UNIVERSITY OF CALIFORNIA

SANTA CRUZ

ESSAYS ON MONETARY POLICY AND INTERNATIONAL MACROECONOMICS

A dissertation submitted in partial satisfaction

of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ECONOMICS

by

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June 2012

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Abstract

Essays on Monetary Policy and International Macroeconomics

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Recent economic events pose challenging questions for macroeconomists. The rising global imbalances raise the issue whether existing international macroeconomic models can explain the patterns observed in the data on real exchange rates and current accounts. The first chapter of this dissertation addresses the question whether a standard portfolio balance model can account for the long-run dynamic behavior of the real exchange rate and net foreign debt in the United States (US). The rest of the dissertation does not test how well theoretical models fit reality but uses models in order to understand reality better. The second and third chapters are motivated by the most significant economic event in the last decade-the US 2008 financial crisis. It triggered a major collapse in US real activity, called the Great Recession, and disrupted the job matching process in the labor market. The second chapter of this dissertation addresses the challenges faced by monetary policymakers in response to an increase in labor market frictions. Two striking features of the Great Recession are the speed and synchronicity with which real activity collapsed across the world. The third chapter analyzes how shocks such as the 2008 crisis are transmitted across countries. The findings of each chapter are briefly summarized in the following paragraphs.

A strand of models of the joint behavior of the current account, net foreign debt stock and the real exchange rate postulate that this behavior is driven by saddle-path dynamics and the related portfolio balance effect. This saddle-path

dynamics is based on the assumption that domestic and foreign assets are imperfect substitutes and that the financial markets clear before the goods markets. Chapter 1 uses the Johansen test for cointegration to check the prediction of a portfolio balance model that the net foreign debt stock and real exchange rate display saddle path dynamics. Newly constructed quarterly series on the face value of the United States net foreign debt as a percentage of nominal GDP, together with data on the broad real effective exchange rate index of the United States Dollar, are analyzed. The results indicate that the US net foreign debt and real exchange rate are cointegrated and do not display saddle path dynamics. The cointegrating relationship is found to be negative and trend-stationary. These empirical results suggest that a richer framework that incorporates the dynamic behavior of relative asset supplies is more appropriate for interpretation of the joint dynamics of the US net foreign debt and real exchange rate.

In chapter 2 I build a dynamic stochastic general equilibrium model with search and matching frictions in the labor market and analyze the optimal monetary policy response to an outward shift in the Beveridge curve. The main finding is that the optimal monetary policy depends on the shock that causes the shift. A fall in the efficiency of matching does not cause an increase in the unemployment gap; the optimal response of the central bank is to stabilize inflation. An increase in the elasticity of employment matches with respect to vacancies presents the policy maker with a trade off between stabilizing inflation and unemployment. The optimal policy response to the efficient labor market shock changes when real wages are sticky but remains unchanged when home and market goods are imperfect substitutes, compared to the case when they are not. When contrasted to a Taylor rule that targets inflation and output growth, the optimal monetary policy is more aggressive in pursuit of its objectives.

Chapter 3 is a joint effort with Abigail Hughes from the Bank of England and explores how financial factors affect the international transmission mechanism. We look at how financial frictions affect the international transmission of country specific productivity shocks. We then explore how two types of shocks that affect the external finance premium are propagated across countries. We build a two country DSGE model with financial frictions to explore the size and nature of international spillovers. Our main findings are that financial frictions magnify movements in international relative prices. In addition, external finance premium shocks can generate significant and persistent international spillovers but they depend on the type of shock. A shock to the dispersion of the productivity of entrepreneurs results in a shift in the foreign aggregate supply curve. A shock to the survival probability of entrepreneurs generates a shift in the foreign aggregate demand curve.

Acknowledgment

I would like to thank my adviser Professor Carl Walsh for his invaluable feedback and guidance throughout this dissertation.

The chapter on financial factors and international spillovers was written jointly with Abigail Hughes from the Bank of England. I would like to thank her for being an excellent co-author who provided outstanding support and economic insight.

Chapter 1

The Portfolio Balance Model and Saddle Path Dynamics

1.1 Introduction and Literature Review

Much of the economic literature about joint movements in the exchange rate and the current account (CA) is based on the assumption that domestic and foreign assets are perfect substitutes. For example, Obstfeld and Rogoff (2005) see the United States (US) current account deficit as a result of an increase in the US demand for foreign goods but explain its life-span with the inability of relative prices such as the real exchange rate (RER) to adjust and clear goods markets. Since the relative prices cannot adjust due to goods markets distortions and international markets still need to clear, this exerts a downward pressure on the nominal, as well as the real, exchange rate and leads Obstfeld and Rogoff (2005) to predict that the dollar will depreciate dramatically and that the major US trading partner China will abandon its peg. However, Obstfeld and Rogoff (2005) ignore the fact that foreign demand for US financial assets has increased due to rising private demand for US equities in the second half of the 1990s and higher foreign private and central bank demands for US bonds in the 2000s. Thus, a framework which relaxes the assumption of perfect substitutability and allows asset market demand shocks to have an effect on the current account and the exchange rate could change the picture substantially.

The potential importance of imperfect substitutability of financial assets on the behavior of the current account, the exchange rate and net financial flows is not a new topic for economic research. The literature on "portfolio balance models" grew popular in the early 1980s with a set of papers, such as Masson (1981), Henderson and Rogoff (1982), and Kouri (1981). These papers relaxed the interest parity condition and instead assumed imperfect substitutability of domestic and foreign assets. While Masson (1981) and Henderson and Rogoff (1982) focus on stability issues, Kouri (1981) concentrates on the effects of changes in portfolio preferences and the implications of imperfect substitutability between assets for shocks to the current account.[1] This strand of the literature seemed largely forgotten throughout the second half of the 1980s and the 1990's but it has been recently revived by Blanchard et al. (2005) who develop a portfolio balance model and use it to interpret the behavior of the US real exchange rate and current account. The value added of their paper is that it allows for a discussion of valuation effects on the behavior of the US current account because it provides a richer description of the joint movements of the real exchange rate and gross asset positions. Blanchard et al. (2005) assume that both U.S. and foreign goods, and U.S. and foreign assets, are imperfect substitutes and argue that two forces have contributed to the steadily increasing US current account deficits since the mid–1990s: first, an increase in the U.S. demand for foreign goods, and second, an

[1]Branson and Henderson (1985) provide a detailed survey of this early literature.

increase in the foreign demand for U.S. assets. According to the dynamics of the model, the first implies a steady depreciation of the dollar and the second an initial appreciation followed by depreciation, to a level lower than before the shock. The net effect depends on the size of each shock but the second shock seems to have been bigger because the increase in the US current account has been accompanied by a real dollar appreciation until late 2001, and a real depreciation since. These predictions are driven by saddle-path dynamics which follows from the assumption that the two key variables of the model, the net foreign debt and the real exchange rate have different adjustment speeds. This, in turn, is driven by the fact that financial asset markets clear faster than goods markets.

Recent empirical research has focused on valuation effects or joint dynamic behavior of the exchange rate and gross financial flows and their importance in explaining the international adjustment process of the current account. PBM predicts that the current account and the real exchange rate affect each other through two channels - the international goods markets and the international financial markets. Recent empirical papers have tested the significance and the size of the valuation channel relative to the trade channel. Lane and Milesi-Ferretti (2002) find that the correlation between the change in the net foreign asset position at market value and the current account is low or even negative. Tille (2003) discusses the effect of the currency composition of U.S. assets on the dynamics of its external debt, and Tille (2008) documents exchange rate effects on rates of return of foreign assets and liabilities for a cross section of countries. These papers find that the valuation channel has a significant effect on the dynamic behavior of the net foreign asset position and the exchange rate. Gourinchas and Rey (2007) estimate the respective contributions of the trade and valuation channels to the external adjustment process of U.S. gross foreign positions. They find that, historically, about 27 percent of the cyclical international adjustment of the United States is realized through valuation effects.

The significance of the valuation effect for exchange rate adjustment seems well established but its impact on the long run behavior of the real exchange rate and whether such an impact actually exists is unclear. Blanchard et al. (2005) construct a portfolio balance model where the presence of significant valuation effects implies that there is a saddle path dynamic relationship between the real exchange rate and the net foreign debt. I exploit the special properties of this saddle-path dynamic relationship in order to test the importance of the valuation channel for the long run behavior of the real exchange rate. I use a methodology developed by Cheung et al. (2004) who note that both co-integration and saddle path dynamics depend on the roots of the system's characteristic polynomial. Such similarity suggests the adoption of a test for cointegration, such as the Johansen procedure, to check for saddle-path dynamics. The Johansen approach does not test for non-stationary behavior directly but exploits the implications of cointegration for the rank of the coefficient matrix defined by the characteristic polynomial and uses the rank condition to infer system dynamics. Cheung et al. (2004) employ a Monte Carlo simulation to demonstrate that the Johansen procedure is sufficiently powerful to discriminate between the two types of dynamics.

I linearize the equilibrium conditions of the Blanchard et al. (2005) model around the steady state and put them in vector error correction (VEC) form. Then, I use the Johansen test for co-integration to check whether the data supports their theoretical prediction. I test for a saddle-path dynamic relationship between the face value of US net foreign debt as a percentage of nominal gross domestic product (GDP) and the real effective exchange rate of the US dollar relative to broad range of its trading partners. The results are in favor of co-integration and indicate that the two variables are governed by a common unit root process. The estimated cointegrating relationship contains a negative trend term which implies that the two variables do not drift apart in the long run and the relationship between them is trend stationary. The significance of this trend term could capture the dynamic behavior of asset supplies, assumed to be fixed in the model. This suggests that a richer theoretical model that incorporates asset supply behavior would be more appropriate for analyzing real exchange rate.

A testable VEC form of the theoretical model is presented in the next section. Section 1.3 describes the data and the methodology. The results of testing for cointegration in quarterly data for the United States net foreign debt (NFD) stock and real effective exchange rate are presented in Section 1.4. Section 1.5 concludes.

1.2 Theoretical Model

The world consists of two countries, the US and the rest of the world. Both US and foreign goods, and US and foreign financial assets are assumed to be imperfect substitutes. Due to the fact that there is home bias both in international goods and asset markets, shocks that shift the relative demand both for US goods and assets have implications for the dynamic behavior of the real exchange rate, the CA and the NFD. The assumption that international financial markets clear before international goods markets is a key element that allows valuation effects to influence the international adjustment mechanism and is responsible for the saddle path dynamics of the bivariate system of the model[2]. The model can be described by two key equations-the portfolio balance relation (PBR) and the

[2]Valuation effect and portfolio balance channel are two terms used interchangeably which refer to the same phenomenon.

current account relation (CAR). The first describes the international market for financial assets:

$$X = \alpha(R_t, s_t)(X - F_t) + [1 - \alpha^*(R_t, s_t)]\,(\frac{X^*}{E_t} + F_t), \tag{1.1}$$

where X is the fixed stock of US assets in terms of US goods, α is the share of wealth that US investors allocate to domestic assets, F_t is the NFD stock of the US, α^* is the share that foreigners invest in their own assets, X^* is the fixed stock of foreign assets and it is converted in terms of US goods with the real exchange rate E_t, defined as the price of US goods in terms of foreign goods. The share of US assets in domestic portfolios depends on R_t, the expected gross rate of return of US assets relative to foreign assets, and on s_t, a portfolio shifter which includes all factors other than R_t that can affect the relative demand for US assets. Two more important assumptions are that UIP does not hold and that both US and foreign investors display home bias. The fact that the UIP does not hold means that the expected gross rates of return between domestic and foreign assets are not equal. An increase in s_t indicates a positive shock to the relative demand for US assets and a rise in R_t, the relative return to US assets, also results in an increase in the share of US assets in the US portfolio. The opposite is true for the effects of s_t and R_t^* on α^*.

These assumptions drive the key variables within the PBR but the relation itself follows from the market clearing condition of international asset markets. Conceptually, it states that in equilibrium the supply of US assets should be equal to the sum of domestic and foreign demand for US assets. Domestic demand for US assets is the share of α of financial wealth that US investors allocate to US assets, where US financial wealth is equal to stock of US assets minus NFD owed to the rest of the world. Similarly, foreign demand for US assets is the share α^* of financial wealth that foreign investors allocate to US assets where foreign wealth is equal to the stock of foreign assets adjusted for the exchange rate plus the net debt stock that the US owes to the rest of the world.

The international goods trade is described by the second key equation of this model, the CAR:

$$F_{t+1} - F_t = rF_{t+1} + D_{t+1}(E_{t+1}, z_{t+1}) \tag{1.2}$$

It simply describes the current account, defined as the sum of interest paid on debt accumulated in previous periods and the trade deficit D_{t+1}, as the mirror image of net international financial flows. The trade deficit is assumed to depend positively on the exchange rate E_{t+1} and on a shifter variable z_{t+1} which stands for all factors other than the exchange rate that can result in an increase for US trade deficit, i.e. z_{t+1} indicates a shift of relative demand away from US goods and toward foreign goods. Using the definition of net debt as the difference between the stock of US assets and US financial wealth and the international financial markets clearing condition, the CAR can be rewritten as:

$$F_{t+1} = (1+r)F_t + [1 - \alpha(R_t, s_t)]\,(X - F_t)\left[(1+r) - (1+r^*)\frac{E_t}{E_{t+1}}\right] + D_{t+1}(E_{t+1}, z_{t+1}). \tag{1.3}$$

The first and last terms on the right are standard: next period's net debt F_{t+1} is equal to this period's net debt F_t times the gross rate of return $1+r$, plus the trade deficit next period D_{t+1}. The term in the middle is the share of foreign assets $[1 - \alpha(R_t, s_t)]$ in US wealth $(X - F_t)$ multiplied by the difference in the US and foreign gross rates of return $\left[(1+r)-(1+r^*)\frac{E_t}{E_{t+1}}\right]$. It reflects valuation effects and is critical for the dynamics of this model. If there is an unexpected decrease in the price of U.S. goods, i.e. an unexpected real dollar depreciation, the dollar value of U.S. holdings of foreign assets increases. The US net debt position improves in two ways, the conventional one, through an improvement in the trade balance, and the second one, through asset revaluation. The strength of the valuation effects depends on the assumption that U.S. gross liabilities are measured in dollars, which means that their value is unaffected by a dollar depreciation.

The model is built to explain the sustainable US CA deficit and its accumulating NFD and their implications for the behavior of the real exchange rate. It focuses on the effects of shifts in relative demand away from U.S. goods (an increase in z_t), and towards U.S. assets (an increase in s_t). The first shift implies a steady depreciation of the dollar. The second shift implies an initial appreciation because of an increase in relative demand for US assets. Due to valuation effects the initial appreciation results in an increase in the trade deficit and a deterioration of the net debt position. Over time, net debt increases and the dollar depreciates. In the new equilibrium, the exchange rate is lower than before the shift because a larger trade surplus is needed to offset the interest payments on the now larger U.S. net debt. The equilibrium dynamics is completely described by equations (1.1) and (1.3). Some additional assumptions are necessary to solve the model: (1), real interest rates are assumed to be constant, (2), supplies of US and foreign assets are perfectly inelastic, and, (3), the US trade deficit is equal to US saving which is only a function of the fixed interest rate. The trade deficit is a linear function of the real exchange rate and the US relative goods demand shifter z_t. The US demand for US assets and foreign demand for foreign assets are symmetric linear functions of the relative return R_t and the relative asset demand shifter s_t, where the share of US assets in US portfolios depends positively on R_t and s_t, while the share of foreign assets in foreign portfolios depends negatively on R_t and s_t. The resulting solutions of the real exchange rate and NFD paths are given by a system of nonlinear first-order simultaneous difference equations. In order to characterize the dynamics graphically and apply the cointegration test procedure, I put the bivariate system in vector error correction (VEC) form. I use a natural logarithm transformation and a first order Taylor approximation around the steady state. Thus, I can rewrite the solution of the model in a convenient matrix form:

$$\Delta Y_t = \mu + AY_{t-1} + V_t, \tag{1.4}$$

where $\Delta = (1 - L)$, L is the lag operator, $Y_t = \begin{bmatrix} logE_t \\ logF_t \end{bmatrix}$ and $\mu = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}$ is a 2x1 vector of constants which are functions of the parameters and the steady state values of the model. $V_t = \begin{bmatrix} V_{1t} \\ V_{2t} \end{bmatrix}$ is a 2x1 vector whose elements are zero-mean disturbances that are linear combinations of the trade deficit shocks z_t, portfolio demand shocks s_t and prediction errors. $A = \begin{bmatrix} A_1 & A_2 \\ A_3 & A_4 \end{bmatrix}$ is a 2x2 matrix of coefficients which is also a function of the steady state values and the underlying parameters of the model.

Let θ_1 and θ_2 be the two roots of the characteristic equation $|A - I\theta| = 0$. Depending on the configuration of the parameters, the model can generate different dynamics. For example, under the assumption that

$$\frac{\partial \bar{E}}{\partial \bar{F}} = \left| \frac{(1-\alpha-\alpha^*)(1-\alpha^*)X}{\left[(1-\alpha)X - (1-\alpha-\alpha^*)\bar{F}\right]^2} \right| > \left| \frac{-\alpha r - (1-\alpha)r^*}{\partial \bar{D}/\partial \bar{E}} \right|, \tag{1.5}$$

the slope of the PBR is steeper than the slope of the CAR. By assumption, the slope of PBR is $\left(-\frac{A_2}{A_1}\right)$ and the slope of CAR is $\left(-\frac{A_4}{A_3}\right)$. Both imply a downward sloping relationship between the real exchange rate and the net foreign debt. Under the above assumption, the adjustment speed of the PBR and, hence, of the real exchange rate is faster than the adjustment speed of the NFD at the steady state. In other words, financial markets clear faster than the goods markets and that is why the valuation channel of adjustment is faster than the trade channel of adjustment. The above assumption implies that $det(A) = A_1A_4 - A_2A_3 < 0$ and $\theta_1 < \frac{A_1\theta_2}{\theta_2 - A_4}$, where θ_1 is the explosive root and θ_2 is the stationary one. In this case, the system exhibits saddle-path dynamics and the associated valuation effect is faster than the trade effect.

The popular cointegration dynamics are also described by (1.4), which is already in error correction form. Under cointegration the rank of A will be equal to one and $det(A) = 0$. This implies that the PBR and the CAR have the same slopes and $\theta_1 = \frac{A_1\theta_2}{\theta_2 - A_4}$. Thus, cointegration dynamics can be viewed as a limiting case of saddle-path dynamics. In the context of the model, the implication of equal slopes means that the adjustment of the CAR accelerates until its speed of adjustment coincides with the PBR's and the two follow the same unit root process. A possible reason for this is that the degree of substitutability between US and foreign assets falls because assets demands are unresponsive to changes in the relative return. The more responsive asset demands are to the relative return, the more elastic they are, the smaller the slope of the CAR is.

