t	Foreign borrowing by banks	Short term foreign debt by banks (excluding deposits, H12) + nonresident deposits (D10) + principal payment by banks of long-term debt (H14) (-parent banks' euro deposits- parent banks' short-term loans)
FG_t	Foreign borrowing by the government	Short term foreign debt by the government and CNB (H12) + principal payment by the government and CNB of long-term debt (H14)
FRB_t^h	Foreign liquid assets of non-banking sector	Cash and deposits in foreign banks of households and firms (H19)
FRB_t^b	Foreign liquid assets of banks	(Mandatory) banks' foreign currency reserves (H7)
RB_t^k	Kuna reserve requirement	Kuna reserve requirement (C1)
RB_t^f	Euro reserve requirement	Euro reserve requirement (C1)
R_t	International reserves	Gross international reserves of CNB (H7)

CHAPTER 3

The Impact of the USD/EUR Exchange Rate on Inflation in CEE Countries

3.1. Introduction

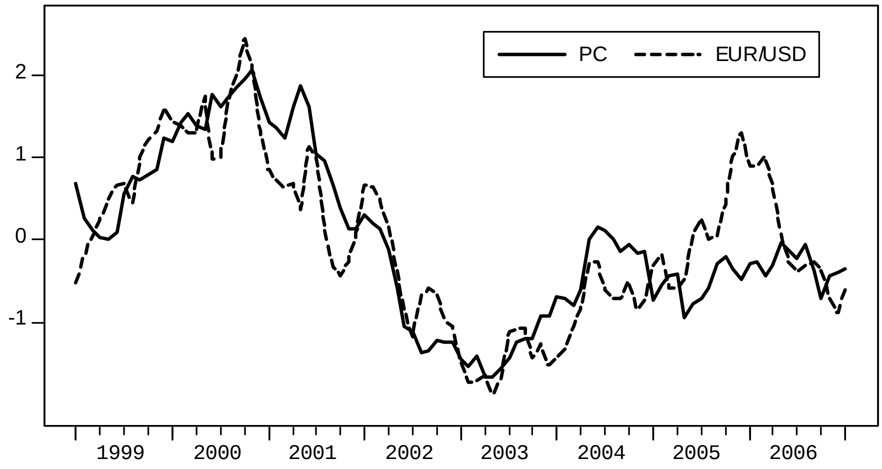
During the last few years there has been growing empirical support for the idea that external factors might have a leading role in explaining business cycles in small open economies[1]. In particular, import prices and exchange rates have been in the focus of empirical studies trying to determine the main sources of inflation in small open economies. This paper suggests that the USD/EUR exchange rate might be considered an additional important determinant of inflation in the Central and East European countries (CEEC), not explicitly analyzed in previous studies.

Our motivation comes from the empirical evidence shown in Figure 3.1. We see a strong correlation between the first principal component of the CEEC's annual consumer price inflation rates and the annual change in the USD/EUR exchange rate. Despite the existence of quite different monetary and exchange rate regimes in the CEEC, it seems that there are some similarities in their inflation paths that might be accounted for by USD/EUR exchange rate fluctuations.

Most previous studies of pass-through in the CEEC focus on effective exchange rates and assume that the individual country can influence effective exchange rates through monetary policy (for a survey of empirical studies of the pass-through in the transition countries see Égert and MacDonald (2006)). Contrary to that, we distinguish between the exchange rate of the domestic currency against the euro and the USD/EUR exchange rate and analyze which

[1]See for example Canova (2003), Cushman and Zha (1997), Jones and Kutan (2004), Mackowiak (2006), Mackowiak (2007). Most of the empirical research on this topic was a reaction to the *old* Keynesian literature that was (unsuccesfully) explaining inflation solely as a domestic phenomenon in a closed economy. The above mentioned empirical research supports a new Keynesian theory of a small open economy that, in addition to domestic factors, takes into account external factors in explaining prices. See Obstfeld and Rogoff (2000) for a basic model of a small open economy where the overall price index depends on domestic prices, import prices and the exchange rate.

Figure 3.1. The EUR/USD exchange rate and the principal component of 9 CEEC (Romania and Slovenia not included) annual inflation rates. Both series are standardised.



portion of the variation in inflation in the CEEC can be attributed to the USD/EUR exchange rate, as an external shock. In addition, we study to what extent USD/EUR exchange rate shocks influence inflation. Finally, we attribute the different impact of the USD/EUR exchange rate on inflation among the CEEC to the different exchange rate regimes.

To measure the impact of the USD/EUR exchange rate on domestic producers and consumer inflation across countries we employ the empirical model of pricing along a distribution chain, as in McCarthy (2008). The advantage of this model is that it has a Vector Autoregression (VAR) representation that allows us to trace the impact of exchange rate fluctuations on inflation at each stage along the distribution chain (importers, producers, consumers). While McCarthy (2008) studies a large open economy that can influence external factors, we adopt a small country assumption where domestic variables cannot influence external variables. In other words, we represent the model of pricing along the distribution chain in the CEEC with a VAR model with block exogeneity restrictions (for external variables) in the spirit of Cushman and Zha (1997) [2]. The imposition of block exogeneity seems a reasonable way to identify foreign shocks from the perspective of the small open economy.

[2] Our approach is similar to Mackowiak (2006) who measured the impact of external shocks on some of the CEEC. He found that most of the volatility of main macro variables comes from abroad.

Our empirical exercise shows that the USD/EUR exchange rate accounts for the largest share of inflation volatility in the CEEC with stable exchange rates of the domestic currency against the euro. Furthermore, the extent of the USD/EUR exchange rate influence on inflation in the CEEC is the largest in the economies with stable exchange rate regimes. This result might be important in the context of the price stability requirement of the Maastricht Criteria: in addition to the internal challenge of keeping low inflation and dealing with the difficulties of the price convergence process, the applicant countries could face problems beyond their influence. Given that most of the CEEC peg their currencies to the euro[3], either because of the conditions of the Exchange Rate Mechanism II (ERM-II) or because of their domestic issues (eurozation in particular), and taking into account the high volatility of the USD/EUR exchange rate, our findings suggest that the CEEC under a fixed or heavily managed exchange rate might face substantial problems in achieving a high degree of price stability.

The decision to include the USD/EUR exchange rate as a separate external factor is motivated by the monetary and exchange rate regimes in the CEEC. Those countries are primarily concerned with fluctuations of their exchange rate against the euro: while all countries (will) have to participate in the ERM-II, some countries use the exchange rate against the euro (previously the Deutsche Mark) to reduce imported inflation and anchor inflation expectations. Since the USD/EUR exchange rate is determined on the global financial market, an individual country is unable to influence it. Nor can it influence world prices. Hence, it cannot simultaneously *manage* both its bilateral exchange rate against the euro and against the dollar. Also for this reason, we refrain from using the effective exchange rate which combines the managed exchange rate against the euro and the exchange rate against the dollar[4]. Therefore, for countries with heavily managed exchange rates to the euro, the USD/EUR exchange rate in fact represents an external shock. By focusing on the stability of their domestic currencies against the euro, the CEEC effectively reduce the exchange rate pass-through of goods priced in euros to domestic inflation. However, since a

[3]Exchange Rate Mechanism II (ERM-II) imposes +/- 15% fluctuations while some countries can adopt smaller bands. Crawling pegs and pegs to currencies other than the euro are inconsistent with the ERM-II.
[4]Given that the CEEC primarily control their exchange rate against the euro, most of the variation of their effective exchange rate comes from the impact of more volatile nominal exchange rate against the dollar rather than more stable price of the euro.

number of commodities are priced in dollars, there is still a pass-through from the dollar, which is amplified by the USD/EUR exchange rate fluctuations.

The paper is organized as follows. Section 3.2 illustrates the model of pricing along the distribution chain applied to the CEEC. Section 3.3 describes the VAR methodology with block exogenous restrictions. Section 3.4 describes the data used and provides a basic description of monetary and exchange rate regimes in the CEEC. Results are presented in Section 3.5, along with a discussion of the impact of the USD/EUR on disaggregated data to confirm our understanding of the transmission channel. The special case of the regime change in Lithuania where the currency peg was changed from the dollar to the euro, is also presented. Section 3.6 concludes.

3.2. The model of pricing along the distribution chain

Our model of pricing includes two stages due to the unavailability of import price data for many CEEC[5]. The stages correspond to producer price inflation and consumer price inflation, each with several components. In each stage, inflation is a function of the previous period conditional expectation of inflation and contemporaneous shocks: a supply shock, a demand shock, an exchange rate shock (either a USD/EUR exchange rate shock in the case of heavily managed exchange rates of the domestic currency against the euro or both a USD/EUR exchange rate shock and a shock to exchange rate of the domestic currency against the euro in case of looser exchange rate regime[6]), a shock to inflation at the previous stage of the distribution chain as well as its own shock.

The supply shock is identified from the world primary commodity prices expressed in dollars[7]. The USD/EUR exchange rate shock is identified from the behavior of the USD/EUR

[5]McCarthy's (2008) model of pricing along distribution chain includes all three stages.

[6]The value of a country's domestic currency can be expressed bilaterally against any other currency. Thus, we could include in the VAR both exchange rate of the domestic currency (DC) against the dollar and against the euro. Both bilateral rates would in this case be a part of the VAR's domestic block. However, although a country can influence any bilateral rate, the ratio of such bilateral rates is exogenously given by the USD/EUR exchange rate which is set on the international financial market ($\frac{DC}{EUR}/\frac{DC}{USD}=\frac{USD}{EUR}$). Since all CEEC are pegged to the euro either directly or throught the ERM-II, we focus on the bilateral exchage rate against the euro, and take the USD/EUR exchange rate as given.