Figures 1.1 and 1.2 illustrate the saddle-path and the cointegration dynamics respectively. Figure 1.1 gives a typical phase diagram for a saddle-path system. The arrows indicate the system dynamics. The unique path that brings the system to its steady state is the saddle-path line, labeled SP in figure 1.1. For a cointegrated system, only one common I(1) process governs the evolution of the system component series. The system converges to its steady state independently of the initial conditions. Under cointegration, there are an infinite number of trajectories that bring the system to its equilibrium. Notice that as the degree of substitutability of US asset relative to foreign assets falls, asset demands become more inelastic and the slope of the CAR rises which causes the CAR locus to rotate clockwise until it overlaps with the PBR locus. In the context of the parameters of the model, as the elasticity of US and foreign asset demand to R falls, the CAR slope $\left(-\frac{A_4}{A_3}\right)$ becomes steeper. Figure 1.2 shows the phase diagram of a cointegrated system, where the two loci overlap. As the degree of substitutability falls the explosive region in figure 1.1 disappears and there is an infinite number of paths leading to the line where the two phase lines overlap.

A third case that should be mentioned is when the rank of matrix A is null which could happen when both A_2 and A_4 are zero. In that case, the real exchange rate and the NFD are independent of each other.

1.3 Methodology and Data

Cheung et al. (2004) demonstrate that the Johansen's procedure, which is a standard test for cointegration, uses the rank of A to infer system dynamics and distinguish between the saddle-path and stationary systems from a cointegrated system.

In the context of a bivariate difference-stationary system, the Johansen test has a typical implementation procedure. First, the maximum eigenvalue statistic of the Johansen procedure tests the null hypothesis that $H_0 : rank(A) = 0$ against the alternative hypothesis that $H_1 : rank(A) = 1$. Under the null hypothesis the unit root components of the two individual series are driven by two separate I(1) processes and there is no cointegration. Under the alternative hypothesis the two variables are cointegrated and driven by one common I(1) process and one stationary process. If the null hypothesis of the first test is rejected, the Johansen procedure considers a second test where the new null hypothesis is $H_1 : rank(A) = 1$ and the new alternative hypothesis is that $H_2 : rank(A) = 2$. Cointegration would be observed if H_1 is not rejected. However, either a stationary system or a saddle-path system implies the rejection of H_1 or acceptance of the alternative hypothesis that A has a full rank.

Alternatively, Johansen proposes the trace statistic to study the cointegrating rank of the A matrix. This test is less restrictive than the maximum eigenvalue test. First, it considers the same null hypothesis that $H_0 : rank(A) = 0$ but against a different alternative hypothesis that $H_1 : rank(A) > 0$. This time the rejection of the null is consistent not only with cointegration but also with saddle path/stationary dynamics. If the null hypothesis of this first test is rejected, the procedure considers the null hypothesis that $H_1 : rank(A) = 1$ against the alternative hypothesis that $H_2 : rank(A) > 1$. The non-rejection of the null hypothesis is again consistent with a full rank for the A matrix and a system that displays saddle-path or stationary dynamics. Although the two tests are slightly different, they lead to the same conclusions regarding the rank of the A matrix and should have similar power in discriminating between cointegration and saddle-path dynamics.

The purpose of this paper is to use the Johansen procedure to test the portfolio balance model presented in Section 2. A quarterly data series on the US NFD position is constructed for the period from the first quarter of 1973 to the first quarter of 2009. The series is built using an initial value of the nominal NFD stock position of the US at the end of 1970 and adding the net international financial flow for every quarter after that in order to obtain the subsequent data points on quarterly stock positions. Data on the NFD stock of the US at the end of 1970 is taken from the database build by Lane and Milesi-Ferretti (2007). Data on the nominal value of net international financial flows is retrieved from the Bureau of Economic Analysis website. However, since the data on net financial flows is in face value while the initial stock is in terms of 2006 US dollars, the consumer price index (CPI) is used to convert the Lane and Milesi-Ferretti NFD estimate in terms of 1970 US dollars. The resulting data series refers to the face value of the NFD for the US from 1973Q1 to 2009Q1 and has a total of 145 observations. Only data after 1973 are considered because the failure of the Bretton Woods system of fixed exchange rates in the beginning of the 1970s has important implications both for NFD and RER dynamics but it is not the issue under study for this paper. The issue under study is whether the US NFD co-moves together with the real exchange rate due to valuation effects resulting from the imperfect substitutability between US and foreign assets. Since the issue tested is the valuation effect resulting from the movement of a real variable, valuation effects resulting from fluctuations in nominal variables should be accounted for before the Johansen test is applied. That is why, the nominal NFD is divided by the nominal GDP of the US and multiplied by a hundred in order to be able to interpret it in percentage terms. The resulting variable is called FS_t. Then, a test for valuation effects due to real fluctuations can be applied to the FS_t ratio because it would address whether the portfolio balance channel is valid for describing the sustainability of US NFD and its relation to the real exchange rate. Data on nominal US GDP is retrieved from the website of the Federal Reserve Bank of Saint Louis.

Since the model described in Section 2 consists of two countries, data on real effective exchange rate indices is retrieved from the website of the Federal Reserve Board of Governors. The first is a broad index which is a weighted average of the foreign exchange values of the US dollar against a large group of major US trading partners. The index weights change over time and are derived from US export share and from US and foreign import shares. The second is the major currencies index which is a weighted average of the foreign exchange values of the US dollar against a subset of currencies in the broad index that circulate widely outside the country of issues. The weights are derived from those in the broad index. Both real indices are constructed using consumer price indices and have monthly frequency. Quarterly series are constructed as averages of monthly observations for the period from 1973Q1 to 2009Q1. Natural logarithm transformation is applied to both indices and the broad index, referred to as $E1_t$, is used for the empirical analysis while the major currencies index referred to as $E2_t$ is used for a robustness check.

Figure 1.3 presents the time series plot of FS_t. The US NFD seems to display an upward quadratic trend. Figure 1.4 shows that the first differenced series of FS_t also displays an upward trend which implies that FS_t indeed has a quadratic trend. Figure 1.5 presents the time series plot of the real effective exchange rate which seems to have no visible trend.

1.4 Testing a Portfolio Balance Model

In this section, the Johansen procedure is used to infer whether the saddle path and the related valuation channel dynamics are an appropriate description of the joint adjustment paths of the US net foreign debt and real exchange rate. The individual data series on FS_t and $E1_t$, described in Section 3, are first tested for unit root. The Augmented Dickey Fuller test is used for both variables. The ADF test uses the underlying regression

$$y_t = c_t + \beta y_{t-1} + \sum_{i=1}^{p-1} \varphi_i \Delta y_{t-i} + e_t, \tag{1.6}$$

where y_t is the time series (either FS_t or $E1_t$) being tested, c_t is the deterministic function of the time index t and $\Delta y_t = y_t - y_{t-1}$ is the first differenced series of y_t. There are various specifications for c_t which can be zero (where the constant term is suppressed), or a constant (where there is a drift term) or $c_t = \gamma_0 + \gamma_1 t$ (where it displays a trend). The ADF test is a type of t-test where the test statistic is $ADF = \frac{\hat{\beta}-1}{std(\hat{\beta})}$ and $\hat{\beta}$ denotes the least squares estimate of β. The null hypothesis that $H_0 : \beta = 1$ is tested against the alternative hypothesis $H_1 : \beta < 1$. Non-rejection of the null hypothesis is consistent with unit root behavior displayed by the time series. The appropriate order of the AR model described by equation (1.6) is selected using the Akaike Information Criteria (AIC). For the differenced series of FS_t an AR(4) model is selected while for the differenced series of $E1_t$ an AR(3) model is selected.

The ADF is an asymmetric test, which means that signs matter when the test statistic is compared to the critical values. Table 1.1 presents the results for FS_t. The test statistic is consistently greater than critical values at all significance levels and the null hypothesis of unit root cannot be rejected. Various specifications of the underlying regression used to test for unit root are considered. The constant term does not seem significant. Results do not change if it is suppressed. If a trend term is included in the regression, the results do not change but it is significant. Recall that the time series plot of the first differenced series of FS_t also shows an upward time trend which implies the possibility of a second unit root or of a quadratic time trend. Hence, a unit root test is performed on the first differenced series of FS_t under various specifications for the deterministic term. The order of the underlying AR model of the second differenced series of FS_t is selected using the AIC procedure and the optimal lag chosen is 3. The results are presented under table 1.2. The null hypothesis for the presence of unit root is rejected at the 10 % level regardless of the specification for the deterministic term. Two specifications for the deterministic term are reported, including a drift and a drift and a trend. It is important to note that the trend term is significant at the 5% level which implies the presence of a quadratic trend in the I(1) process that governs the behavior of FS_t.

Table 1.3 presents the results for $E1_t$. The ADF test suggests that $E1_t$ is I(1) with a drift when an AR(3) model is fitted for the differenced series while increasing the order of the AR model to 14 and 19, the hypothesis of unit root cannot be rejected at the 5% and 10% level. A trend term is included in the regression but is consistently insignificant while the drift term stays consistently significant. Overall, the evidence in favor of unit root both for FS_t and $E1_t$ is strong enough to justify a cointegration test for their joint dynamics.

Before proceeding to test for co-integration, for notational convenience the bivariate system as equation (1.4) is rewritten in its general form:

$$\Delta Y_t = \mu_t + AY_{t-1} + \sum_{i=1}^{k-1} A_i \Delta Y_{t-i} + V_t, \tag{1.7}$$

where no parameter restrictions are imposed on matrices A and A_i. The lagged first differences of Y_t's are included to control for serial correlation in V_t and to guarantee that it is a white noise process. Before implementing the test, the lag parameter k needs to be selected; it refers to the order of the underlying VAR model that is fitted to the first differenced series of Y_t. The AIC selects a value of 5 for k.

Another consideration before the Johansen test is applied is the specification of the deterministic term μ in equation (1.7). Five cases are possible:

1. None or $\mu_t = 0$: In this case, all component series of Y_t are I(1) without a drift and the stationary series $\omega_t = \beta' Y_t$ has a zero mean. Note that $A = \alpha\beta'$ where α is a 2x1 vector, whose elements are said to be the "weights" of the stationary series ω_t and β is 1x2 vector of coefficients, which is known as the "cointegrating vector".

2. Restricted constant or $\mu_t = \mu_0 = \alpha c_0$, where c_0 is a one dimensional non-zero constant vector: In this case, the component series are I(1) without a drift but the stationary series ω_t has a non-zero mean.

3. Constant or $\mu_t = \mu_0$, which is non-zero: Here, the component series are I(1) with a drift μ_0 and the stationary series ω_t may have a non-zero mean.

4. Restricted trend or $\mu_t = \mu_0 + \alpha c_1 t$, where c_1 is a non-zero vector: In this case, the component series are I(1) with a drift μ_0 and the stationary series ω_t has a linear time trend related to $\alpha c_1 t$.

5. Trend or $\mu_t = \mu_0 + \mu_1 t$, where μ_1 is non-zero: Here, the component series are I(1) with a quadratic time trend and ω_t has a linear time trend.

The component series of Y_t are $E1_t$ and FS_t. Recall that for $E1_t$, the ADF results indicate random walk with a drift but not a trend while for FS_t, the ADF results indicate random walk without a drift but with a quadratic trend. The model predicts that μ is a constant (specification 3) which is a function of the underlying parameters and the steady state values of the variables but the empirical properties of the component series suggest specifications 4 and 5. Thus, in implementing the Johansen procedure to test for saddle path dynamics in the bivariate system described by equation (1.7), three specifications are considered. Both the Johansen maximum eigenvalue and trace statistics are reported.

The results of the Johansen tests are reported in Table 1.4. Both the maximum eigenvalue and trace statistics reject the null hypothesis $H_0 : rank(A) = 0$ at the one percent level. However, the results for the null hypothesis $H_1 : rank(A) = 1$ are dramatically different depending on whether the cointegrating relationship contains a linear trend or not. Recall that the assumptions of the theoretical model suggest that the cointegrating vector includes only a constant term. That is because US and foreign assets supplies are assumed to be perfectly inelastic and the real interest rates are also assumed to be fixed. The data shows that if these assumptions are maintained and only a constant term is included in the model, the hypothesis of saddle-path dynamics cannot be rejected. The null that A has a full rank is not rejected at the 5% level when the cointegrating vector only includes a constant term and the theoretical assumptions are maintained.

However, the empirical properties of the component series suggest a different behavior for the tested dynamic system. The time series plots of the FS_t variable and its ADF test results indicate the presence of a quadratic trend. At the same time, the real effective exchange rate does not have a trend. Thus, if there exists a long run relationship between the two, it should also have a trend. When the Johansen test is performed under the assumption that there is a trend between the two component series, the null hypothesis of cointegration cannot be rejected at the 1% level. If I estimate the VEC models with reduced rank one in the case when the quadratic trend is restricted to the cointegrating vector and when it is not, the dynamic system can be described by equation (1.8) under a restricted trend and (9) under a trend, respectively.[3]

$$\begin{bmatrix} \Delta FS_t \\ \Delta E1_t \end{bmatrix} = \begin{bmatrix} 0 \\ 0.004 \end{bmatrix} +$$

$$+ \begin{bmatrix} 0.00242170 \\ -0.0000357 \end{bmatrix} \begin{bmatrix} 1 & 793.85 & -3648.847 & 1.514282 \end{bmatrix} \begin{bmatrix} FS_{t-1} \\ E1_{t-1} \\ 1 \\ t \end{bmatrix} +$$

$$+ \sum_{i=1}^{4} A_i \Delta Y_{t-i} + V_t \tag{1.8}$$

$$\begin{bmatrix} \Delta FS_t \\ \Delta E1_t \end{bmatrix} = \begin{bmatrix} 0.0037871 \\ -0.0046559 \end{bmatrix} + \begin{bmatrix} 0.00000642 \\ 0.00020220 \end{bmatrix} t +$$

$$+ \begin{bmatrix} .0030725 \\ -.0000975 \end{bmatrix} \begin{bmatrix} 1 & 590.9691 & -2724.224 & 1.279406 \end{bmatrix} \begin{bmatrix} FS_{t-1} \\ E1_{t-1} \\ 1 \\ t \end{bmatrix} +$$

$$+ \sum_{i=1}^{4} A_i \Delta Y_{t-i} + V_t \tag{1.9}$$

The cointegrating vector describes the long-run relationship between the two component series which, in the context of our model, means that it defines the steady state. Note that if I include a trend term in the cointegrating space, I make

[3]The values of the matrices A_i and the standard errors V_t are not reported for notational simplicity.

the steady state directly dependent on the time horizon t. For simplicity, assume (1) that the system is initially at steady state where the component series are stationary and, hence, $\Delta Y_t = 0$, (2) that that there are not contemporaneous or recent exogenous shocks to affect the short run values and, hence, $\sum_{i=1}^{4} A_i \Delta Y_{t-i} = 0$, (3) that the intercepts governing the dynamic behavior of ΔY_t are zero, and (4) that V_t follows a Gaussian distribution with a zero mean. Then, under a restricted trend the steady state or the long-run equilibrium of our model can be described by the following equation:

$$\bar{F}S = 3648.84 - 793.85\bar{E}1 - 1.514282t \quad (1.10)$$

First, equation (1.10) implies a negative relationship between the real exchange rate and the net foreign debt. This means that as the net foreign debt rises, the real exchange rate depreciates. Second, equation (1.10) implies that the values of the net foreign debt and the real exchange rate fall together as the time horizon t increases. Alternatively, the larger t, the smaller the difference between the two steady state phase lines. This means that as time progresses the two component series draw closer together and do not drift apart. The larger t, the closer they are to their common mean which here is assumed to be zero. In other words, the predicted linear relationship between the two component series is trend-stationary.

What is the intuition behind the negative and trend-stationary long run relationship between the steady state values of the NFD and the RER for the US? Within the bounds of the model I can explain the negative relationship between the two component series with US and foreign assets being increasingly unsubstitutable. Recall that this results in a decrease of the slope of the CAR until it equals the slope of PBR. However, under this explanation I assume a cointegrating relationship without a trend, only with the presence of a constant. The significance of the trend term within the estimated cointegrating vector is contrary to the prediction for long run dynamics implied by the PBM. What does the data capture that has been overlooked by the portfolio balance theory? Two important assumptions are that the long run real interest rates and that asset supplies are fixed. However, there has been a fall in the long run world interest rates and an increase in the supply of US assets throughout the sample period. Both of these imply an increase in the stock of US net foreign debt with time. Positive supply shocks to US assets could explain the rise in US NFD throughout time despite the real depreciation of the US dollar. Thus, the empirical results suggest that a richer framework which takes account of time varying asset supplies and asset supply shocks is needed to interpret the joint behavior of the NFD and the RER.

To check the robustness of these results several tests were done. First, $E1_t$ is replaced with $E2_t$ in the analysis and then FS_t is replaced by the real value of NFD adjusted for fluctuations in price indices such as the CPI or the GDP implicit price deflator. Data on price indices are retrieved from the website of the Federal Reserve Bank of Saint Louis. The results are not changed. The two variables under consideration continue to display cointegration dynamics.

1.5 Conclusion

The Portfolio Balance Model is a prominent explanation for describing the joint behavior of the CA and real exchange rate in recent years. Assuming that US and foreign assets are imperfect substitutes and that financial markets clear faster than goods markets, valuation effects govern the joint behavior of the NFD and real exchange rates and lead the model to display saddle-path dynamics. This paper puts the portfolio balance model of Blanchard et al. (2005) in VEC form and brings it to the data. The Johansen procedure is used to test for cointegration and discriminate between cointegration and saddle path dynamics. The empirical result is that NFD and the real exchange rate of the US are cointegrated and that this cointegrating relationship is trend stationary. As time progresses, the two component series draw closer together and do not drift apart. A negative long run relationship between the US NFD and RER is predicted by the data. It could be capturing the fact that relative supply of US assets has increased in recent decades together with a fall in the long-run interest rate. The empirical results suggest that a theoretical model that incorporates the dynamic behavior of asset supplies might be more appropriate for interpreting the joint behavior of the US NFD and RER.