[7]Despite the growing international role of the euro, prices of most tradables, especially commodities, are formed in dollars. An actual transaction may take place in any currency even though the price is set in dollars, which limits the potential use of the information about the invoicing currency for determining the role of foreign currencies in country's trade. For that reason, and in the absence information about individual

exchange rate after taking the supply shock into account. These two shocks make the exogenous block that is unaffected by the domestic business cycle[8]. In contrast to previous studies that combine the two external shocks to save degrees of freedom (see for example Mackowiak (2006)) our intention is to analyze the impact of each external factor separately to see which of the two has the dominant role. The demand shock is identified from the dynamics of the output gap after taking into account the supply shock and the exchange rate shock. The shock to the exchange rate of the domestic currency against the euro (in countries with *looser* exchange rate regime) is identified from the behavior of the exchange rate of the domestic currency against the euro after taking the supply shock into account, the USD/EUR exchange rate shock and the demand shock. The last two shocks (the demand shock and the domestic currency shock), together with the dynamics of producer and the consumer prices, comprise the domestic block, that can be affected by the exogenous block.

The structure of the model suggests that the it can be cast into a recursive VAR framework estimation as described in the next section

3.3. Methodology - Vector Autoregression Analysis with block exogeneity restrictions

In this section we describe the VAR framework that is used to identify the shocks in the model and their impact on prices.

Let y_1 be an n_1 dimensional vector of external variables. Let y_2 be an n_2 dimensional vector of domestic (small open economy) variables. We combine both vectors in $y = [y_{1,}y_2]'$. Now consider a dynamic system of equations:

$$\sum_{s=0}^{p} A_s y_{t-s} = \varepsilon_t, \tag{3.1}$$

countries' import prices, we use the world commodity prices (IMF) expressed in dollars in order to model the import price inflation.

[8]Due to shortness of data and unavailability of some of the series we were forced to adopt more parsimonious approach by reducing the number of external variables. By focusing on the (indirect) exchange rate pass-through as a model for describing inflation dynamics, we dismiss a number of other potential external shocks which could also affect an economy (for example foreign interest rates or foreing demand shock). However, it seems that a number of shocks are mutually correlated (for example GDP gap in Germany, interest rate in Euro zone and the USD/EUR exchange rate) and the model can be reduced to save degrees of freedom from already short series for countries under the investigation.

where A_0 is (regular) contemporaneous matrix of coefficients, $\{\varepsilon_t\}_{t=0}^{\infty}$ are i.i.d. random vectors with multivariate normal distribution $MVN(0, I)$, and A_j are block lower triangular matrices of dimension $(n_1 + n_2) \times (n_1 + n_2)$, that have the following form:

$$A_j = \begin{bmatrix} A_{11}^j & 0 \\ A_{21}^j & A_{22}^j \end{bmatrix}, \ j = 0, \ldots, p.$$

Submatrices A_{lk}^j are of $n_l \times n_k$ dimension for $l, k = 1, 2$ and $j = 1, \ldots, p$.

The form of A_j assumes block exogeneity restrictions which represent the underlaying idea that foreign shocks can affect the small open economy, but not the other way around.

After multiplication by A_0^{-1}, equation (3.1) yields a corresponding reduced form VAR model:

$$y_t = \sum_{s=1}^{p} B_s y_{t-s} + \eta_{t,} \tag{3.2}$$

where $A_0^{-1}\varepsilon_t = \eta_t \sim MVN(0, \Sigma_\eta)$ and $B_j = A_0^{-1}A_j$ for $j = 0, \ldots, p$. It can be shown (see Lütkepohl (2005)) that matrices of coefficients B_s inherit[9] block exogeneity form so that:

$$B_j = \begin{bmatrix} B_{11}^j & 0 \\ B_{21}^j & B_{22}^j \end{bmatrix}, \ j = 1, \ldots, p.$$

Note that this is equivalent to the statement that the domestic block does not Granger cause the foreign block, i.e. that domestic block does not help to forecast (in the MSE sense) the variables in the foreign block. This is a standard and testable assumption when modelling the small open economy's reaction to the foreign shocks.

[9]Lower triangularity is also inherited in the $MA(\infty)$ representation which implies no response of the foreign variables to the domestic shocks. See Lütkepohl (2005) for details.

Given the autoregressive representations (3.1) and (3.2), we can derive the corresponding moving average representations:

$$
\begin{aligned}
y_t &= (A_0 - A_1 L + ...A_p L^p)^{-1}\varepsilon_t = \\
&= (D_0 + D_1 L + D_2 L^2 + ...)\varepsilon_t = \\
&= D(L)\varepsilon_t
\end{aligned}
\tag{3.3}
$$

and

$$
\begin{aligned}
y_t &= (I - B_1 L - ...B_p L^p)^{-1}\eta_t = \\
&= (I + C_1 L + C_2 L^2 + ...)\eta_t = \\
&= C(L)\eta_t
\end{aligned}
\tag{3.4}
$$

Given the reduced form residuals η_t with the corresponding estimate Σ_η (having $\frac{n(n+1)}{2}$ unique elements) and coefficient matrices B_i and C_i, one can recover impulse responses $D_{i,}$ subject to normalization condition $\Sigma_\eta = A_0^{-1}A_0^{'-1}$. In order to identify A_0, we need to impose at least $\frac{n(n-1)}{2}$ additional restrictions. For that purpose, let us define $\varepsilon_t = A_0\eta_{t,}$ where A_0 is a lower triangular Cholesky factor[10] of noise covariance matrix Σ_η. It follows that $E[\varepsilon_t\varepsilon_t^{'}] = E[A_0\eta_t\eta_t^{'}A_0^{'}] = A_0E[\eta_t\eta_t^{'}]A_0^{'} = A_0\Sigma_\eta A_0^{'} = I$ and orthogonality holds. For alternative types of identification see Cushman and Zha (1997) and Mackowiak (2006).

When pursuing this type of identification, the ordering in y becomes crucial, and accordingly robustness needs to be investigated. The reduced form VAR model was estimated applying the feasible least squares estimator. Details concerning the estimation and structural analysis of VAR processes with parameter constraints and the type of (3.2) models can be found in Lütkepohl (2005).

[10] A_0 is a lower triangular matrix such that $A_0^{-1}(A_0^{-1})^{'} = \Sigma\eta$. Such decomposition always exists for a symmetric and positive-definite matrix. It can be shown that every covariance matrix is symmetric and positive-definite.

3.4. Data

The data were taken from the IMF's International Financial Statistics (IFS) database. For the external block, which is the same for all countries, we use the IMF's Primary Commodity Price Index (WCP_t) as a measure of world prices and the USD/EUR exchange rate (USD/EUR_t)[11]. The domestic block consists of the output gap, defined as the deviation of GDP (in constant prices) from its trend (Gap_t)[12], the exchange rate of domestic currency against the euro (DC/EUR_t), the producer price index (PPI_t), and the consumer price index (CPI_t) for each country. DC/EUR_t was calculated as a product of the domestic currency against the U.S. dollar rate and the USD/EUR rate. All the price and exchange rate data are in quarterly averages (prices, exchange rate) from 1998 (first quarter) to 2006 (third quarter).

Table 3.1. Monetary and exchange rate regimes and inflation in CEECs

	Monetary regime	Changes in monetary regime since 1998
Bulgaria	Currency board	
Croatia	Managed floating	
Estonia	Currency board	
Latvia	Peg to euro ± 1%	2004: Re-pegged its currency from SDR to EUR
Lithuania	Currency board	2002: Re-pegged its currency from USD to EUR
Slovenia	Euro	2007: Adopted euro; previously: managed floating
Czech Republic	Inflation targeting	
Hungary	Inflation targeting	
Poland	Inflation targeting	2001 changed from managed to independent floating
Romania	Inflation targeting	2001 changed from managed float to crawling bands
Slovak Republic	Inflation targeting	Previously: managed floating

The most serious problem with the CEEC data is structural breaks. The first kind of structural breaks pertains to the undergoing transition process that could affect parameter stability. In our analysis, we bracket this type of structural break as we analyze the late phase of the transition. However, the second kind of structural break - changes in monetary

[11]Prior to the introduction of the euro, we use the USD/DEM exchange rate and transform it into the USD/EUR using the DEM/EUR conversion rate, sinced the Deutsche Mark was the most important currency in the CEEC.
[12]Real GDP data are not available for Bulgaria and Romania. We use industrial production (deflated using the CPI) instead.

and exchange rate regime - presents more serious problems since it might affect the price formation process that we analyze. As shown in Table 3.1, an exchange rate regime change occurred in more than half of the CEEC in our sample.

Although we do not model the determinants of the regime changes, we group countries according to different monetary and exchange rate regimes in two ways: by type of regime currently in place and by the severity of the regime change those countries undertook during the period under the investigation.

When looking at existing monetary regime, we distinguish between exchange rate targeters and inflation targeters. Exchange rate targeters include countries with fixed exchange rate against the euro or ones with small oscillations against the euro. The extreme example is Slovenia which adopted the euro at the beginning of 2007. There are two currency boards (Bulgaria and Estonia), a fixer (Lithuania), one country with a tight (1%) exchange rate band (Latvia), and a managed floater (Croatia). Those countries seem to be perfect candidates for our analysis since the USD/EUR exchange rate corresponds to their exchange rate against the dollar. The other group consists of the inflation targeters: the Czech Republic, Hungary, Poland, Romania and Slovak Republic. However, there are significant differences among them in terms of exchange rate stability against the euro (see table 3.2).

Table 3.2. Consumer price index/Exchange rates correlations and coefficients of variation

	Bg	Ee	Cz	Hr	Hu	Lv	Lt	Pl	Ro	Sk	Si
Correlations											
CPI-(DC/EUR)	-0.10	0.03	-0.26	-0.13	-0.04	-0.01	-0.08	-0.17	0.66	0.00	0.62
CPI-(EUR/USD)	0.38	0.40	0.07	0.58	0.29	0.11	0.29	0.52	0.41	0.03	0.25
Coef. of variation											
DC/EUR	0.00	0.00	0.08	0.02	0.03	0.09	0.10	0.07	0.34	0.06	0.09
DC/USD	0.14	0.14	0.18	0.14	0.14	0.05	0.17	0.11	0.13	0.18	0.13

Note: DC = domestic currency. Bulgaria (Bg), Croatia (Hr), Czech Republic (Cz), Estonia (Ee), Hungary (Hu), Latvia (Lv), Lithuania (Lt), Poland (Pl), Romania (Ro), Slovak Republic (Sk), Slovenia (Si).