1.6 Tables and Figures

Figure 1.1: Saddle Path Dynamics

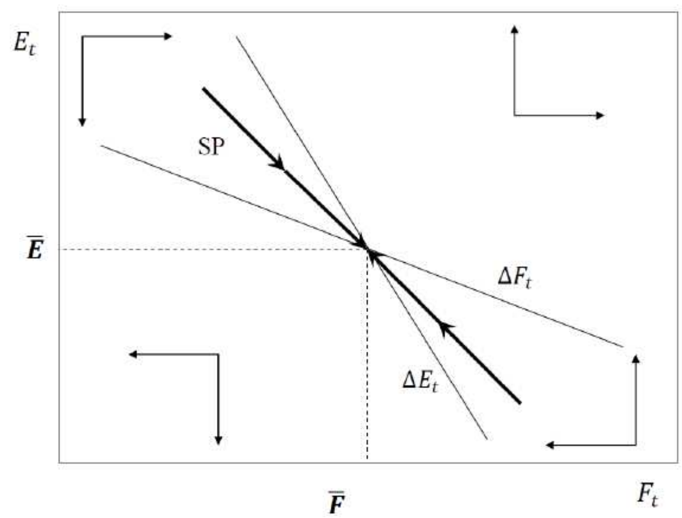


Figure 1.2: Cointegration Dynamics

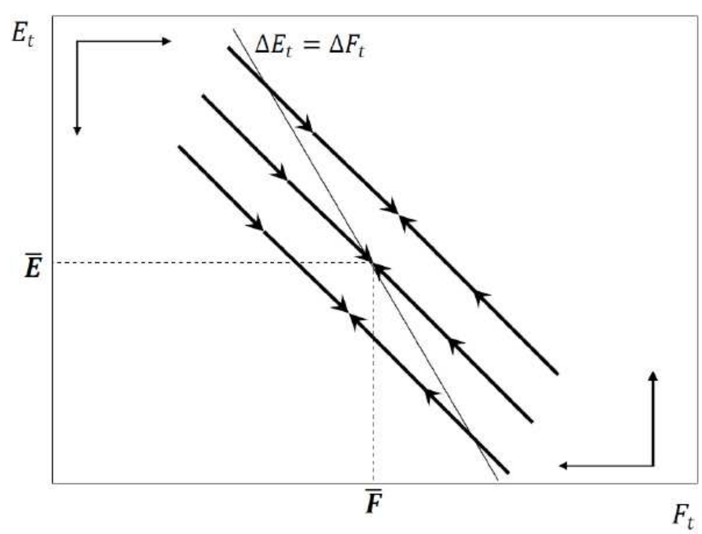


Figure 1.3: Time Series Plot of the Face Value of US NFD as a % of Nominal GDP

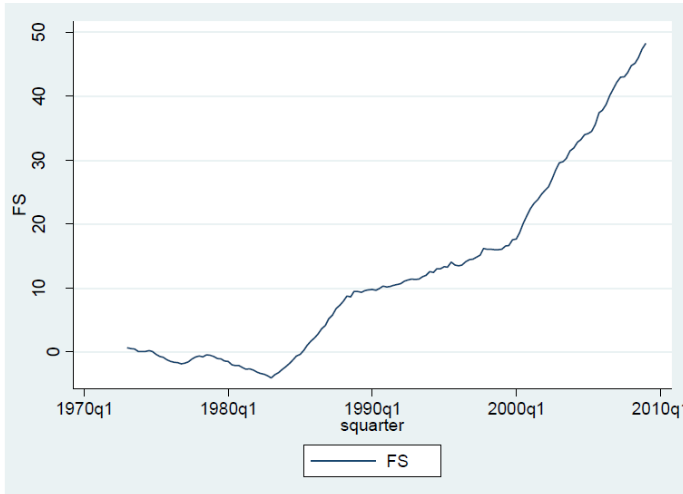


Figure 1.4: Time Series Plot of the First Differenced Series of FS

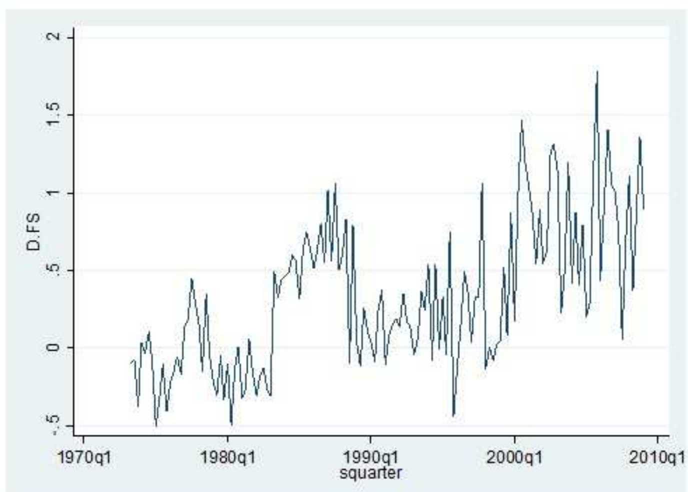


Figure 1.5: Time Series Plot of the Broad Real Effective Exchange Rate Index for the US

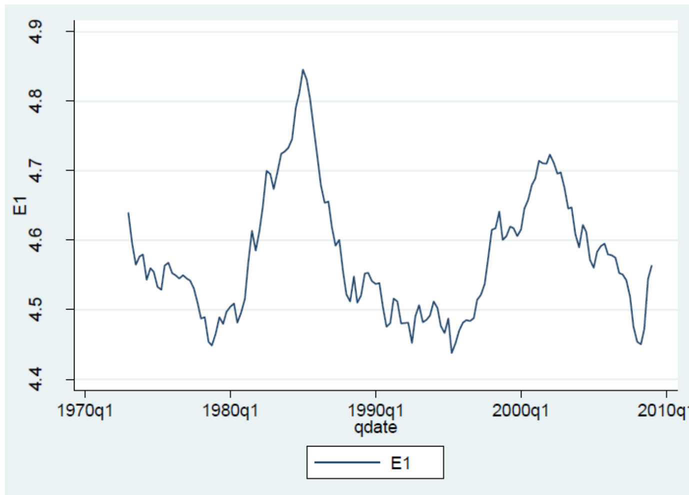


Table 1.1: Augmented Dickey-Fuller test results for FS_t

	ADF test statistic	Drift t-statistic	Trend t-statistic
Lag=4			
Drift	1.771	1.19	
Drift and Trend	-0.68	-1.1	1.79***

Notes: The Augmented Dickey-Fuller test for unit root for the US net foreign debt as a percentage of nominal GDP. The ADF procedure tests the null hypothesis of unit root against the alternative of a stationary root. The ADF test statistic is reported under the first column and its significance is compared to MacKinnon critical values. The lag parameter "Lag =" is selected using the Akaike information criterion. Two specifications for the deterministic term of the underlying regressions are reported, including "drift" and "drift and trend." The standard t-test statistics of the regression coefficients in front of the drift and trend terms in the regression are reported under columns two and three, respectively. Significance at the 10%, 5% and 1% levels are indicated by "***", "**" and "*". The hypothesis of unit root is not rejected. The result is robust to different specifications for the deterministic term.

Table 1.2: Augmented Dickey-Fuller test results for ΔFS_t

	ADF test statistic	Drift t-statistic	Trend t-statistic
Lag=3			
Drift	-2.076478	1.806723***	
Drift and Trend	-3.221420***	-0.887654	2.438010**

Notes: The Augmented Dickey-Fuller test for unit root for the first differenced series of the US net foreign debt as a percentage of nominal GDP. The ADF procedure tests the null hypothesis of unit root against the alternative of a stationary root. The ADF test statistic is reported under the first column and its significance is compared to MacKinnon critical values. The lag parameter "Lag =" is selected using the Akaike information criterion. Two specifications for the deterministic term of the underlying regressions are reported, including "drift" and "drift and trend." The standard t-test statistics of the regression coefficients in front of the drift and trend terms in the regression are reported under columns two and three, respectively. Significance at the 10%, 5% and 1% levels are indicated by "***", "**" and "*". The hypothesis of unit root is not rejected at the 5% level. The result is robust to different specifications for the deterministic term.

Table 1.3: Augmented Dickey-Fuller test results for $E1_t$

	ADF test statistic	Drift t-statistic
Drift		
Lag=3	-2.394	2.40**
Lag=14	-3.204**	3.21*
Lag=19	-3.343**	3.35*

Notes: The Augmented Dickey-Fuller test for unit root for the US broad real effective exchange rate index. The ADF procedure test the null hypothesis of unit root against the alternative of a stationary root. The ADF test statistic is reported under the first column and its significance is compared to MacKinnon critical values. The lag parameter "Lag =" is selected using the Akaike information criterion and a graph of the partial autocorrelation function. Only the "drift" specification of the deterministic term in the underlying regression is reported. The standard t-test statistics of the regression coefficients in front of the drift term is reported under column two. Significance at the 5% and 1% levels are indicated by "**" and "*". The hypothesis of unit root is not rejected at the 1% level of significance. The result is robust to different levels of the lag parameter.

Table 1.4: Johansen cointegration test results

	Max. Eigenvalue Statistic		Trace Statistic	
	Rank(A)=0	Rank(A)=1	Rank(A)=0	Rank(A)=1
Lag=5				
Constant	23.9307*	4.284**	28.2147*	4.284**
Restricted Trend	26.8848*	6.8815	33.7663*	6.8815
Trend	23.6819*	0.4651	24.147*	0.4651

Notes: The Johansen tests for cointegration between the US net foreign debt as a percentage of nominal GDP and the broad real effective exchange rate index of the US dollar are presented. Both the maximum eigenvalue statistic "Max. Eigenvalue Statistic" and the trace statistics "Trace Statistic" are reported. The null hypotheses are given underneath the statistic labels. The alternatives for the maximum eigenvalue statistic are Rank(A) = 1 and Rank(A) = 2 and those for the trace statistic are Rank(A) > 0 and Rank(A) > 1. The lag parameter "Lag =" is selected using the Akaike information criterion. Three specifications for the deterministic term are considered, including a "constant", a "restricted trend" and a "trend." Significance at the 5% and 1% levels are indicated by "**" and "*". The hypothesis of Rank(A) = 0 is rejected by both statistics. The hypothesis of Rank(A) = 1 is rejected at the 5% level if the cointegrating vector only includes a constant term and is not rejected if it includes a trend term.

Chapter 2

Optimal Monetary Policy in Response to Shifts in the Beveridge Curve

2.1 Motivation and Contribution

The recent global crisis originated in the financial sector but the subsequent impact on the US labor market is unusual. Figure 2.1 shows a plot with the US unemployment rate on the horizontal axis and the job openings rate on the vertical axis. The US Bureau of Labor Statistics provides monthly data releases on unemployment via the Current Population Survey (CPS) and on job openings via the Job Openings and Labor Turnover Survey (JOLTS). The plot encompasses the period from December 2000 to July 2011. There is an inverse relationship between the unemployment and the job opening rates for the period before and during the Great Recession, from December 2000 to June 2009. This negative relationship is described with a solid downward sloping line called the Beveridge curve (BC).

Each point on it represents a different degree of output. Recessions typically result in a downward movement along the Beveridge curve as unemployment rises and the job opening rate falls. The standard monetary policy prescription in such recessions is to engage in expansionary actions. Figure 2.1 suggests that in the period after the Great recession, from July 2009 to July 2011, the US Beveridge curve shifted outward as both the unemployment and the job opening rates rose. I build a dynamic stochastic general equilibrium (DSGE) model with search and matching frictions in the labor market and analyze the optimal monetary policy response to an outward shift in the Beveridge curve.

2.1.1 Interpreting the Shift

In an extensive review of the literature Petrongolo and Pissarides (2001) show that the US labor market frictions can be described by a simple matching function:

$$m_t = d v_t^{\alpha} u_{t-1}^{1-\alpha}, \tag{2.1}$$

where v_t is the job openings rate, u_t is the unemployment rate, d is the efficiency of matching and $0 < \alpha < 1$ is the elasticity of matching with respect to vacancies. After normalizing the variables by the size of the labor force the number of unemployed at the end of period t is:

$$u_t = 1 - N_t + \rho N_t = 1 - (1 - \rho) N_t, \tag{2.2}$$

where ρ is the exogenous job separation rate and N_t is employment. Then, the number of employed workers at the end of period t is a function of the jobs that survived from last period and the newly formed matches in the current period,

$$N_t = (1-\rho)N_{t-1} + m_t. \tag{2.3}$$

These conditions imply a downward sloping steady state relationship between vacancies and unemployment, which describes the Beveridge curve as,

$$v = \left[\frac{\rho}{(1-\rho)\,d}\right]^{\frac{1}{\alpha}} (1-u)^{\frac{1}{\alpha}} u^{\frac{\alpha-1}{\alpha}}. \tag{2.4}$$

Equation (2.4) implies that the BC can shift for three reasons, an increase in the job separation rate ρ, a fall in the efficiency of matching d and a change in the elasticity α. A decrease in the match efficiency d would result in a parallel outward shift in the BC because for a given number of unemployed the number of vacancies would have to be higher in order to generate the same number of new hires. If ρ increases, the BC curve again shifts out proportionately but for a different reason. A given level of employment would now produce a higher number of inflows into unemployment which would have to be balanced by a larger number of vacancy postings to generate the same steady state level of flows out of unemployment. A change in the elasticity of matches with respect to vacancies makes the curve pivot. If the economy is operating on the lower portion of the curve, as seems to be the case at the end of the Great Recession where vacancies are low and unemployment high, then a rise in α can be interpreted as an outward shift in the Beveridge Curve. An increase in α would make vacancy postings less reactive to a given unemployment rate. Using the matching function, the hiring rate can be defined as $q_t = d\left(\frac{v_t}{u_{t-1}}\right)^{\alpha-1}$. For a given vacancy-unemployment ratio, the hiring rate becomes less elastic (recall that $\alpha < 1$) and thus less responsive to aggregate labor market conditions. Furthermore, the JOLTS hiring rate shows a substantial decline which would be consistent with a rise in the match elasticity. The JOLTS monthly data on total non-farm separation rates, however, also show that ρ actually declined from 4% to 3% in the post recession period. Therefore, the second two parameters are more likely to be the source of the shift.

I transform the matching function using natural logarithm transformation and estimate directly using constrained linear regression. I impose the constraint that the matching function displays constant returns to scale and the coefficients on vacancy and unemployment rates sum up to one. I use JOLTS monthly data series on hiring rate, job openings rate and CPS data on the unemployment rate. Table 2.1 reports the estimation results for the period before and during the Great Recession and for the period after it. These results suggest that the efficiency of matching declined by 0.074 while the elasticity increased by 0.033. This estimation exercise should be taken with a grain of salt because it ignores multicollinearity issues and potential bias due to omitted variables and the small sample for the post-recession period.

However, there are a number of empirical studies such as Kirkegaard (2009), Sahin et al. (2011), and Kannan et al. (2011) who use more sophisticated econometric methods and document an outward shift of the US Beveridge curve as a result of the crisis. Elsby et al. (2010), Kocherlakota (2010), Sahin et al. (2011) argue that the outward shift is due to a fall in the matching efficiency of labor markets. A temporary fall in matching efficiency results from either sectoral or geographical mismatch. Most of the unemployed workers after the Great Recession come from the construction and manufacturing sector while the bulk of vacancies are in the education and health sector. The low resale value of workers' houses limits their geographical mobility from areas with few job openings to areas with more available vacancies. Alternatively, Barnichon and Figura (2011) attribute the decline in the matching efficiency after the Great Recession to an increase in the dispersion in labor market conditions, the fact that tight labor markets coexist with slack ones. Borowczyk-Martins et al. (2011) show that the rise in unemployment after the Great Recession is caused by a fall in matching efficiency rather than a fall in labor demand. Only Lubik (2011) considers both an efficiency shock and an elasticity shock as a potential sources for the shift of the Beveridge curve. His results seem to suggest that the most likely source of the shift is a fall in the efficiency of matching.

2.1.2 Contribution and Results

There is a growing literature on optimal monetary policy in response to unemployment in the context of search and matching labor markets within a general equilibrium model. The most closely related paper is Ravenna and Walsh (2011) which explicitly derives the objective function of the policymaker as a second order approximation to the welfare of the representative agent. They emphasize that optimal monetary policy involves closing gaps between macroeconomic variables and their *time varying* efficient counterparts. The policymaker faces three different trade-offs due to the presence of sticky prices, home goods sector and search frictions. For that reason, the objective function of the policymaker should not only minimize fluctuations of the consumption gap and inflation but also in vacancies. They show that if the policymaker ignores fluctuations in vacancies when he sets the optimal nominal interest rate, there is a substantial loss in welfare. The economic intuition behind the policy trade-offs can be easily traced to the fundamental frictions that impact labor markets and firms' price setting behavior. This makes their model very suited to analyze optimal monetary policy problems.

My contribution to the literature is that I introduce two new types of shocks that shift the Beveridge curve and analyze the optimal monetary policy response to them. I also make two additional modifications to the Ravenna and Walsh (2011) framework because I want to analyze their effect on policy trade-offs arising from unemployment volatility. First, I make real wages sticky. This assumption generates inefficient fluctuations in the way the surplus from an employment match is shared between the worker and the firm. Shimer (2005) demonstrates that matching with flexible real wages set by Nash bargaining cannot generate the level of unemployment volatility seen in the data. Introducing a real wage rigidity increases the volatility of unemployment. Second, I make home goods and market goods imperfect substitutes.[1] This highlights the fact that fluctuations in the marginal rate of substitution between home and market goods affect the payoffs of unemployed workers. Thus, a time-varying marginal rate of substitution makes unemployment and inflation more volatile.

The results indicate that the monetary policy response depends on the source of the shift of the BC. If the efficiency of matching falls, unemployment does not fluctuate relative to its efficient level and the unemployment gap remains stable. The central bank that acts optimally need not deviate from a policy of price stability and it lowers the nominal interest rate in order to offset the fall in inflation. However, if the elasticity of matches with respect to vacancies rises, the economy deviates from its efficient equilibrium because the search friction is exacerbated. The elasticity shock acts like a cost push shock; it presents the policy maker with a trade off between stabilizing the unemployment gap and inflation. The optimal policy is still to lower the interest rate in order to offset the rise in the unemployment gap but the central bank has to put the economy though 25

[1] Ravenna and Walsh (2011) assume that home and market goods are perfect substitutes

quarters of inflation in order to achieve its goal.

I also explore the implications for two assumptions of the model about the optimal behavior of the central bank and the dynamics of key variables. For this reason, I only show the optimal policy response to a fall in the efficiency of matching, a shock which does not result in a deviation from the efficient equilibrium except for its inflationary impact. The assumption of sticky wages makes the economy deviate from its efficient equilibrium in response to the shock. As a result, the presence of real wage rigidity presents the central bank with a trade off between stabilizing inflation and the unemployment gap. On the other hand, the assumption that home and market goods are imperfect substitutes does not have an effect on the monetary policy decision. It does not create inefficient fluctuations in the unemployment gap, only increases the volatility of inflation which fluctuates in response to changes in the relative price of market and home goods. Hence, the central bank needs to lower the nominal interest rate more in order to stabilize inflation.

Both the assumption of real wage rigidity and imperfect substitution between home and market consumption make unemployment more volatile along the business cycle. This result is important because assuming imperfect substitution is a way to resolve the Shimer puzzle. Shimer (2005) shows that unemployment in search and matching models is not volatile enough along the business cycle because most of the adjustment is done by the real wage. Assuming sticky real wages or shocks that generate a deviation from the real wage implied by Nash Bargaining are mechanisms to generate more volatile unemployment. However, since 1984 the average variability of real wages in the US has increased and a number of studies have shown that the real wages of new hires are the most volatile. Imperfect substitutability between home and market goods is an appealing alternative assumption that generates higher unemployment volatility in search and matching models.

Finally, the optimal policy response is compared to the case where the central bank acts according to a Taylor rule that targets inflation and output growth. In response to both types of shocks, the behavior of the optimal policy maker is more aggressive than in the case of a Taylor rule. When the efficiency of matching falls, the Taylor rule central bank lowers the nominal interest rate by less than is optimal because it does not put such high weight on inflation stability as the optimal policy maker. When the elasticity of matching rises, the roles are reversed. The Taylor rule again implies a more muted response to the rise in the unemployment gap but because it puts higher weight on inflation variability than on unemployment variability in response to this particular shock.

Section 2.2 describes the theoretical framework used for analysis. Section 2.3 presents the optimal monetary policy problem while section 2.4 discusses calibration and methodology. Section 2.5 interprets the results and section 2.6 concludes.