Unfortunately, some of the countries recently undertook significant regime change that changed the price formation process, so we cannot analyze them using the VAR. On one extreme are Slovenia and Romania, which in their attempt to achieve real exchange rate stability have gone through a gradual disinflation and depreciation before achieving price stability. A serious policy change from the perspective of our analysis occurred in two Baltic countries that changed the peg currency. The most interesting case is Lithuania, which repegged from the dollar to the euro in February 2002. This shift should lead to a change of sign in the estimated the USD/EUR exchange rate pass-through coefficients. A similar case is Latvia, which repegged from the SDR to the euro in February 2004. Because of the estimation problems in the cases of Slovenia and Romania as a result of regime shifts, we exclude those two countries from our analysis. Furthermore, due to the short sample, we are unable to model the regime change in Latvia and Lithuania, so we also exclude them from our analysis.

The most interesting for our analysis are the countries with fixed (or managed) exchange rate to the Deutsche Mark prior to 1999 and the euro afterwards (Bulgaria, Croatia and Estonia). We compare their results with countries that moved from more managed to less managed regime - usually in the form of the inflation targeting (Czech Republic, Hungary, Poland, Slovak Republic) - before or during the period under the investigation.

Prior to the estimation, we test the block exogeneity restrictions on the constrained VAR specification in order to find out whether such constraints are supported by the actual CEEC's data. We have already mentioned that block exogeneity is equivalent to the hypothesis that the domestic block does not Granger cause the foreign block. Given Wald test's p-values from table 3.3, we conclude that a priori exogenous restrictions in the VAR specification have been well chosen.

Table 3.3. Null hypothesis: domestic block does not Granger-cause foreign block

	Bg	Hr	Cz	Ee	Hu	Pl	Sk
p-value	0.071	0.915	0.221	0.116	0.182	0.492	0.404

Note: Bulgaria (Bg), Croatia (Hr), Czech Republic (Cz), Estonia (Ee), Hungary (Hu), Poland (Pl), Slovak Republic (Sk).

3.5. The impact of the USD/EUR exchange rate on inflation in the CEEC

Due to the short data series available and the low power of unit root tests[13], we estimate the model in the first differences (as in McCarthy (2008)). This way we study only the short term effects, while possible long run relations are not identified.

When estimating the VAR, we examined several different setups. Most importantly, we tried to estimate the VAR with and without the exchange rate of the domestic currency against the euro. The reason for this is that in some cases (Bulgaria, Croatia, Estonia) the oscillations in the domestic currency against the euro were too small to have any material impact on inflation. Although the VAR model with the domestic currency produces impulse responses with the expected direction, the results are not statistically significant. To save degrees of freedom, we remove the domestic currency from the VAR model for Bulgaria, Croatia, and Estonia. The VAR lag length of two quarters is a compromise between the length of the series and the time needed for the exchange rate shock to manifest itself on prices. After checking for all the necessary diagnostics[14] we estimate (3.2) for 3 CEEC (Bulgaria,Croatia, Estonia) with the exogenous block $y_{1t} = [WP_t, USD/EUR_t]'$ and the domestic block $y_{2t} = [Gap_t, PPI_t, CPI_t]'$. For the inflation targeters (Czech Republic, Hungary, Poland and Slovak Republic), a somewhat richer specification with the domestic currency was used ($y_{2t} = [Gap_t, LC/EUR_t, PPI_t, CPI_t]'$).

Table 3.4. Portmanteau test for autocorrelation (lag=12, no autocorrelation under the null hypothesis) and stability conditions

	Bg	Hr	Cz	Ee	Hu	Pl	Sk
Portmanteau test (p-values)	0.08	0.57	0.10	0.10	0.12	0.08	0.04
Root's modulus (minimum)	1.41	1.44	1.10	1.17	1.11	1.12	1.24

Note: Bulgaria (Bg), Croatia (Hr), Czech Republic (Cz), Estonia (Ee), Hungary (Hu), Poland (Pl), Slovak Republic (Sk).

[13] For the evidence on the low power of unit root see e.g. Schwert (1989), DeJong, Nankervis, Savin and Whiteman (1992) or Leybourne and McCabe (1994).

[14] In Table 3.4 we provide results from Portmanteau test for autocorrelation. In addition we report the minimum modulus root from determinantal polynomial $det(I - A_1 z - -A_p z^p)$, A_j denoting reduced form VAR coefficient matrices. VAR process is stable if this polynomial has no roots in or on the complex unit circle (see Lütkepohl (2005)) - sufficient condition for the VAR stability is that the minimal modulus is greater than unity.

The variance decomposition of the specified VAR model presented in tables 3.5 and 3.6 shows that external shocks have a large impact on the variation of domestic variables. With a two year horizon (8 quarters ahead), shocks in world commodity prices and the USD/EUR on average account for about a half of variation of the PPI (51%) and the CPI (42%)[15]. The USD/EUR seems to cause more variation in consumer prices than the world commodity prices, while the world commodity prices seem to have the more prominent role in the determination of the producer prices.