2.2 Theoretical Model

The model consists of three types of agents. Households derive utility from the consumption of market and home produced goods. Home and market goods are assumed to be substitutes. In the baseline version of the model they are perfect substitutes and their relative price is constant. The case of imperfect substitutes with a diminishing marginal rate of substitution is also considered. The production process has two stages. There are wholesale firms who employ labor to produce a wholesale good which is sold in a perfectly competitive market. Retail firms transform the wholesale good into differentiated final goods which they sell to households in an environment of monopolistic competition. The labor market is characterized by search frictions. Wholesale firms use up retail goods in order to post vacancies and form productive employment matches. Households members are either employed or searching for a job. The real wages are a weighted average between last period's wage and the current Nash bargaining real wage. Retail firms adjust prices according to a standard Calvo specification.

2.2.1 Households

The household consists of a continuum of individuals, of whom some are employed and some unemployed. The employed produce market goods and the unemployed produce home goods. The household consumes a bundle

$$C_t = \left[a(C_t^m)^\phi + (1-a)(C_t^h)^\phi\right]^{1/\phi}, \tag{2.5}$$

where $0 < a < 1$ governs preferences of market versus home goods and $\epsilon_h = \frac{1}{1-\phi}$ is the elasticity of substitution between home and market goods. The baseline model treats home and market goods as perfect substitutes where $\phi = 1$ and $C_t = C_t^m + C_t^h$. The household derives utility from the basket of goods based on preferences with constant risk parameter σ:

$$U(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma}. \tag{2.6}$$

This utility specification implies that the marginal rate of substitution is a decreasing and convex function of the relative consumption of home to market goods $\frac{C_t^h}{C_t^m}$, where

$$MRS_t = \frac{MU(C_t^h)}{MU(C_t^m)} = \left(\frac{1-a}{a}\right)\left(\frac{C_t^h}{C_t^m}\right)^{\phi-1}. \tag{2.7}$$

In the case of perfect substitution between home and market consumption the marginal rate of substitution is constant $MRS_t = 1$.

The total labor force is one and is divided between market goods production N_t and home goods production $1 - N_t$. N_t is the number of people engaged in market production. Employment adjusts only along the extensive margin. The home goods production function is:

$$C_t^h = w^u(1 - N_t), \tag{2.8}$$

where w^u can be interpreted as a constant productivity parameter in the production function of the home good.

Market consumption is a continuum of goods purchased from retail firms

$$C_t^m \leq \left[\int_0^1 C_t^m(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}. \tag{2.9}$$

The expenditure minimization problem over the bundle of market goods delivers the following relative demand function and a price index

$$C_t^m(j) = \left[\frac{P_t^m(j)}{P_t^m}\right]^{-\epsilon} C_t^m \tag{2.10}$$

$$P_t^m = \left\{\int_0^1 \left[P_t^m(j)\right]^{1-\epsilon} dj\right\}^{\frac{1}{1-\epsilon}} \tag{2.11}$$

P_t^m is the market consumer price index which is used to construct the standard measure of inflation.

The household receives income from its members employed in the market sector who obtain a nominal wage W_t, interest income from one period risk free bonds delivering a nominal return i_t and dividend income from ownership of the monopolistic retailers T_t. The household's expenditures include consumption C_t^m and risk-free bond purchases B_t. The household budget constraint is given by

$$P_t^m C_t^m + B_t = W_t N_t + (1 + i_{t-1}) B_{t-1} + T_t \tag{2.12}$$

The household maximizes the present discounted value of its utility $E_t \sum_{i=0}^{\infty} \beta^i \frac{C_{t+i}^{1-\sigma}}{1-\sigma}$ subject to the budget constraint and chooses C_t^m and B_t. Its utility maximization problem results in a standard Euler equation

$$\frac{\lambda_t}{P_t^m} = \beta E_t \frac{\lambda_{t+1}}{P_{t+1}^m}(1 + i_t) \tag{2.13}$$

where $\lambda_t = aC_t^{1-\sigma-\phi}(C_t^m)^{\phi-1}$is the marginal utility of one unit of market consumption.

The household trades off optimally between home and market goods as long as the implicit price of the home good relative to the price of the market good is equal to the marginal rate of substitution. I use this optimal condition to define an implicit price index for the home good:

$$P_t^h = MRS_t P_t^m \tag{2.14}$$

Note that in the baseline version of the model when home and market goods are perfect substitutes, this implicit price is equal to P_t^m.

2.2.2 Wholesale Firms

The wholesale producers are identical and operate in a perfectly competitive market. They possess constant returns to scale technology that is linear in employment:

$$Y_t^w = ZN_t, \tag{2.15}$$

where Z is a productivity parameter that is normalized to one at the steady state.

The firm sells its output Y_t^w to final producers at price P_t^w, hires workers N_t at a wage W_t and buys a continuum of final goods $v_t(j)$ at prices $P_t^m(j)$ to post vacancies at a period cost k. Its value in terms of final consumption units is the present discounted sum of its revenues less its employment and hiring expenditures:

$$F_t = \frac{P_t^w}{P_t^m} Y_t^w - \frac{W_t}{P_t^m} N_t - \frac{k \int_0^1 P_t^m(j) v_t(j) dj}{P_t^m} + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) F_{t+1}.$$

To post vacancies v_t, firms buy $v_t(j)$ units of each final good variety j subject to the constraint

$$v_t \leq \left(\int_0^1 v_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}. \tag{2.16}$$

Firms minimize their expenditure over a basket of final goods varieties which delivers the following demand function:

$$v_t(j) = \left(\frac{P_t^m(j)}{P_t^m} \right)^{-\epsilon} v_t. \tag{2.17}$$

The intermediate producer faces the same prices as the household. The firm keeps v_t vacancy open at a cost per period k, so that its total expenditure on vacancies is $k \int_0^1 P_t^m v_t(j) dj$.

The total expenditure on final goods by wholesalers and households can be aggregated as follows,

$$\int_0^1 P_t^m(j)C_t^m(j)dj + k\int_0^1 P_t^m(j)v_t(j)dj = \int_0^1 P_t^m(j)(C_t^m(j) + kv_t(j))dj$$

$$= \int_0^1 P_t^m(j)Y_t^d(j)dj = \int_0^1 P_t^m(j)((\frac{P_t^m(j)}{P_t^m})^{-\epsilon}C_t^m + k(\frac{P_t^m(j)}{P_t^m})^{-\epsilon}v_t)dj$$

$$= \int_0^1 ((P_t^m(j))^{1-\epsilon}dj(P_t^m)^{\epsilon}(C_t^m + kv_t) = P_t^m C_t^m + P_t^m kv_t$$

2.2.3 Retail Firms

The nominal marginal cost faced by a retail firm is the price paid for its wholesale input P_t^w. The retailer differentiates the wholesale output at no cost based on a constant returns to scale technology $Y_t(j) = Y_t^w(j)$. The retail firm minimizes its real cost $min_{Y_t^w(j)}\frac{P_t^w Y_t^w(j)}{P_t^m}$ subject to $Y_t(j) = Y_t^w(j)$, where the optimal condition and the envelope theorem give a definition of the real marginal cost as $\frac{P_t^w}{P_t^m}$.

The retail firms choose prices in a monopolistically competitive setting via a Calvo mechanism. Each period only a fraction $1-\omega$ of firms is allowed to adjust prices. This mechanism results in sticky prices and in the case of inflation, in an inefficient dispersion of consumption across different varieties. Monopolistic competition with Calvo pricing implies that the firms maximize the present discounted value of their current and future profits $\sum_{i=0}^{\infty}(\omega\beta)^i E_t\left\{D_{i,t+i,}\left[\frac{(1+s)P_t^m(j)-P_{t+i}^w}{P_{t+i}^m}\right]Y_{t+i}(j)\right\}$ subject to the demand curve $Y_{t+i}(j) = Y_{t+i}^d(j) = \left[\frac{P_t^m(j)}{P_{t+i}^m}\right]^{-\varepsilon}Y_{t+i}^d$, where s is a monopolistic competition subsidy and $D_{i,t+i,} = \frac{\lambda_{t+i}}{\lambda_t}$ is the relative growth of marginal utility of consumption from period t to period $t+i$. This profit maximization problem is formulated in terms of market consumption units and results in the following optimal condition for prices:

$$\frac{P_t^m(j)}{P_t^m} = \frac{\varepsilon \sum_{i=0}^{\infty} \left\{ (\omega\beta)^i E_t \left[D_{i,t+i}, \left(\frac{P_{t+i}^w}{P_{t+i}^m} \right) Y_{t+i}^d \right] \right\}}{(\varepsilon - 1)(1+s) \sum_{i=0}^{\infty} \left\{ (\omega\beta)^i E_t \left[D_{i,t+i}, \left(\frac{1}{P_{t+i}^m} \right) Y_{t+i}^d \right] \right\}}. \tag{2.18}$$

2.2.4 Market Clearing

Total retail demand must equal supply

$$Y_t = A_t \left(C_t^m + kv_t \right). \tag{2.19}$$

where $A_t \equiv \int_0^1 \left(\frac{P_t^m(j)}{P_t^m} \right)^{-\epsilon} dj$ is a price dispersion term. The economy-wide resource constraint requires that total consumption must equal total production

$$C_t = \left[a(Y_t - kv_t)^{\phi} + (1-a)(w^u(1-N_t)^{\phi} \right]^{1/\phi}. \tag{2.20}$$

2.2.5 Labor Market

Search frictions are present in the labor market. Each period a share ρ of the matches m_t, defined as filled job openings, in period t is destroyed. The number of unemployed at the end of period t is

$$u_t = 1 - N_t + \rho N_t = 1 - (1-\rho)N_t, \tag{2.21}$$

where ρ is the exogenous job separation rate.

The matching function is

$$m_t = d_t v_t^{\alpha_t} u_{t-1}^{1-\alpha_t} = d_t \theta_t^{\alpha_t} u_{t-1}, \tag{2.22}$$

where $\theta_t \equiv v_t/u_{t-1}$ is the labor market tightness and $0 < \alpha_t < 1$ is the elasticity of matching with respect to vacancies. α_t follows an AR(1) process with persistence ρ_α and standard deviation σ_α. d_t is a parameter that governs the efficiency of matching and follows an AR(1) process with persistence ρ_d and standard deviation σ_d.

The flow of employed workers has the following law of motion

$$N_t = (1-\rho)N_{t-1} + m_t = (1-\rho)N_{t-1} + d_t \theta_t^{\alpha_t} u_{t-1}. \tag{2.23}$$

The value of a vacancy is zero in equilibrium implying that the expected value of a filled job this period has to be equal to the unit cost of posting a vacancy:

$$q_t J_t = k, \tag{2.24}$$

where q_t is the job-filling probability defined as

$$q_t \equiv \frac{m_t}{v_t}. \tag{2.25}$$

The value of a filled job is equal to the firm's current period profit plus the discounted value of having a match in the following period. If the marginal worker produces Z of output units and W_t is the nominal wage paid to the worker, then the value of a filled job in terms of the market consumption is

$$J_t = \frac{P_t^w}{P_t^m} Z - \frac{W_t}{P_t^m} + (1-\rho)\beta E_t D_{t,t+1} J_{t+1} \tag{2.26}$$

Defining the real wage as

$$w_t \equiv \frac{W_t}{P_t^m} \tag{2.27}$$

the payoff from hiring a worker can be rewritten as

$$J_t = \frac{P_t^w}{P_t^m} Z - w_t + (1-\rho)\beta E_t D_{t,t+1} J_{t+1}. \tag{2.28}$$

The reservation wage for the firm is the wage which gives at least a surplus $J_t = 0$,

$$w_t^{rf} = \frac{P_t^w}{P_t^m} Z + (1-\rho)\beta E_t D_{t,t+1} J_{t+1}.$$

Substituting for the firm's surplus from the job posting condition delivers an expression which says that the real marginal benefit from employing a worker must equal the real marginal cost,

$$\frac{P_t^w}{P_t^m} Z = w_t + \frac{k}{q_t} - (1-\rho)\beta E_t D_{t,t+1} \frac{k}{q_{t+1}}.$$

Similarly, the firm's reservation wage is the wage

$$w_t^{rf} = \frac{P_t^w}{P_t^m} Z + (1-\rho)\beta E_t D_{t,t+1} \frac{k}{q_{t+1}}. \tag{2.29}$$

Define the job finding probability for a worker as

$$pr_t \equiv \frac{m_t}{u_{t-1}}.$$

The real value of being employed is a sum of the real wage and the future payoff from being employed adjusted for the job survival probability and for the likelihood of being fired and getting V^u_{t+1},

$$V^e_t = w_t + \beta E_t D_{t,t+1} \left\{ (1-\rho) V^e_{t+1} + \rho \left[pr_{t+1} V^e_{t+1} + (1 - pr_{t+1}) V^u_{t+1} \right] \right\}. \qquad (2.30)$$

An unemployed worker stays at home and produces a w^u units of home goods whose value in terms of market goods is $\frac{P^h_t}{P^m_t} = MRS_t$. The value of w^u in terms of market goods can be interpreted as an unemployment benefit. The payoff from being unemployed is the sum of the 'unemployment benefit' and the future payoff from staying unemployed or from becoming employed adjusted for the job finding probability

$$V^u_t = MRS_t w^u + \beta E_t D_{t,t+1} \left[(1 - pr_{t+1}) V^u_{t+1} + pr_{t+1} V^e_{t+1} \right]. \qquad (2.31)$$

The surplus from employment over unemployment is:

$$V^s_t = V^e_t - V^u_t = w_t - MRS_t w^u + \beta(1-\rho) E_t D_{t,t+1} (1 - pr_{t+1}) V^s_{t+1}. \qquad (2.32)$$

The workers' payoff from a match is affected by the size of the unemployment benefit which has a fixed component w^u and an endogenous component MRS_t. The time-varying component fluctuates with unemployment and inflation. A rise in unemployment increases the relative quantity of home goods, reduces the marginal rate of substitution MRS_t and the unemployment benefit. A rise in inflation lowers the relative price of home goods $\frac{P^h_t}{P^m_t}$ and also reduces the unemployment benefit. The reservation wage for a worker is the wage that delivers a surplus

$V_t^s = 0$:

$$w_t^{rw} = MRS_t w^u - \beta(1-\rho)E_t D_{t,t+1}(1-pr_{t+1})V_{t+1}^s \tag{2.33}$$

If a matched worker and firm form a Nash bargain over the wage, the bargaining set is determined by the two reservation wages: $[w_t^{rw}, w_t^{rf}]$. The wages are negotiated according to the game described by Hall (2005) which delivers a real wage rigidity in the form of a social norm.

$$w_t = \lambda\left[bw_t^{rf} + (1-b)w_t^{rw}\right] + (1-\lambda)w_{t-1}. \tag{2.34}$$

The wage is a weighted average of the Nash bargaining wage and the past wage, where λ is a parameter that governs the degree of real wage stickiness and b describes the degree of bargaining power of workers.

Setting $\lambda = 1$ and and using the fact that $V_t^s = \frac{b}{1-b}J_t = \frac{b}{1-b}\frac{k}{q_t}$ in equation (2.32) yields the following expression for the real wage,

$$w_t = w^u MRS_t + \left(\frac{1}{1-b}\right)\frac{k}{q_t} - (1-\rho)\beta E_t D_{t,t+1}\left(\frac{k}{q_{t+1}}\right)\left(\frac{b}{1-b}\right)(1-pr_{t+1}).$$

Substituting this result into (2.28), I obtain that the relative price of wholesale goods in terms of retail goods is

$$\frac{P_t^w}{P_t^m} = \frac{1}{\mu_t} = \frac{\eta_t}{Z},$$

where η_t is the effective cost of labor and is defined as

$$\eta_t \equiv \left(\frac{1}{1-b}\right)\frac{k}{q_t} - (1-\rho)\beta E_t D_{t,t+1}\left(\frac{k}{q_{t+1}}\right)\left(\frac{1}{1-b}\right)(1-bpr_{t+1}) + MRS_t w^u. \tag{2.35}$$

The marginal rate of substitution affects inflation through η_t. A rise in the marginal rate of substitution corresponds to an increase in the value of home relative to market goods. This increases wages in the wholesale sector and raises the wholesale prices relative to retail prices. The resulting rise in the marginal cost of the retail firms and fall in the retail price markup increases inflation.

Monetary policy also affects inflation through η_t. A rise in the nominal interest rate lowers $D_{t,t+1}$and lowers the value of a future match. This raises the current marginal cost because it reduces the value of any future recruitment cost savings the firm has obtained due to having formed a match in the current period. The fact that hiring costs are directly affected by the nominal interest rates indicates that the monetary policy works through a cost channel as well as though a standard aggregate demand channel.

2.3 Optimal Policy

The policymaker maximizes the welfare of the representative agent

$$W = max \textstyle\sum_{i=0}^{\infty} \beta^i U(C_{t+i}) \tag{2.36}$$

subject to a list of the structural equations describing the economy, including the optimality conditions of the competitive equilibrium economy, the market clearing conditions and relevant definitions and laws of motion. A full list is included in part 1 of the appendix to chapter 2. The number of endogenous variables that the policymakers choose exceeds the number of constraints by the number of policy instruments that the policymakers have at their disposal. Here the policymaker has only one policy instrument which is the nominal interest rate i_t.

The optimal policy problem is solved using the Lagrangian method. The general form of the problem can be summarized, using Lagrange multipliers as:

$$max_{x_t} E_t \left\{ \sum_{i=0}^{\infty} \beta^i b(x_{t+i-1}, x_{t+i}, x_{t+i+1}, \epsilon_{t+i}) \right.$$

$$\left. + \sum_{i=-\infty}^{\infty} \beta^i \lambda_{t+i} E_{t+i}^I \left[f(x_{t+i-1}, x_{t+i}, x_{t+i+1}, \epsilon_{t+i}) \right] \right\} \tag{2.37}$$

where x_t is the vector of endogenous variables, λ_t is a column vector of Lagrange multipliers and E_t^I is an expectation operator over an information set including all past and future realizations of the policy variables, and distributions of future shocks ϵ_t. The expectation operator E_t integrates over an information set including only the past values of the variables and the distributions of ϵ_t . The constraints f take place at all times, and are conditioned on the current period $t + i$ as the policymaker knows that the agents at time $t + i$ will use all available information in that period. The maximization problem results in the following first order conditions written in general form:

$$E_t \left\{ \frac{\partial}{\partial x_t} \left[b(x_{t-1}, x_t, x_{t+1}, \epsilon_t) \right] + \beta \frac{\partial}{\partial x_t} \left[b(x_t, x_{t+1}, x_{t+2}, \epsilon_{t+1}) \right] \right.$$

$$\beta^{-1} \lambda_{t-1} \frac{\partial}{\partial x_t} \left[f(x_{t-2}, x_{t-1}, x_t, \epsilon_{t-1}) \right]$$

$$\lambda_t \frac{\partial}{\partial x_t} \left[f(x_{t-1}, x_t, x_{t+1}, \epsilon_t) \right]$$

$$+\beta^i \lambda_{t+1} E^I_{t+1} \left[\frac{\partial}{\partial x_t} f(x_t, x_{t+1}, x_{t+2}, \epsilon_{t+1}) \right] \Bigg\} = 0 \tag{2.38}$$

The advantage of the Lagrangian approach is that it highlights the different information sets that the policymaker faces when making an optimal policy decision. The problem specified above describes the optimal policy under commitment when the policymaker acts according to the *timeless perspective* approach. The idea is that the policymaker chooses the policy in the distant past and promises to optimize according to equation (2.38). The constraints in f are valid from the infinite past to the infinite future and the policy has started before period 0, sometime in the distant past.

When the policymaker acts under commitment, he faces a time inconsistency problem as the optimal conditions for x_{t+1} in period t and for x_{t+1}in period $t+1$ might differ. In this case, the policymaker has the incentive to re-optimize every period and deviate from the optimal condition in the previous period. His policy commitment is not credible. The timeless perspective implies that the initial conditions for the backward multipliers are ignored. The optimization is performed numerically with DYNARE++ using second order perturbation methods on the optimal monetary policy conditions.

The disadvantage of the Lagrangian approach is that it does not highlight economically inefficient tradeoffs present in the policy maker's objective function. Since the policymaker faces a number of tradeoffs, the objective function does not simply minimize the fluctuations of variables relative to their steady state levels. The job of the policymaker who acts optimally is to minimize the fluctuation of *gaps* of dynamic variables versus their time-varying efficient counterparts. For example, the central bank should not stabilize the unemployment gap relative to its steady state level, defined as $\hat{u}_t = \frac{u_t}{u_{ss}} - 1$, but the gap of unemployment relative to its efficient level, $\tilde{u}_t = \frac{\hat{u}_t}{\hat{u}_t^e} - 1$.[2] The optimal benchmark of the policymaker is not the steady state but the efficient *dynamic* equilibrium of the economy. Hence, the drawbacks of the Lagrangian approach are two. First, the objective function of the policymaker is not derived explicitly as a function of fluctuations of gaps of unemployment and inflation. Second, the dynamic efficient benchmark of the policymaker is not characterized explicitly.

It is important how efficiency is defined. There are four inefficiencies in the model, including monopolistic competition in the final goods sector, sticky retail prices, sticky real wages and a search friction in the labor market. Monopolistic competition is inefficient because retail firms have market power. They set prices that are too high and lead to an inefficiently low demand. Calvo price stickiness results in an inefficient price dispersion that leads to an inefficient composition of the market consumer basket as households buy more of the cheaper varieties than they would in an efficient outcome. The search friction on the labor market results in too few productive matches and equilibrium unemployment. The real wage rigidity increases the aggregate cost of search and results in an inefficient composition of the home versus market consumption good basket.

An efficient dynamic equilibrium eliminates these inefficiencies. The sticky prices inefficiency is eliminated by imposing a constant markup $\mu_t = \mu$ and maintaining price stability. The monopolistic inefficiency is eliminated by imposing

[2] Note that $\hat{u}_t = \frac{u_t}{u_{ss}} - 1$ and $\hat{u}_t^e = \frac{u_t^e}{u_{ss}^e} - 1$.

a markup equal to one $\mu = 1$. The search friction can usually be eliminated by imposing the Hosios condition where the elasticity of the matching function with respect to unemployment is set equal to the bargaining share of workers, $1 - \alpha = b$. Finally, the real wage rigidity is eliminated by changing the social norm and setting $\lambda = 1$.

2.4 Parametrization and Methodology

The parametrization is based on standard parameters taken from the literature. Table 2.2 gives a list of the parameter values for the baseline version where home and market goods are perfect substitutes. Table 2.3 reports the parametrization under the version when home and market consumption are imperfectly substitutable. The source of the values for standard parameters is Ravenna and Walsh (2011). The choice of values of the non-standard parameters is discussed below.

In both versions of the model, the vacancy cost k is set to to deliver a steady state ratio of vacancies to employment $\frac{v}{N}$ of 11 percent which is close to the average quarterly value of 10% based on JOLTS. The productivity parameter w^u is calibrated to deliver a steady state replacement ratio of unemployment benefits to real wages of about 0.54 in the base line version and 0.56 in the imperfect substitution version.

The steady state level of the efficiency of the matching function d is set to deliver a steady state job finding probability of about 0.9 in the baseline version and 0.86 in the imperfect substitutes version. The values are relatively higher compared to the standard estimate of 0.71 but it is in line with the recent estimates of Davis et al. (2010) who report a daily job-filling probability of around 5 percent. This implies a quarterly probability of filling a vacancy q of 0.98.

When home and market consumption are imperfect substitutes, the parameter ϕ is set to fit an elasticity of substitution between market and home goods of 3. Benhabib et al. (1991) set this elasticity equal to 5 in their most preferred specification. In McGrattan et al. (1997) the estimated elasticity is slightly less than 2, while in Schorfheide (2003) the estimate is around 2.3. Using micro data, Rupert et al. (1995) estimate a value of around 1.8, Aguiar and Hurst (2007) estimate a value of around 2 and Gelber and Mitchell (2009) estimate a value of around 2.5. Karabarbounis (2010) estimates it at 3.393.

The preference parameter a in the consumption aggregate is set to 0.6 and is based on estimate of Karabarbounis (2010).

I set the parameters that describe the stochastic process of the efficiency of matching to a persistence ρ_d of 0.8 and a standard deviation σ_d of 0.05. The estimation of the matching function for the post recession period implied that the efficiency of matching fell by 0.074. However, this result may be subject to a bias due to omitted variables or a small sample. Therefore, I parametrize the behavior of the efficiency shock based on two empirical studies. Sedlacek (2010) relaxes the assumption of a constant matching function and shows that fluctuations in the efficiency of matching are an important determinant of job finding rate variation. Estimates of the matching function are severely complicated by poor data on vacancies. However, he estimates a model where not only match efficiency but also vacancies are unobserved. The results show that match efficiency is procyclical and can explain 26-35% of job finding rate variation. He estimates a persistence parameter of about 0.719 and a standard deviation of 5.9% percent along the business cycle. Beauchemin and Tasci (2007) construct a multiple-shock version of the Mortensen-Pissarides labor market search model to investigate the basic model's well-known tendency to under predict the volatility of key labor market variables. Data on U.S. job finding and job separation probabilities are used to help estimate the parameters of a three-dimensional shock process comprising labor productivity, job separation, and matching or 'allocative' efficiency. They estimate the parameters of the efficiency shock to be $\hat{\rho}_d = 0.807$ and $\hat{\sigma}_d = 0.051$.

The standard deviation σ_α and the persistence ρ_α of the matching elasticity shock are assumed to be 0.1 and 0.8, respectively. The estimation of the matching function for the post recession period implied that the elasticity of matching rose by about 0.033 However, this standard deviation is too small to result in a substantial shift in the model based Beveridge curve. The variability in the unemployment and inflation is not sufficient in order to get a sense of the trade offs that the central bank faces after an elasticity shock. That is why the standard deviation of the shock was set to 0.1, a number large enough to generate a substantial rise in unemployment on impact (about 2%) . This value was also chosen based on Lubik (2011) who uses a Bayesian approach to estimate a dynamic version of the search and matching labor model. He finds that in the post recession period the elasticity of matching rose by about 0.16.

Solving the deterministic steady state of a non-linear system of equations is non-trivial and the first order conditions for the optimal policy add considerable complexity. DYNARE++ provides a solution for the steady state of the model under the optimal policy and even calculates an initial guess for the Lagrange multipliers but it requires a good initial guess for the steady state values of the decentralized competitive model. The structural equations that are the constraints of the optimal monetary policy problem can be reduced to a non-linear expression that involves the model parameters and labor market tightness. I solve it numerically using the calibration in table 2.2 and obtain a root of 0.68. For the version of the the model where home and market goods are imperfect substitutes, the labor market tightness takes a value of 0.25. I use these as my measures for the steady state level of labor market tightness. A detailed solution of the steady state is described in part 2 of the appendix to chapter 2.

A discussion of the simulation exercises performed and the results follows.

2.5 Results

Four sets of results are reported in this section. First, the model is simulated under the assumption that home and market goods are perfect substitutes and real wages are flexible. The optimal monetary policy to two types of shocks is analyzed. The first type is a negative one standard deviation shock to the efficiency of matching and the second is a positive one standard deviation shock to the elasticity of employment matches with respect to vacancies. Next, I analyze the effect of two modeling assumptions on the optimal monetary policy response of the central bank. The model is simulated under the assumption of sticky wages and the results are compared to the baseline version where there is no real wage rigidity. In the third set of results, home and market goods are assumed to be imperfect substitutes; the implications of this assumption for the optimal policy response are compared to the case of perfect substitution. Finally, the optimal monetary policy response is compared to the policy behavior implied by a standard Taylor rule. The impulse response functions are reported in the units of the respective variables relative to the steady state. For example, in the baseline case unemployment increases by two percent on impact in response to a negative shock to the efficiency of matching.

2.5.1 Optimal Policy under Flexible Wages and Perfect Substitutes

2.5.1.1 Shock to the Efficiency of Matching

Figure 2.2 shows that the fall in the efficiency of matching causes an increase in unemployment because it leads to fewer employment matches in the economy. On the firm side, worsening labor market conditions lead to a rise in hiring costs and make firms post fewer vacancies on impact. The increase in unemployed workers corresponds to a shift of resources from the market toward the home good sector. Household consumption of home goods rises at the expense of falling market good consumption. Household aggregate consumption spending falls on impact which means that it is dominated by movements in market consumption.

The fall in the efficiency of the labor market leads workers to expect that it will be harder to find a job in the future. The value of having a job today increases because the future probability of making a successful match falls. As a result, the worker is willing to take a much lower reservation wage which pushes down the real wage and the price of wholesale goods relative to retail goods. This lowers the marginal cost of retail firms and leads to a fall in inflation. Figure 2.2 illustrates that the optimal monetary policy in response to the shock is to lower the interest rate in order to stabilize inflation. The policy maker is not facing trade-offs in meeting the objectives of stabilizing unemployment and inflation. This is because the rise in unemployment is not inefficient; actual and "natural" unemployment rise by the same amount which leaves the unemployment gap unchanged. Hence, the central bank does not need to worry that rising unemployment will reduce welfare because consumption is falling or because the composition of the household basket between market and home goods is suboptimal. It only needs eliminate inflation because price dispersion would lead to inefficient composition of the household market consumption across different varieties.

2.5.1.2 Shock to the Elasticity of Matching

When the shift in the BC curve results from a rise in the elasticity of matching with respect to vacancies, the central bank faces a policy trade-off. This shock generates a deviation from the Hosios condition which requires that $b = 1 - \alpha_t$ and makes unemployment rise relative to its efficient counterpart (see figure 2.3). Vacancies are not reactive enough to changes in unemployment. Therefore, more workers than is efficient stay without a job because firms reaction is not elastic enough and vacancies do not rise as much as is efficient. The increase in α makes the hiring rate q_t temporarily less sensitive to changing labor market conditions. The decline in the expected probability of filling a vacancy makes the firms willing to offer disproportionately high wages in order to attract workers. This pushes up the real wage and inflation. The central bank faces a trade-off between stabilizing inflation and labor market variables. If it raises the interest rate, it will stabilize inflation but worsen the rise in unemployment and mute the rise in vacancies. If it lowers it, it will reduce the unemployment and the vacancies gap, but increase the rise in inflation. Figure 2.3 suggests that the central bank chooses to stabilize labor market variables as the nominal interest rate falls by 8% on impact. The trade-off is apparent in the fact that the economy has to suffer a 2% rise in inflation for about 25 quarters.

2.5.2 Optimal Policy under Sticky Wages and Perfect Substitutes

The optimal monetary policy in response to a fall in the efficiency of matching changes when real wages are sticky. The reported impulse response are under the assumption of a high degree of real wage rigidity where $\lambda = 0.1$. The fact that the real wage cannot fall enough to absorb the shock implies retail firms are forced to lower their markups after their hiring costs rise. This pushes up inflation. At the same time, since the real wage cannot adjust enough, unemployment becomes more volatile. Firms are forced to make fewer matches than is efficient and actual unemployment rises by more than "natural" unemployment which raises the unemployment gap. The central bank faces a trade-off between raising the interest rate in order to offset the inflationary impact of the shock and lowering the interest rate in order to close the unemployment gap. Figure 2.4 illustrates that the optimal monetary policy maker is not able to meet either of his objectives perfectly. He lowers the nominal interest rate in order to weaken the rise in unemployment but he is not aggressive enough to prevent unemployment from rising by more than under flexible wages. The third panel of figure 2.4 also shows that central bank is forced to suffer persistent inflation both as a consequence of the shock and of its expansionary policy actions.

2.5.3 Optimal Policy under Flexible Wages and Imperfect Substitutes

The results under the assumption that home and market goods are imperfect substitutes are reported next. The optimal policy response is simulated under the assumption the elasticity of substitution is 3 and that there is a slight home bias $a = 0.6$ towards the consumption of market goods. The first panel of figure 2.5 shows that the nominal interest rate falls by more than under the assumption of perfect substitutes. This is because inflation volatility increases as home and market goods become imperfect substitutes. Equation (2.35) demonstrates the fluctuations in the relative price of home and market goods lead to fluctuations in the effective cost of labor and more fluctuations in inflation. The fall in the efficiency of matching leads to a shift of workers from the market toward the home sector and generates a rise in the relative supply of home goods. This reduces the relative value of the "unemployment benefit" which lowers inflation more than when home and market goods are perfect substitutes. In order to stabilize inflation, the central bank needs to lower the nominal interest rate by a larger amount.

The second panel of figure 2.5 shows that when market and home when home and market goods are imperfect substitutes unemployment becomes more volatile. On impact, unemployment rises by less because households are not as willing to substitute the fall in market goods consumption with a rise in home goods consumption. However, diminishing marginal rate of substitution means that households require larger amounts of home goods in order to be compensated for each marginal decrease in the consumption of market goods. That is why unemployment rises by a greater amount later. This result implies that assuming imperfect substitutability between home and market goods is a way to resolve the Shimer puzzle. Shimer (2005) shows that unemployment in search and matching models is not volatile enough along the business cycle because most of the adjustment is done by the real wage. Imperfect substitutability between home and market goods is an assumption that generates higher unemployment volatility in the search and matching labor model.

2.5.4 Optimal Policy versus a Taylor Rule

This section examines how the optimal monetary policy differs from the policy responses under a standard Taylor rule that includes inflation and output growth,

$$\beta(1+i_t) = (1+\pi_t)^{\gamma_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{\gamma_y}, \tag{2.39}$$

γ_π and γ_y are the policy weights that determine how aggressive the policymaker is in stabilizing inflation and output fluctuations. These values of these coefficients are set in order to ensure that the model is stationary and that the behavior of the central bank satisfies the principle that the nominal interest rate should respond more than one for one to inflation fluctuations. Hence, $\gamma_\pi = 3.5$ and $\gamma_y = 0.5$.

Figure 2.6[3] compares the monetary policy response to a fall in the efficiency of matching. The optimal policy is to pursue price stability while the Taylor rule policy requires that the nominal interest rate responds to the fall in output growth. Comparing the dynamic paths of the nominal interest rate rule and the optimal policy suggests that Taylor rule implies a less aggressive pursuit of price stability than the optimal policy. Figure 2.6 shows that the central bank that acts optimally needs to lower the interest rate by 3% on impact while the central bank that acts according to a Taylor rule only lowers it by 1%. Therefore, inflation is not perfectly stable and household welfare is lower due to price dispersion. As firms raise their markups in order to absorb their rising hiring costs, they do not have to adjust their employment margins as much and unemployment rises by less than under the optimal policy.

Figure 2.7 compares the monetary policy responses to a rise in the elasticity of matching with respect to vacancies. The nominal interest rate again falls

[3] Real wages are assumed to be flexible.

less sharply on impact. The central bank acting under a Taylor rule is not able to offset the rise in unemployment as successfully as the optimal policy maker. Consequently, the economy experiences less variability in inflation compared to the case under optimal monetary policy. In fact, inflation falls on impact in the Taylor rule case.

2.6 Conclusion

I build a DSGE model with search and matching frictions where the home and market goods are imperfect substitutes and real wages are sticky. I use it to analyze the optimal monetary policy response to outward shifts in the Beveridge curve. The optimal response to two types of shocks is compared. The first shock is a fall in the ability of the labor markets to match unemployed workers to unfilled job openings. The second is an increase in the elasticity of matching with respect to vacancies which makes the hiring rate less responsive to labor market conditions.

The results indicate that the monetary policy response depends on the source of the shift of the BC. If the efficiency of matching falls, unemployment does not fluctuate relative to its efficient level and the unemployment gap remains stable. The central bank that acts optimally need not deviate from a policy of price stability. However, the elasticity shock acts like a cost push shock; it presents the policy maker with a trade off between stabilizing the unemployment gap and inflation. These findings suggest that it is important to identify the source of the shift of the BC. Lubik (2011) draws a conclusion that the elasticity shock is an unlikely candidate. In addition, CPI inflation has been consistently low between 0 and 0.5% and relatively stable in the post recession period despite the

Fed's expansionary monetary policy actions. Thus, the behavior of inflation also suggests that conditional on the assumption that the Fed acts optimally, the most likely source of the shift is a fall in the efficiency of matching.

I also explore the implications of assuming sticky real wages about the optimal behavior of the central bank in response to the efficiency shock. The presence of a real wage rigidity presents the central bank with a trade off between stabilizing inflation and the unemployment gap. Considering recent findings about the increased volatility of real wages in post-1984 US data (see Galí et al. (2010)), this result implies that the central bank needs to worry about its assumptions about real wage rigidities when it makes its monetary policy decision. Assuming highly rigid real wages can result in a monetary policy decision that is too expansionary on impact.

The current version of the model helps think about unemployment and the optimal response to fluctuations in the labor market but it excludes the intensive margin of employment and fluctuations in output per hour. The behavior of productivity in the post 1984 is puzzling because its correlation with output fell and implied that labor productivity is countercyclical. I plan to add an intensive margin to the model and explore the implied behavior of labor productivity after a shift in the BC and when the central bank acts optimally.