Table 3.5. PPI's variance decomposition

	Qtr's ahead	WPC	USD/EUR	Ex. shocks	Gap	DC/EUR	PPI	CPI
Bulgaria	t+1	0.70	0.00	0.70	0.00	/	0.30	0.00
	t+8	0.65	0.10	0.75	0.06	/	0.19	0.01
Croatia	t+1	0.21	0.17	0.38	0.01	/	0.61	0.00
	t+8	0.41	0.19	0.60	0.03	/	0.35	0.01
Estonia	t+1	0.07	0.14	0.21	0.02	/	0.77	0.00
	t+8	0.17	0.26	0.43	0.02	/	0.50	0.05
Czech Republic	t+1	0.49	0.00	0.49	0.04	0.01	0.47	0.00
	t+8	0.68	0.02	0.70	0.12	0.05	0.09	0.04
Hungary	t+1	0.00	0.04	0.04	0.03	0.37	0.56	0.00
	t+8	0.08	0.27	0.35	0.18	0.18	0.26	0.04
Poland	t+1	0.36	0.00	0.36	0.01	0.27	0.35	0.00
	t+8	0.33	0.03	0.36	0.04	0.29	0.21	0.10
Slovak Republic	t+1	0.10	0.02	0.12	0.01	0.00	0.87	0.00
	t+8	0.16	0.20	0.36	0.04	0.04	0.56	0.01
Exchange rate fix.	t+1	0.33	0.10	0.43	0.01	/	0.56	0.00
	t+8	0.41	0.18	0.59	0.04	/	0.35	0.01
Inflation targeters	t+1	0.24	0.02	0.25	0.02	0.16	0.56	0.00
	t+8	0.31	0.13	0.44	0.10	0.14	0.28	0.05
Average	t+1	0.28	0.05	0.33	0.02	/	0.56	0.00
	t+8	0.35	0.15	0.51	0.07	/	0.31	0.04

The variance decomposition indicates that external shocks account for a large share of price volatility (both PPI and CPI) in all countries regardless of the policy regime. This is, however, due to the movement of the world commodities prices. The impact of the USD/EUR in explaining inflation variance is greater in countries with stable exchange rate against the euro (Bulgaria, Croatia and Estonia) where it explains 28% of the variance in

[15]We have also estimated a similar VAR (as in Mackowiak (2006)) with the world prices denominated in euro and therefore the USD/EUR rate has been excluded from this specification. Results were similar as in tables 3.5 and 3.6.

CPI and 18% of the variance in PPI. Countries that retain a higher degree of independent monetary policy seem to be able to use it to protect themselves from such shocks, as the USD/EUR fluctuations explains a smaller share of price variance (8% of CPI and 13% of PPI).

Table 3.6. CPI's variance decomposition

	Qtr's ahead	Wpc	USD/EUR	Ex. shocks	Gap	DC/EUR	PPI	CPI
Bulgaria	t+1	0.14	0.16	0.30	0.06	/	0.07	0.57
	t+8	0.17	0.23	0.40	0.06	/	0.09	0.45
Croatia	t+1	0.24	0.42	0.66	0	/	0.01	0.32
	t+8	0.32	0.33	0.65	0.06	/	0.13	0.15
Estonia	t+1	0.33	0.23	0.56	0.00	/	0.10	0.33
	t+8	0.23	0.29	0.52	0.06	/	0.24	0.19
Czech Republic	t+1	0.03	0.06	0.09	0.07	0.03	0.02	0.80
	t+8	0.56	0.06	0.62	0.15	0.03	0.02	0.18
Hungary	t+1	0.13	0.00	0.13	0.25	0.08	0.01	0.53
	t+8	0.08	0.19	0.27	0.24	0.21	0.11	0.18
Poland	t+1	0.32	0.12	0.44	0.00	0.08	0.03	0.45
	t+8	0.27	0.04	0.31	0.01	0.21	0.07	0.39
Slovak Republic	t+1	0.00	0.06	0.06	0.01	0.00	0.69	0.23
	t+8	0.14	0.04	0.18	0.04	0.18	0.45	0.16
Exchange rate fix.	t+1	0.24	0.27	0.51	0.02	/	0.06	0.41
	t+8	0.24	0.28	0.52	0.06	/	0.15	0.26
Inflation targeters	t+1	0.12	0.06	0.18	0.08	0.05	0.19	0.50
	t+8	0.26	0.08	0.35	0.11	0.16	0.16	0.23
Average	t+1	0.17	0.15	0.32	0.06	/	0.13	0.46
	t+8	0.25	0.17	0.42	0.09	/	0.16	0.24

The size of the impact of different shocks is measured using the impulse responses for each country (Table 3.7). The impulse responses show that the shock in the world commodity prices affects domestic variables through various channels. Producer costs (PPI), and to some extent also consumer prices, are immediately affected. With a time lag, the producer price shock is further transmitted to consumer prices in the form of higher costs. A similar channel also works for the USD/EUR exchange rate shock: appreciation of the euro against the dollar instantly reduces producer costs and to a lesser extent consumer prices, which suggests that prices of goods that represent a significant share of the consumer basket react strongly to movements in the world market. This is also confirmed by the disaggregated data (see the next section). Here an important channel goes from the producer costs to the prices of consumer goods, which is in line with theory and the logic that the USD/EUR exchange rate to a large extent works as an important cost factor. Since we use quarterly frequency, it is possible that there is an immediate effect of the PPI to the CPI.