2.7 Tables and Figures

Figure 2.1: Beveridge Curve with Data on Vacancies and Unemployment from JOLTS

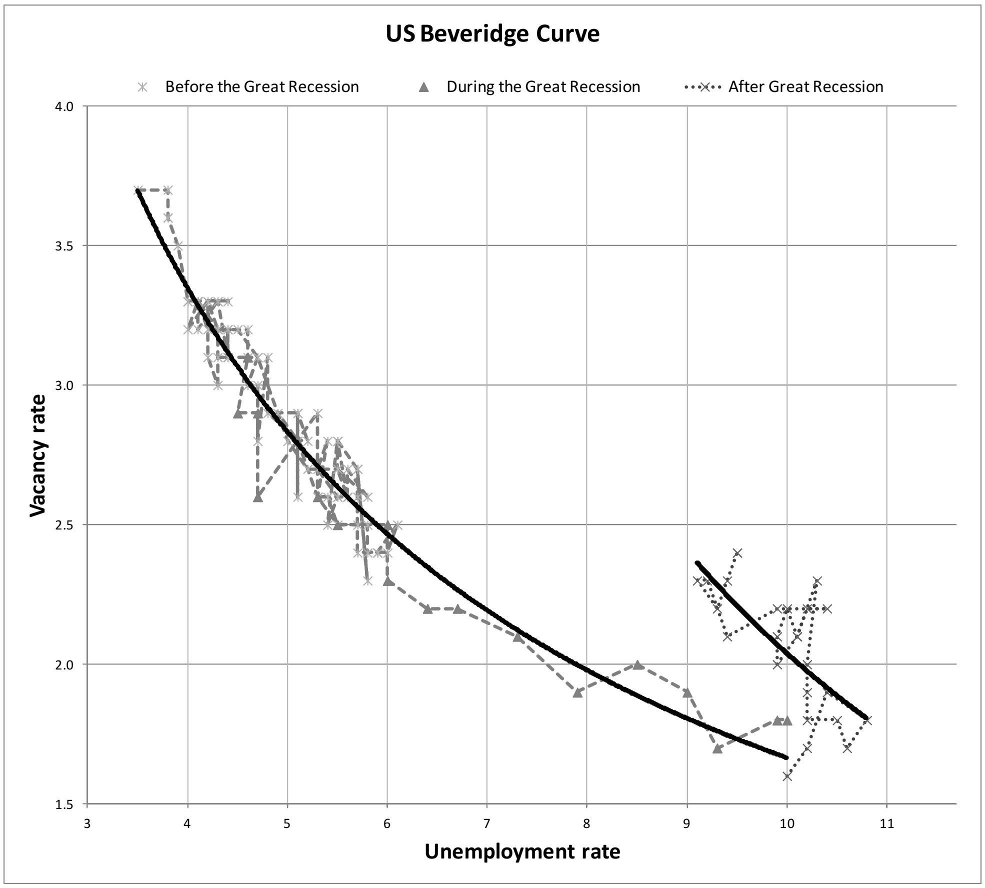


Figure 2.2: Optimal Monetary Policy to a Matching Efficiency Shock

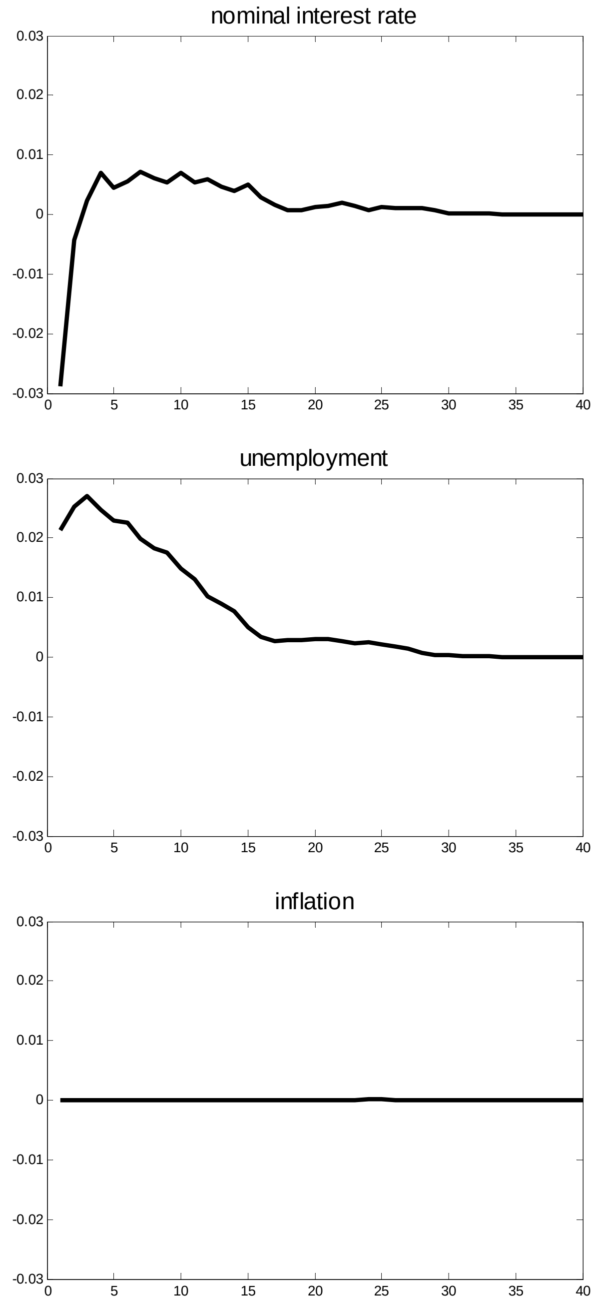


Figure 2.3: Optimal Monetary Policy to a Matching Elasticity Shock

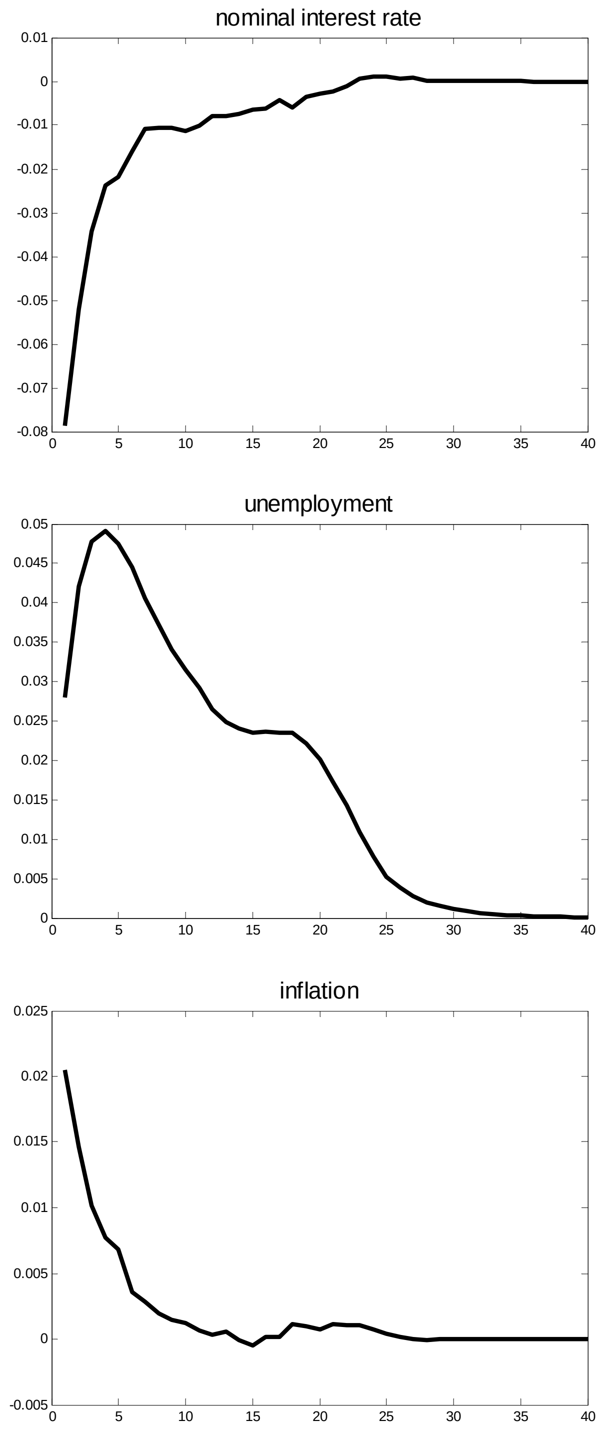


Figure 2.4: Optimal Monetary Policy to a Matching Efficiency Shock

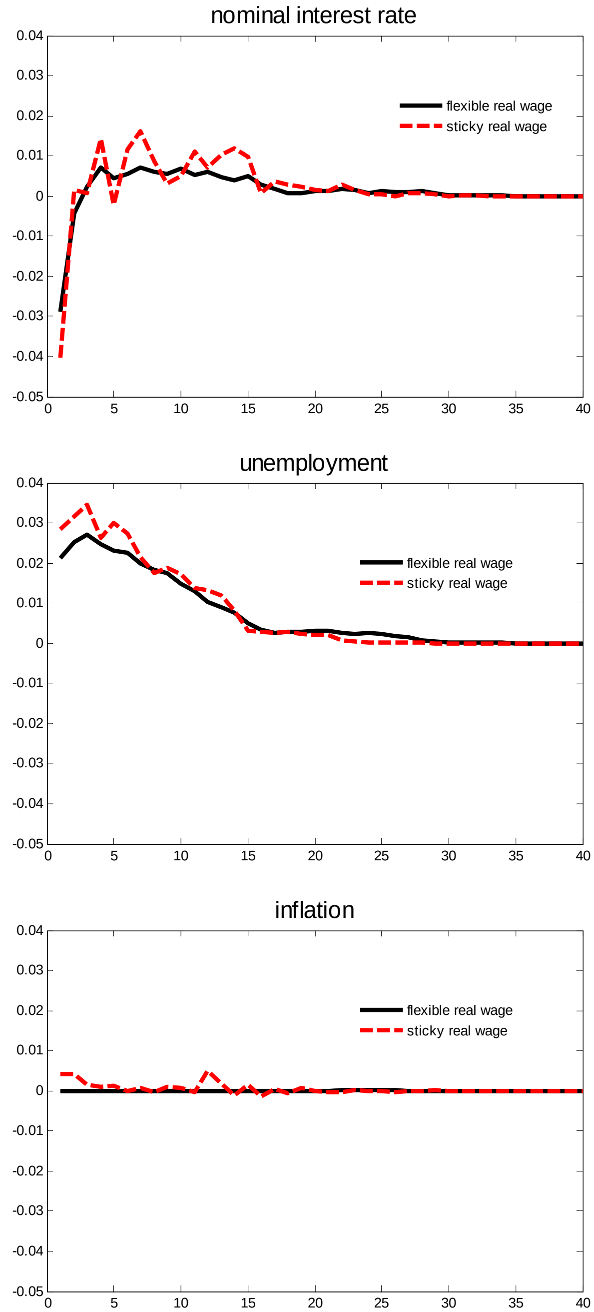


Figure 2.5: Optimal Monetary Policy to a Matching Efficiency Shock

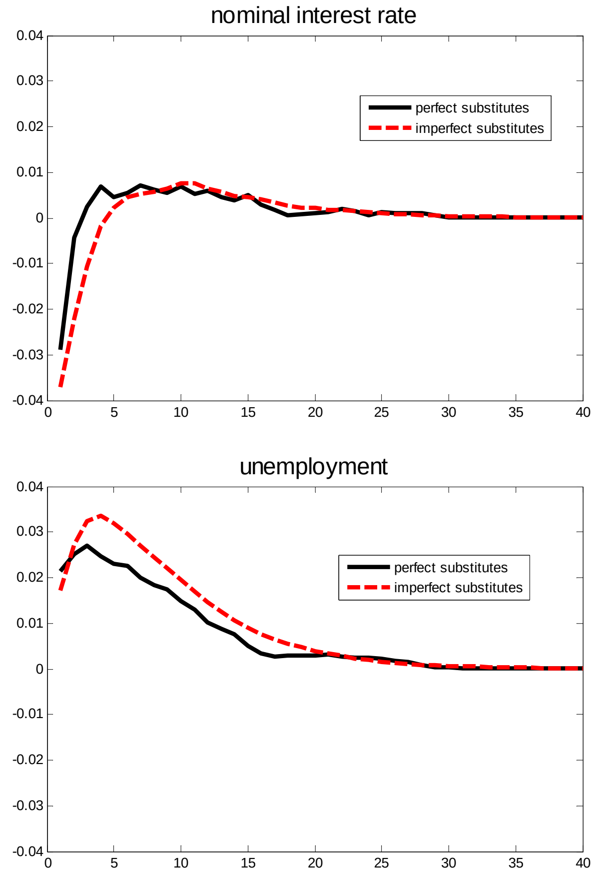


Figure 2.6: Optimal Monetary Policy to a Matching Efficiency Shock

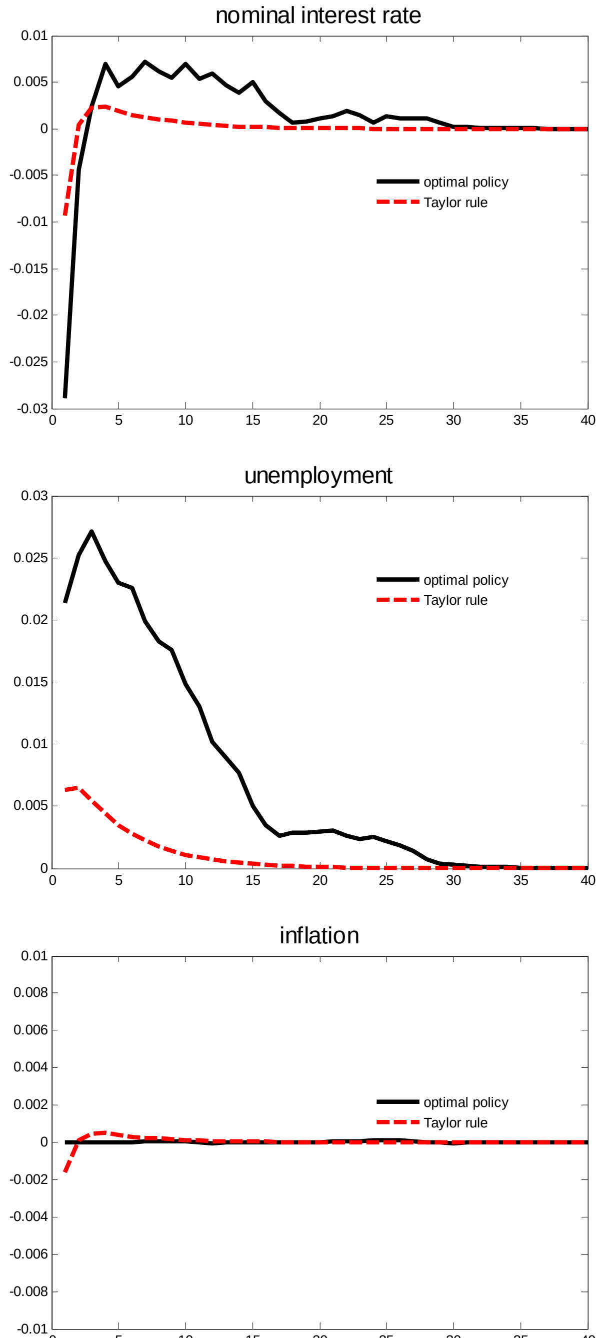


Figure 2.7: Optimal Monetary Policy to a Matching Elasticity Shock

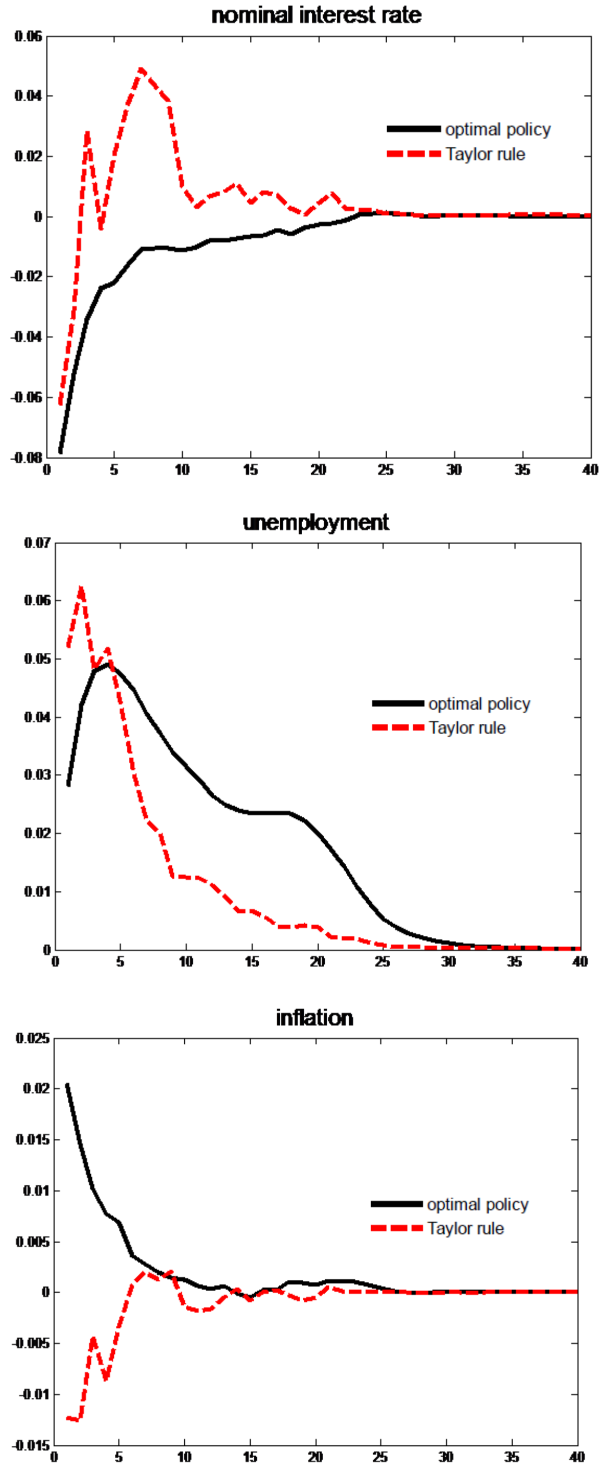


Table 2.1: Estimation of Matching Function

	Period before and during the Great Recession 12/2000-06/2009			Period after the Great Recession 07/2009-07/2011		
	Constant	Job Openings	Unemployment	Constant	Job Openings	Unemployment
Hiring	0.247* (0.021)	0.902* (0.019)	0.098* (0.019)	0.173* (0.042)	0.935* (0.116)	0.065 (0.116)
Notes: "*" indicates significance at the 1% level.						

Table 2.2: Values of Structural Parameters Under Perfect Substitution

Parameter	Description	Value	Source
β	Household discount factor	0.99	Ravenna and Walsh (2011)
σ	Risk aversion	2	Ravenna and Walsh (2011)
w^u	Unemployment benefit	0.42	Target $\frac{w^u}{w_{ss}} = 0.54$
ω	Fraction of firms adjusting prices each period	0.75	Ravenna and Walsh (2011)
ρ	Average probability of job destruction	0.1	Ravenna and Walsh (2011)
k	Vacancy posting cost	0.49	Target $\frac{v_{ss}}{Y_{ss}} = 0.11$
α	Elasticity of the matching function to vacancies	0.5	Ravenna and Walsh (2011)
d	Steady state efficiency of matching	0.75	Target $q_{ss} = 0.9$ and $N_{ss} = 0.94$
b	Bargaining power of workers	0.5	Ravenna and Walsh (2011)
σ_d	Standard deviation of efficiency shock	0.05	Sedlacek (2010)
ρ_d	Persistence of the efficiency shock	0.8	Sedlacek (2010)
σ_α	Standard deviation of the elasticity shock	0.1	Lubik (2011)
ρ_α	Persistence of the elasticity shock	0.8	Assumed
s	Monopolistic competition subsidy	0.2	Ravenna and Walsh (2011)
ϵ	Elasticity of substitution between intermediate inputs	6	Ravenna and Walsh (2011)

Table 2.3: Values of Structural Parameters Under Imperfect Substitution

Parameter	Description	Value	Source
ϕ	Elasticity of substitution between home and market goods	2/3	Karabarbounis (2010)
a	Weight on consumption of market goods	0.6	Karabarbounis (2010)
β	Household discount factor	0.99	Ravenna and Walsh (2011)
σ	Risk aversion	2	Ravenna and Walsh (2011)
w^u	Unemployment benefit	0.3	Target $\frac{w^u}{w_{ss}} = 0.56$
ω	Fraction of firms adjusting prices each period	0.75	Target$\frac{MRS_{SS}w^u}{w_{ss}} = 0.54$
ρ	Average probability of job destruction	0.1	Ravenna and Walsh (2011)
k	Vacancy posting cost	0.9	Target $\frac{v_{ss}}{Y_{ss}} = 0.11$
α	Elasticity of the matching function to vacancies	0.5	Ravenna and Walsh (2011)
d	Steady state efficiency of matching	0.43	Target $q_{ss} = 0.86$
b	Bargaining power of workers	0.5	Ravenna and Walsh (2011)
σ_d	Standard deviation of efficiency shock	0.05	Sedlacek (2010)
ρ_d	Persistence of the efficiency shock	0.8	Sedlacek (2010)
σ_α	Standard deviation of elasticity shock	0.1	Sedlacek (2010)
ρ_α	Persistence of the elasticity shock	0.8	Sedlacek (2010)
s	Monopolistic competition subsidy	0.2	Ravenna and Walsh (2011)
ϵ	Elasticity of substitution between intermediate inputs	6	Ravenna and Walsh (2011)

2.8 Appendix

2.8.1 Part 1 List of Structural Equations

$$\max E_t \sum_{i=0}^{\infty} \beta^i \frac{C_{t+i}^{1-\sigma}}{1-\sigma} \tag{2.40}$$

with respect to $\{c_t, y_t, v_t, u_t, N_t, p_t^m, p_t^h, rp, \pi_t^m, \pi_t, \mu_t, w_t^{rf}, w_t^{rw}, w_t, q_t, J_t, V_t^s,$ $i_t, r_t, m_t, \theta_t, pr_t, p_t^{mo}, S1_t, S2_t, A_t\}_{i=0}^{\infty}$

subject to

$$Y_t = ZN_t \tag{2.41}$$

$$C_t^h = w^u(1 - N_t) \tag{2.42}$$

$$C_t = \left[a(C_t^m)^\phi + (1-a)(C_t^h)^\phi\right]^{1/\phi} \tag{2.43}$$

$$MRS_t = \left(\frac{1-a}{a}\right)\left(\frac{C_t^h}{C_t^m}\right)^{\phi-1}. \tag{2.44}$$

$$\lambda_t = aC_t^{1-\sigma-\phi}(C_t^m)^{\phi-1} \tag{2.45}$$

$$\lambda_t = \beta E_t \lambda_{t+1} \frac{(1+i_t)}{(1+\pi_{t+1}^m)} \tag{2.46}$$

$$u_t = 1 - (1-\rho)N_t \tag{2.47}$$

$$N_t = (1-\rho)N_{t-1} + d_t\theta_t^{\alpha}u_{t-1} \tag{2.48}$$

$$J_t = \frac{\kappa}{q_t} \tag{2.49}$$

$$\frac{Z}{\mu_t} - w_t + (1-\rho)\beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)J_{t+1} = J_t \tag{2.50}$$

$$w_t^{rf} = Z\frac{p_t^m}{\mu_t} + (1-\rho_t)\beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)J_{t+1} \tag{2.51}$$

$$w_t - MRS_t w^u + (1-\rho)\beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)(1-pr_{t+1})V_{t+1}^s = V_t^s$$

$$w_t^{rw} = MRS_t w^u - (1-\rho)\beta E_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)(1-pr_{t+1})V_{t+1}^s \tag{2.52}$$

$$1 + r_t = E_t\left(\frac{1+i_t}{1+\pi_{t+1}^m}\right) \tag{2.53}$$

$$m_t = d_t u_{t-1}^{1-\alpha_t} v_t^{\alpha_t} = d_t u_{t-1}\theta_t^{\alpha_t} \tag{2.54}$$

$$\theta_t = \frac{v_t}{u_{t-1}} \tag{2.55}$$

$$q_t = \frac{m_t}{v_t} = d_t\theta_t^{\alpha_t - 1} \tag{2.56}$$

$$pr_t = \frac{m_t}{u_{t-1}} = d_t \theta_t^{\alpha_t} \tag{2.57}$$

$$p_t^{mo} = \frac{\varepsilon}{\varepsilon - 1} \frac{1}{(1+s_t)} \frac{S1_t}{S2_t} \tag{2.58}$$

$$S1_t = \frac{1}{\mu_t} \lambda_t Y_t + \beta \omega E_t S1_{t+1} \tag{2.59}$$

$$S2_t = \lambda_t Y_t + \beta \omega E_t S2_{t+1} \tag{2.60}$$

$$w_t = \lambda \left[b w_t^{rf} + (1-b) w_t^{rw} \right] + (1-\lambda) w_{t-1} \tag{2.61}$$

$$(1+\pi_t^m)^{1-\epsilon} = \frac{\omega}{\left[1 - (1-\omega)\left(p_t^{mo}\right)^{1-\epsilon}\right]} \tag{2.62}$$

$$Y_t = A_t \left(C_t^m + k v_t\right) \tag{2.63}$$

2.8.2 Part 2 Steady State

Let the productivity $Z = 1$ and debt $B_{ss} = 0$. Note also that $\pi^m_{ss} = 0$ and $D_{ss} = 1$. The Euler equation implies that the nominal interest rate $i_{ss} = \frac{1}{\beta} - 1$. The Fisher equation implies that $r_{ss} = i_{ss}$. Under an efficient steady state the markup is $\mu^e_{ss} = 1$. Under an inefficient steady state where $s = 0$, the markup is $\mu_{ss} = \frac{\varepsilon}{(\varepsilon - 1)}$. The Hosios condition of efficiency requires that $b_{ss} = 1 - \alpha$. The Nash bargaining set at the steady state is determined by the two reservation wages: $[w^{rw}_{ss}, w^{rf}_{ss}]$. The steady state wage is determined by Nash bargaining

$$w_{ss} = b_{ss} w^{rf}_{ss} + (1 - b_{ss}) w^{rw}_{ss} \tag{2.64}$$

First, I rewrite the surpluses of the worker and the firm in terms of the differences between the real wage and the reservation wages, $V^s_{ss} = w_{ss} - w^{rw}_{ss}$ and $J_{ss} = w^{rf}_{ss} - w_{ss}$ and use them to rewrite $w^{rw}_{ss} = w_{ss} - V^s_{ss}$ and $w^{rf}_{ss} = w_{ss} + J_{ss}$. I substitute for the reservation wages in the wage equation $w_{ss} = b_{ss}(w_{ss} + J_{ss}) + (1 - b_{ss})(w_{ss} - V^s_{ss})$. Then, I simplify and rearrange to obtain that the surplus of the worker V^s_{ss} is proportional to the surplus of the firm J_{ss}, $V^s_{ss} = \frac{b_{ss}}{1 - b_{ss}} J_{ss}$. Using the vacancy posting condition $J = \frac{k}{q_{ss}}$, I show that the surplus of the worker is a function of the job filling probability and the vacancy cost:

$$V^s_{ss} = \frac{b_{ss}}{1 - b_{ss}} \frac{k}{q_{ss}} \tag{2.65}$$

I substitute this result in the worker surplus equation to obtain that $\frac{b_{ss}}{1 - b_{ss}} \frac{k}{q_{ss}} = w_{ss} - w^u MRS_{ss} + \beta(1 - \rho)(1 - pr_{ss}) \frac{b_{ss}}{1 - b_{ss}} \frac{k}{q_{ss}}$. Then, I subtract the firm surplus condition $\frac{1}{\mu_{ss}} = w_{ss} + \frac{k}{q_{ss}} - (1 - \rho)\beta \frac{k}{q_{ss}}$ to get $\frac{b_{ss}}{1 - b_{ss}} \frac{k}{q_{ss}} - \frac{1}{\mu_{ss}} = -w^u MRS_{ss} + \beta(1 - \rho)(1 - pr_{ss}) \frac{b_{ss}}{1 - b_{ss}} \frac{k}{q_{ss}} - \frac{k}{q_{ss}} + (1 - \rho)\beta \frac{k}{q_{ss}}$. Next, I rearrange

$$\frac{1}{\mu_{ss}} - w^u MRS_{ss} = \frac{b_{ss}}{1-b_{ss}}\frac{k}{q_{ss}} - \beta(1-\rho)(1-pr_{ss})\frac{b_{ss}}{1-b_{ss}}\frac{k}{q_{ss}} + \frac{k}{q_{ss}} - (1-\rho)\beta\frac{k}{q_{ss}}.$$

The right hand side can be further simplified

$$\frac{b_{ss}}{1-b_{ss}}\frac{k}{q_{ss}} - \beta(1-\rho)(1-p_{ss})\frac{b_{ss}}{1-b_{ss}}\frac{k}{q_{ss}} + \frac{k}{q_{ss}} - (1-\rho)\beta\frac{k}{q_{ss}} =$$

$$= \frac{1}{1-b_{ss}}\frac{k}{q_{ss}} - (1-\rho)\beta\frac{k}{q_{ss}}(1+(1-pr_{ss})\frac{b_{ss}}{1-b_{ss}}) =$$

$$= \frac{1}{1-b_{ss}}\frac{k}{q_{ss}} - (1-\rho)\beta\frac{1}{1-b_{ss}}\frac{k}{q_{ss}}(1-b_{ss}pr_{ss})$$

Finally, I obtain that

$$\frac{1}{\mu_{ss}} - w^u MRS_{ss} = \frac{1}{1-b_{ss}}\frac{k}{q_{ss}} - (1-\rho)\beta\frac{1}{1-b_{ss}}\frac{k}{q_{ss}}(1-b_{ss}pr_{ss}). \tag{2.66}$$

The next step is to use the home goods production function $C^h_{ss} = w^u(1-N_{ss})$, the market production function $Y_{ss} = N_{ss}$ and the market sector clearing condition $C^m_{ss} = Y_{ss} - kv_{ss}$[4] to substitute in the definition of the marginal rate of substitution $MRS_{ss} = \frac{(1-a)(C^h_{ss})^{\phi-1}}{a(C^m_{ss})^{\phi-1}}$. I obtain that

$$MRS_{ss} = \frac{(1-a)(w^u(1-N_{ss}))^{\phi-1}}{a(N_{ss}-kv_{ss})^{\phi-1}}$$

[4]Note that the price dispersion term $A_{ss} = 1$ at the steady state.

Then, I divide both the numerator and the denominator by $N_{ss}^{\phi-1}$and the expression above becomes $MRS_{ss} = \frac{(1-a)(w^u(\frac{1-N_{ss}}{N_{ss}}))^{\phi-1}}{a(1-k\frac{v_{ss}}{N_{ss}})^{\phi-1}}$. I rearrange the definition of the unemployment rate $\frac{1-N_{ss}}{N_{ss}} = \frac{u_{ss}}{N_{ss}} - \rho$. I substitute the matching function in the employment accumulation equation $\rho N_{ss} = d_{ss}\theta_{ss}^{\alpha}u_{ss}$ and rearrange it to obtain $\frac{u_{ss}}{N_{ss}} = \frac{\rho}{d_{ss}\theta_{ss}^{\alpha}}$. I substitute this result in the definition of the unemployment rate $\frac{1-N_{ss}}{N_{ss}} = \frac{\rho}{d_{ss}\theta_{ss}^{\alpha}} - \rho$. I can also write the vacancy to employment ratio in terms of labor market tightness $\frac{v_{ss}}{N_{ss}} = \theta_{ss}\frac{u_{ss}}{N_{ss}} = \theta_{ss}\frac{\rho}{d_{ss}\theta_{ss}^{\alpha}} = \frac{\rho}{d_{ss}\theta_{ss}^{\alpha-1}}$. Finally, I express the marginal rate of substitution only in terms of structural parameters and steady state labor market tightness

$$MRS_{ss} = \frac{(1-a)\left[w^u(\frac{\rho}{d_{ss}\theta_{ss}^{\alpha}} - \rho)\right]^{\phi-1}}{a(1-\frac{k\rho}{d_{ss}\theta_{ss}^{\alpha-1}})^{\phi-1}}$$

The definitions of the job finding and job filling probabilities and the matching function imply that $q = d\theta_{ss}^{\alpha-1}$ and $pr = d\theta_{ss}^{\alpha}$. Substitute these in equation (2.42) to obtain

$$\frac{1}{\mu_{ss}} - w^u\frac{(1-a)\left[w^u(\frac{\rho}{d_{ss}\theta_{ss}^{\alpha}} - \rho)\right]^{\phi-1}}{a(1-\frac{k\rho}{d_{ss}\theta_{ss}^{\alpha-1}})^{\phi-1}}$$

$$= \frac{1}{1-b_{ss}}\frac{k}{d\theta_{ss}^{\alpha-1}} - (1-\rho)\beta\frac{1}{1-b_{ss}}\frac{k}{d\theta_{ss}^{\alpha-1}}(1-b_{ss}d\theta_{ss}^{\alpha}) \tag{2.67}$$

When home and market goods are perfect substitutes $a = 0.5$ and $\phi = 1$, this equation reduces to

$$\frac{1}{\mu_{ss}} - w^u = \frac{1}{1-b_{ss}}\frac{k}{d\theta_{ss}^{\alpha-1}} - (1-\rho)\beta\frac{1}{1-b_{ss}}\frac{k}{d\theta_{ss}^{\alpha-1}}(1-b_{ss}d\theta_{ss}^{\alpha}) \tag{2.68}$$

The system is reduced to one nonlinear equation in one unknown θ_{ss}. I solve this numerically with the specified calibrations in tables 2.1 and 2.2.

Chapter 3

Financial Factors and International Spillovers

3.1 Introduction

Two striking features of the Great Recession are the speed and synchronicity with which real activity collapsed across the world. Following adverse developments in the US subprime mortgage market global financial markets became severely disrupted. Moreover, the effect of this disruption was not limited to the financial sector; global real output and trade declined dramatically and central banks took unprecedented coordinated action, in part, to alleviate the adverse impacts of the financial market shocks on real activity. Many economies entered the longest contraction of output seen since the Great Depression. And the proportion of economies entering recession was higher than at any point since the Great Depression. The exceptional degree of global interdependence in financial and real variables suggests a strong international transmission mechanism of shocks originating in the financial sector.

Understanding the inter-linkages between financial and real variables has been given increased attention by policy makers and academics following the financial crisis. There is a new and growing literature aimed at understanding how country specific financial market shocks are transmitted internationally. This paper contributes to the literature by addressing two questions; first it examines how financial frictions affect the international transmission mechanism. Second, it explores the international spillovers from country-specific credit spread shocks.

To answer these questions we build a two country DSGE model with financial frictions. The impacts of financial frictions are examined by looking at the dynamic responses of foreign country variables to a productivity shock in the home country with financial frictions turned on, compared to the case without. Then two types of credit spread shocks are introduced to the home economy and the dynamic responses of foreign variables are analyzed. Our examination of the type of credit spread shock and its impact on international spillovers is an addition to the literature.

A number of studies look at how the financial sector propagates shocks originating in the real sector (Gertler and Kiyotaki (2010), Goodfriend and McCallum (2007)). But one explanation for the Great Recession is that financial market shocks actually drove declines in investment and activity, meaning there may be a role for financial factors in driving domestic and foreign business cycle fluctuations. For example, empirical evidence from Cetorelli and Goldberg (2011) documents a strong relationship between adverse liquidity shocks to advanced economies banking systems and shocks to credit supply in emerging economies, with knock on effects on real activity. In contrast there are relatively few studies which investigate the macroeconomic impact of direct disturbances to financial factors and the role played by the financial sector as a source of business cycle fluctuations particularly in an open economy framework. Smets and Wouters (2007) and Gilchrist et al. (2009) look at the role of financial factors in driving business cycle fluctuations but these are in closed economy frameworks. A new area of literature has begun to look at international spillovers from financial shocks by extending open economy models to incorporate international linkages between investor's balance sheets (Paustian and Søndergaard (2010)). In a similar framework Dedola and Lombardo (2010) stress the importance of international spillovers through the equalization of credit spreads. However, few have examined the importance of the nature of the credit market shock for international propagation channels and the impact on the real economy.

To examine these issues we extend Faia (2007)'s two country DSGE model with financial frictions to allow for shocks to the financial sector. The benefit of using a simple framework is that it allows us to explore the size and nature of international spillovers with clearly defined propagation channels and international linkages. We particularly focus on the propagation of credit spread shocks which are excluded from Faia's original analysis.

Financial frictions are introduced via a financial accelerator mechanism along the lines of Bernanke et al. (1999). Investors pay an external finance premium (EFP) to borrow funds from households via financial intermediaries. The cost of borrowing varies over the business cycle which means when the economy is hit by a negative shock the cost of borrowing increases. Krugman (2008) described the global diffusion of the recent financial crisis as evidence of an international financial multiplier at work. Borrowers highly exposed to foreign lenders were subject to collapsing asset values. Falls in asset values undermined their credit worthiness and reduced net worth restricting leveraged investors access to credit. Krugman (2008) suggests this had an impact on lending behavior in the foreign economy since it adversely affected foreign credit spreads and more general asset prices, with knock on consequences for real activity.

Collateral constraints, of the type introduced by Kiyotaki and Moore (1997), have also been used to capture financial accelerator effects in open economy DSGE models (Devereux and Yetman (2010)). Whilst these may be better suited to capture balance sheet effects associated with the process of financial deleveraging there is some new evidence to suggest a credit spread equalization channel is important in the propagation of financial shocks from one country to another which may be missed with collateral constraints (Dedola and Lombardo (2010)). In addition we are interested in finding a model which replicates data observations. Brzoza-Brzezina et al. (2010) suggest EFP type constraints outperform collateral constraints in data, whereas collateral constraints deliver better co movement and qualitative results. For this reason we favor using an EFP to introduce financial frictions to our model.

Our paper introduces two types of credit spread shock. The first affects the elasticity of credit spreads with respect to the net worth of borrowers and the second affects financial agent's net worth directly. Few studies have looked explicitly at the impact of different shocks that affect credit spreads. Dedola and Lombardo (2010) and Christiano et al. (2010) examine the consequences of a shock to the elasticity of external financing which is equivalent to the first type of credit spread shock that we introduce to our model. They find significant and persistent effects on real variables from such shocks. In contrast, as far as we are aware, there are few studies which have looked at the impact of a shock which operates more directly via net worth. Considering the patterns of international propagation from such shocks is particularly interesting in the context of the current juncture, characterized by large and synchronized declines in asset prices and macroeconomic variables, driven by negative developments in financial markets. And in a time of significant changes to financial market regulations which may impact on the value of financial agents collateral thereby more directly affecting their net worth, this shock is particularly relevant.