Directions of the impulses are as expected for most countries. Only one (Slovakia) shows a *wrong* sign of the impact of the USD/EUR shock on the CPI. In all other countries, euro appreciation against the dollar leads to drop in prices. The size varies: 2 years after, the shock ranges from -0.08 for Poland to -0.3 for Bulgaria, with average of -0.14. Again, larger effects are found in countries with stable exchange rate against the euro (-0.22 vs. -0.09). This result is partially supported by the impact of the domestic currency shock on inflation. Again, for all countries it has expected sign and ranges from 0.10 for the Czech Republic to 0.56 for Hungary.

Table 3.7. CPI's response to one unit residual shock

Impulse		Bg	Hr	Ee	Cz	Hu	Pl	Sk	Fix.	Target.	Av.
WPC	t+1	0.05 (*)	0.01	0.06 (*)	0.04 (*)	0.03 (*)	0.07 (*)	0.06	0.04	0.05	0.05
	t+4	0.10 (*)	0.07 (**)	0.07 (*)	0.14 (**)	-0.01	0.15 (*)	-0.01	0.08	0.07	0.07
	t+8	0.15 (*)	0.08 (**)	0.11 (*)	0.30 (**)	0.02	0.20 (*)	-0.01	0.11	0.13	0.12
USD/EUR	t+1	-0.16 (**)	-0.08 (**)	-0.12 (**)	-0.05 (*)	0.02	-0.05 (*)	0.06	-0.12	-0.01	-0.05
	t+4	-0.30 (**)	-0.13 (**)	-0.22 (**)	-0.07	-0.05	-0.07	0.08	-0.22	-0.03	-0.11
	t+8	-0.32 (**)	-0.13 (**)	-0.20 (**)	-0.14	-0.18	-0.08	0.06	-0.22	-0.09	-0.14
Gap	t+1	-0.03	0.01	0.00	-0.55	0.57 (*)	0.05	0.13	-0.01	0.05	0.03
	t+4	0.00	0.19 (**)	0.33 (*)	0.10	0.97 (*)	0.16	0.89 (*)	0.17	0.53	0.38
	t+8	-0.01	0.20 (**)	0.22 (*)	2.22 (**)	-0.34	0.16	1.55 (*)	0.14	0.90	0.57
DC/EUR	t+1	/	/	/	-0.01	0.19 (*)	0.10 (*)	0.16	/	0.11	/
	t+4	/	/	/	0.10	0.61 (**)	0.24 (*)	0.47 (*)	/	0.36	/
	t+8	/	/	/	0.10	0.56 (**)	0.35 (*)	0.49 (*)	/	0.38	/
PPI	t+1	0.33 (**)	0.00	0.50 (**)	0.16	0.21	0.34 (*)	0.71 (**)	0.28	0.36	0.32
	t+4	0.44 (**)	0.09 (*)	1.55 (**)	0.43 (*)	0.75 (*)	0.62	1.16 (**)	0.69	0.74	0.72
	t+8	0.43 (**)	0.11 (*)	1.39 (**)	0.43 (*)	0.23	0.83	1.03 (*)	0.64	0.63	0.64
CPI	t+1	0.52 (**)	0.53 (**)	0.56 (**)	1.09 (**)	1.06 (**)	0.95 (**)	0.59 (**)	0.54	0.92	0.76
	t+4	0.64 (**)	0.65 (**)	0.32 (**)	1.32 (**)	1.01 (**)	2.11 (**)	0.86 (**)	0.54	1.33	0.99
	t+8	0.58 (**)	0.65 (**)	0.06	1.41 (**)	0.49 (*)	3.17 (**)	0.74 (*)	0.43	1.45	1.01

Note: (*) - significance at 68% level and (**) - significance at 95% level.
Calculation based on 1500 Efron-type bootstrap replications.
Bulgaria (Bg), Croatia (Hr), Czech Republic (Cz), Estonia (Ee), Hungary (Hu), Poland (Pl),
Slovak Republic (Sk). Fix. - Fixers, Target. - Targeters, Av - Averages.

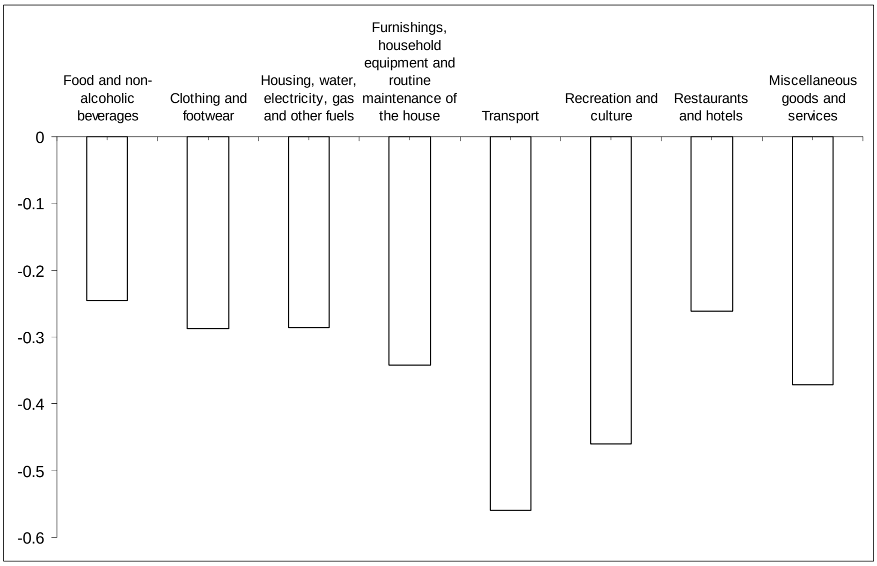
The result that countries with stable exchange rates against the euro are most susceptible to USD/EUR fluctuations is expected, since they are unable to compensate for this change in import cost through the domestic exchange rate.

3.5.1. Evidence from the disaggregated price data

Price movements of the individual items (categories) in the consumer basket can increase our understanding of how the USD/EUR influences domestic inflation. For that purpose we calculate simple correlations between the annual inflation of individual components in the consumer basket and the annual rate of change of USD/EUR exchange rate. We expect that there is a (strong) negative correlation between the USD/EUR rate and tradable products whose prices are expressed in dollars (and whose prices became cheaper when the euro appreciates against the dollar).

We use Eurostat data collected for the HICP, aggregated into categories. Thus it is sometimes difficult to distinguish between imported and the domestically produced goods and services that make up an individual consumption category (for example Recreation and culture). For that reason, we report data only the main categories.

Figure 3.2. Correlations beetwen CPI items (averaged across CEEC) and USD/EUR exchange rate.

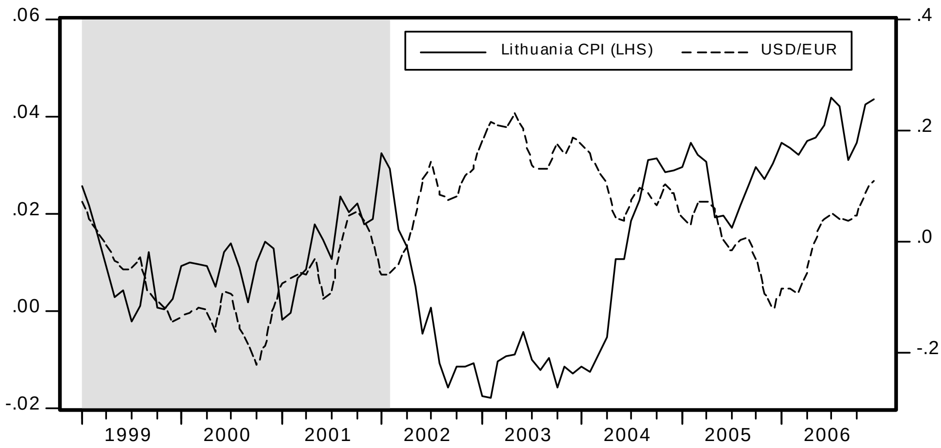


Examination of the disaggregated price data available for the CEEC shows that there is a negative correlation between movement of the USD/EUR and prices of most consumer goods and services (averaged across CEEC), as shown in Figure 3.2. The strongest negative correlation is present for goods and services, in the group *Transport* and *Recreation and culture*, which both have a large share of imported goods. Correlations are weaker in groups with larger share of domestic inputs such as *Food*, *Housing* and *Restaurants and hotels.*

3.5.2. *A natural experiment* - the case of Lithuania

Although the lack of data prevent us from conducting a proper econometric analysis, countries that changed their exchange rate policy represent a natural experiments for our hypothesis. The prime candidate is Lithuania, which changed its peg from the dollar to the euro in February 2002. As it is shown in Figure 3.3, we find the *expected* change in the direction (sign) of correlation between the USD/EUR exchange rate from positive to negative- the correlation between Lithuania's inflation and the USD/EUR exchange rate changed from 0.46 during the 1999-2002m1 (shaded area) to -0.69 from 2002m2-2006. The depreciation of the dollar against euro seems to have contributed to the deflation Lithuania faced after the policy shift. The euro appreciation in 2006, however, did not have an immediate effect on the Lithuanian CPI due to domestic factors (liberalization of administrative prices in particular), and Lithuania barely missed the inflation criterion for joining the eurozone.

Figure 3.3. Correlation between CPI inflation in Lithuania and the USD/EUR exchange rate.



3.6. Conclusion

Our empirical analysis shows that in the countries with stable exchange rates against the euro, fluctuations of the USD/EUR exchange rate might be one of the leading factors responsible for inflation variation. This might be because the stable exchange rate managed to bring down the major external sources of inflation coming from euro-denominated goods, as well as by anchoring domestic inflation expectations. Given recent large fluctuations of the USD/EUR exchange rate, with no additional monetary instruments to contain their effects, in the stable exchange rate regimes the largest impact on price volatility comes from abroad, although the actual pass-through of the USD/EUR is similar in size in all CEEC's regardless of the policy regime. Therefore, our findings suggest that in the case of a significant appreciation of the dollar in the run-up to the eurozone, in countries with stable exchange rate a possible inflationary (external) shock needs to be dealt with by economic policies other than monetary policy. The 1.5% buffer in the Maastricht criteria might not be enough to accommodate rising inflation in the case of a larger dollar appreciation.

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