Results suggest that financial frictions magnify movements in international relative prices. In addition, external finance premium shocks can generate significant and persistent international spillovers. Crucially the international spillover depends on the way the credit spread shock is modeled. A “risk” shock to the dispersion of the productivity of entrepreneurs results in a shift in the foreign aggregate supply curve. A “net worth” shock to the survival probability of entrepreneurs generates a shift in the foreign aggregate demand curve.

In our model the labor supply response of foreign households plays a crucial role in the transmission of the shocks from one country to the other. A significant labor supply response of the foreign household to both a domestic productivity and “risk” shock drives output and consumption co-movement across countries. This resolves some of the well known output correlation puzzle seen in standard open economy models (see Backus et al. (1994)). However, the degree of output co-movement crucially depends on the strength of this channel. We find with a shock to the net worth this channel is less significant.

This paper is structured as follows: Section 3.2 contains an overview of the model and methodology while section 3.3 has the model simulations. Section 3.4 concludes.

3.2 Model and Methodology

The economy is a two-country, two traded good dynamic stochastic general equilibrium (DSGE) model. The Home (H) and Foreign (F) country are symmetric. Variables for the F country are denoted with an asterisk. There are 6 agents in each country: households, final good producers, intermediate producers, entrepreneurs, a financial intermediary and a central bank. As a result, the economy contains 10 markets. Each country contains markets that are in autarky, including a capital market where entrepreneurs supply capital to intermediate goods firms, a labor market where households work for the intermediate producers, an intermediate inputs market where intermediate producers supply inputs to final goods firms, and a market for loanable funds coordinated by a financial intermediary which obtains deposits from the households and extends loans to entrepreneurs. Entrepreneurs are not directly linked to the entrepreneurs and financial intermediaries in the other country. Our model contains the standard international linkages of open economy DSGE models. Final goods firms in each country produce and sell a continuum of domestic varieties to the households and entrepreneurs in both countries and households engage in international trade of risk-free real bonds denominated in foreign currency. The central bank acts mechanically according to a Taylor rule.

Our model contains inefficiencies which impact the markets for final goods, international bonds, capital and loanable funds. Final goods producers are monopolistically competitive and set prices in Calvo fashion. International risk free bonds are not perfectly mobile across countries because domestic households pay a premium when they purchase foreign currency bonds. The production of capital is subject to adjustment costs. The market for loanable funds is subject to asymmetric information between the borrower and the lender. This last inefficiency is not standard for New Keynesian open economy models because it introduces a financial friction which affects international spillovers in two ways. First, it provides a channel through which credit spread shocks spillover to the international real sector and second, it amplifies movements in international prices and net international flows.

3.2.1 Model

3.2.1.1 Household Problem

The household maximizes the expected discounted sum of utilities that it obtains from consumption and hours worked

$$\max E_t\{\sum_{i=0}^{\infty} \frac{C_{t+i}^{1-\sigma}}{1-\sigma} - \frac{H_{t+i}^{1+\phi}}{1+\phi}\}, \tag{3.1}$$

where β, is the discount factor, σ the parameter of risk aversion, ϕ is the Frisch elasticity of wages to labor supply, H_t is total hours and C_t is final goods consumption consumption basket. The utility function is continuous, differentiable, and separable in consumption and hours and increasing and concave in consumption and decreasing and convex in hours. The household faces the following nominal budget constraint

$$P_t C_t + D_t + P_t \frac{B_{h,t}^*}{e_t^r} \leq W_t H_t + R_{t-1}^n D_{t-1} + P_t R_{t-1}^F \frac{B_{h,t-1}^*}{e_t^r} + \Pi_t \tag{3.2}$$

The left hand side is household expenditure on consumption and saving in the form of nominal domestic deposits D_t and risk-free real foreign-currency bonds $B_{h,t}^*$. The international bonds are debt contract denominated in foreign currency that are signed between home and foreign households where one country is usually the lender and the other the borrower. The two countries are symmetric in everything but international bond trade. The debt contracts are denominated in foreign currency and due to exchange rate risk the home households have to pay a premium for trading them. The right hand side is the income households receive as a wage W_t from working hours N_t, as a nominal $R^n_{t-1}$from holding deposits D_{t-1} last period , as a real return $R^F_{t-1}$from investing in real international bonds $B^*_{h,t-1}$ last period, and dividend income from owning firms. The international bonds are converted into real domestic currency units by dividing by the real exchange rate, defined as the relative price of domestic consumption goods relative to foreign consumption goods:

$$e^r_t \equiv \frac{e_t P_t}{P^*_t} \tag{3.3}$$

The household maximizes the present value of its utility subject to its budget constraint in order to choose quantities $\{C_t, B_t, D_t, H_t\}^{\infty}_{t=0}$. taking prices $\{P_t, R_t, R^n_t, W_t\}^{\infty}_{t=0}$ and the initial wealth endowments D_{t-1}, B_{t-1} as given. Its optimal conditions include equation (3.4), which is a labor supply condition equating the marginal rate of substitution between leisure and consumption to the real wage, equation (3.5), an Euler equation with respect to the nominal deposits and equation (3.6), an Euler equation with respect to the real international bonds

$$\frac{H^{\phi}_t}{C^{-\sigma}_t} = \frac{W_t}{P_t} \tag{3.4}$$

$$\beta E_t \frac{R^n_t}{P_{t+1}/P_t} \frac{C^{-\sigma}_{t+1}}{C^{-\sigma}_t} = 1 \tag{3.5}$$

$$\beta E_t(\frac{C_{t+1}}{C_t})^{-\sigma}(\frac{e^r_t}{e^r_{t+1}})R^F_t = 1. \tag{3.6}$$

The first order conditions of the foreign household are identical, except for the optimality condition with respect to the foreign bond purchases which is:

$$\beta E_t(\frac{C^*_{t+1}}{C^*_t})^{-\sigma}R^*_t = 1. \tag{3.7}$$

Domestic households pay a spread between the interest rate on the foreign currency portfolio R^F_t and the foreign interest rate R^*_t which is an increasing function of the real value of its net foreign asset position $\frac{B^*_t}{e^r_t}$:

$$\frac{R^F_t}{R^*_t} = \exp(-pr(\frac{B^*_{h,t}}{e^r_t} - \frac{B^*_h}{e^r})) \tag{3.8}$$

This spread may reflect a country specific risk or imperfect international capital mobility. In open economy models with incomplete asset markets the deterministic steady state depends on the initial conditions of the economy and the steady state is compatible with any level of net foreign assets. In a stochastic environment the model generates non-stationary variables as net foreign assets follow a unit root process. A debt elastic spread is necessary in order to achieve a unique steady state and ensure that the net foreign asset position is a stationary variable. A necessary condition that ensures that the uncovered interest parity holds is that:

$$E_t\{(\frac{C_{t+1}}{C_t})^{-\sigma}(\frac{e^r_t}{e^r_{t+1}})\exp(-pr(\frac{B^*_{h,t}}{e^r_t} - \frac{B^*_h}{e^r}))\} = E_t\{(\frac{C^*_{t+1}}{C^*_t})^{-\sigma}R^*_t\}. \tag{3.9}$$

The household at home consumes a basket of the two traded goods

$$C_t = [(1-\gamma)^{\frac{1}{a}} C_{f,t}^{\frac{a-1}{a}} + \gamma^{\frac{1}{a}} C_{h,t}^{\frac{a-1}{a}}]^{\frac{a}{a-1}}. \tag{3.10}$$

$C_{h,t}$ and $C_{f,t}$ are the amounts of the domestic good and imported foreign good that the household consumes. γ is the home bias parameter that determines the share of domestic goods in the consumption basket and a is the elasticity of substitution between the two goods. The expenditure minimization problem of the domestic household implies a demand for domestic goods $X_h, t = \gamma(\frac{P_{h,t}}{P_t})^{-a} X_t$, a demand for imports $X_{f,t} = (1-\gamma)(\frac{P_{f,t}}{P_t})^{-a} X_t$, and a consumer price index $P_t = [(1-\gamma)(P_{f,t})^{1-a} + \gamma(P_{h,t})^{1-a}]^{\frac{1}{1-a}}$. Foreign households have an identical set of conditions, including $X^*_{f,t} = \gamma^*(\frac{P^*_{f,t}}{P^*_t})^{-a} X^*_t$, $X^*_{h,t} = (1-\gamma^*)(\frac{P^*_{h,t}}{P^*_t})^{-a} X^*_t$ and $P^*_t = [\gamma^*(P^*_{f,t})^{1-a} + (1-\gamma^*)(P^*_{h,t})^{1-a}]^{\frac{1}{1-a}}$ which are domestic demand, demand for imports and CPI, respectively.

3.2.1.2 Producers

There are several stages of production in each country. Intermediate firms use labor and capital in order to produce an identical input which final producers differentiate at no cost to obtain a tradable final good that can be sold to households for consumption and to entrepreneurs for consumption or investment in capital.

Intermediate Producers Intermediate producers rent capital K_t from entrepreneurs at a rental rate R^k_t and hire labor N_t at a nominal wage W_t in order to produce an intermediate good Y^w_t and sell it at a price P^w_t. The labor that the intermediate firms employ is a function of hours H_t worked by the household and hours H^e_t worked by the entrepreneur:

$$N_t = (H^e_t)^{1-\eta} (H_t)^{\eta}, \tag{3.11}$$

where η is the fraction of household labor used by the intermediate firms. They use a constant returns to scale technology:

$$Y_t^w = A_t {K_t}^{\alpha} {N_t}^{1-\alpha}, \tag{3.12}$$

where A_t is TFP shock which follows an AR(1) process with persistence parameter ρ_A and standard deviation σ_A. Intermediate producers operate in a perfectly competitive environment in which profit maximization implies the following capital and labor demand optimal conditions:

$$\frac{R_t^k}{P_{h,t}} = \frac{P_t^w}{P_{h,t}} \alpha (\frac{Y_t}{K_t}) \tag{3.13}$$

$$\frac{W_t}{P_{h,t}} = \frac{P_t^w}{P_{h,t}} \eta (1-\alpha) (\frac{Y_t}{H_t}) \tag{3.14}$$

$$\frac{W_t^e}{P_{h,t}} = \frac{P_t^w}{P_{h,t}} (1-\eta)(1-\alpha) \frac{Y_t}{H_t^e}. \tag{3.15}$$

We assume that the entrepreneurs supply labor inelastically and normalize the total amount of labor that the entrepreneur is supplying H_t^e to one. This implies that $N_t = (H_t)^{\eta}$ In the calibrations below we keep the share of income going to entrepreneurial labor small (on the order of .01), so that this modification of the standard production function does not have significant direct effects on the results.

Final Good Producers Final goods producers operate in monopolistically competitive environment and set their prices in Calvo fashion. Each period only a fraction $1-\omega$ of producers are allowed to adjust prices. The optimization problem is standard and delivers the following rule for the optimal price:

$$P^{o}_{h,t}(i) = \frac{b}{(b-1)} E_t \frac{\sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{-\sigma} P_{t+i}^{w} (P_{h,t+i})^b (X_{ht+i} + X^{*}_{ht+i})}{\sum_{i=0}^{\infty} \omega^i \beta^i C_{t+i}^{-\sigma} (P_{h,t+i})^b (X_{ht+i} + X^{*}_{ht+i})} \tag{3.16}$$

Note that each firm produces a different variety which enters the consumption function as a domestic composite good which is symmetric for H and F

$$X_{ht} = (\int_0^1 X_{ht}(i)^{\frac{b-1}{b}})^{\frac{b}{b-1}} \tag{3.17}$$

$X_{ht}(i) = C_{ht}(i) + C^{e}_{ht}(i) + I_{ht}(i)$ is the total demand for variety i for household and entrepreneurial consumption and investment. b is the elasticity of substitution between varieties. This implies the following demand function for each variety:

$$X_{ht}(i) = (\frac{P_{h,t}(i)}{P_{h,t}})^{-b} X_{ht} \tag{3.18}$$

where the domestic producer price index.

$$P_{h,t} = (\int_0^1 P_{h,t}^{1-b}(i))^{1-b} \tag{3.19}$$

An identical set of equations applies to Foreign. The law of one price holds for each variety

$$P^{*}_{h,t}(i) = e_t P_{h,t}(i) \tag{3.20}$$

which can be aggregated to a similar conditions which hold for the home and the foreign good sectors, $P^{*}_{h,t} = e_t P_{h,t}$ and $P^{*}_{f,t} = e_t P_{f,t}$.

3.2.1.3 Entrepreneurs

There are a continuum of entrepreneurs indexed by j who act as financial agents. Each period they rent out capital to intermediate firms at a rate R_t^k and finance the production of new capital $K_t(j)$ by buying investment goods at price Q_t. Each period a random and time varying fraction of entrepreneurs exits the market, denoted by $1 - s_t\chi$ and an equal fraction enters. s_t is a shock that follows an AR(1) process with a persistence parameter ρ_s and a standard deviation σ_s. A positive shock increases the survival probability of the entrepreneurs. With a survival probability lower than one, entrepreneurs face a fixed horizon problem, which reduces their effective discount factor, making them more impatient and ensures that they do not accumulate enough wealth to become fully self-financing. Entrepreneurs also work and receive a wage W_t^e from the intermediate firms. This wage guarantees that entrepreneurs always have enough resources to finance capital production and the economy never stops producing. Entrepreneurs finance capital production partly with their own financial wealth $NW_t(j)$ and partly with loans $L_t(j)$ from a bank.

$$L_t(j) = Q_t K_t(j) - NW_t(j) \tag{3.21}$$

Each entrepreneur is subject to an idiosyncratic productivity shock which converts his capital to $a_{e,t}(j)K_t(j)$, where $a_{e,t}$ is a random variable, distributed independently across time and across entrepreneurs with a cumulative density function $F(a_{e,t}(j))$. It follows log normal distribution with a unitary mean and a time varying standard deviation $f_t\sigma_{a^e}$. f_t is a second financial shock which follows an AR(1) process with persistence ρ_f and standard deviation σ_f. This shock preserves the average productivity across entrepreneurs but changes the dispersion of their productivity distribution. A positive realization makes the tails of the a_e distribution fatter and increases the number of entrepreneurs with very low and very high productivity. Entrepreneurs observe the realization of their productivity before deciding how much capital to produce. They produce capital subject to a depreciation rate δ and capital adjustment costs:

$$K_t = (1-\delta)K_{t-1} + I_t - \frac{\Phi}{2}(\frac{I_t}{K_{t-1}} - \delta)^2 K_{t-1} \tag{3.22}$$

This set up implies the following optimal conditions that determine the price of capital and ex-post return to capital:

$$Q_t = (1 - \Phi(\frac{I_t}{K_t} - \delta))^{-1} \tag{3.23}$$

$$R^e_t \equiv \frac{Q_t(1-\delta) + \frac{R^k_t}{P_t}}{Q_{t-1}} \tag{3.24}$$

where the rate of return of an individual entrepreneur is $a_{et}(j)R_{et}$.

3.2.1.4 Financial Intermediary and Optimal Contract

An asymmetric information problem arises between the bank and entrepreneur because the idiosyncratic productivity shock a_e is privately observed by the entrepreneurs. The bank has to pay a monitoring cost μK_t to observe the shock. The asymmetric information creates a moral hazard problem because the entrepreneur has the incentive to misreport the true value of a_e in order to borrow at a lower rate. The bank and the entrepreneur face a principal agent problem which delivers the conditions for the optimal contract between two parties. The optimal financial contract lasts one period and is renegotiated every period. It is affected by the business cycle through the net worth NW_t and the price of capital Q_t and treats these two variables as given. Its purpose is to eliminate the moral hazard problem and ensure that the entrepreneurs always report their productivity level truthfully. Both the capital production technology and the monitoring technology are linear and have constant returns to scale, which means that the marginal costs are constant and makes aggregation possible. The entrepreneurs net worth is sufficiently small in order to make external financing necessary. Then, the contract is risky debt. The contract can be described in terms of the amount of produced capital and the cut-off level of productivity at which entrepreneurs start to default. The entrepreneurs default if the productivity shock is lower than their return on capital $Q_{t-1}R^e_t a^e_t K_t < R^L_t(Q_t K_t - NW_t)$ or if their productivity is lower than some cut-off productivity level $\bar{a}^e_{t+1}$, defined as

$$\bar{a}^e_{t+1} = \frac{R^L_{t+1}(Q_t K_t - NW_t)}{R^e_{t+1} Q_t K_t}. \qquad (3.25)$$

The bank monitors the project only if the entrepreneurs default, in which case it seizes all the returns. The net entrepreneurial income is the expected return on capital $\int_{\bar{a}^e_{t+1}}^{\infty}[R^e_{t+1}Q_t K_t a_{et+1}]dF(a_{et+1})$ less the amount of loan repayment $\int_{\bar{a}^e_t}^{\infty} R^L_{t+1} L_t dF(a_{et+1})$ Substituting from the condition for the cutoff productivity level, the net share of income attributed to the entrepreneur is

$$\Gamma_{t+1} R^e_{t+1} Q_t K_t, \qquad (3.26)$$

where $\Gamma_t = [1 - \int_0^{\bar{a}^e_{t+1}} a_{et+1} dF(a_{et+1}) - \bar{a}^e_{t+1}(1 - \int_0^{\bar{a}^e_{t+1}} dF(a_{et+1}))]$ is the fraction of expected net capital received by the entrepreneurs The expected net income of the lender on such contract is

$$\Omega_{t+1} R^e_{t+1} Q_t K_t \tag{3.27}$$

where $\Omega_{t+1} = [(1-\mu)\int_0^{\bar{a}^e_{t+1}} a_{et+1} dF(a_{et+1}) + \bar{a}^e_{t+1}(1-\int_0^{\bar{a}^e_{t+1}} dF(a_{et+1}))]$ is the fraction of net capital received by the Bank. The sum of the two fractions is lower than one $\Gamma_{t+1} + \Omega_{t+1} = 1 - \mu \int_0^{\bar{a}^e_{t+1}} a_{et+1} dF(a_{et+1})$, so that on average $\mu \int_0^{\bar{a}^e_{t+1}} a_{et+1} dF(a_{et+1})$ of the capital is destroyed by monitoring and the rest is split between the borrower and the lender. The zero profit condition for the lender implies that the return from lending to the entrepreneurs has to be equal to the cost of raising loanable funds which is the *real* deposit rate

$$\int_{\bar{a}^e_t}^{\infty} R^L_{t+1} L_t dF(a_{et+1})) + (1-\mu) \int_0^{\bar{a}^e_{t+1}} [R^e_{t+1} Q_t K_t a_{et+1}] dF(a_{et+1}) \geq \left(\frac{R^n_t}{1 + E_t \pi_{t+1}} \right) L_t$$

We can rewrite it as

$$\Omega_{t+1} R^e_{t+1} Q_t K_t \geq \left(\frac{R^n_t}{1 + E_t \pi_{t+1}} \right) (Q_t K_t - NW_t) \tag{3.28}$$

The optimal contract specifies a pair of $\{\bar{a}^e_{t+1}, K_{t+1}\}$ which maximizes the entrepreneur's expected return subject to the zero profit conditions which is effectively the participation constraint for the bank. Define the external finance premium efp_t as the spread between the gross return to the entrepreneurs and the risk free real interest rate

$$efp_t \equiv E_t \left[\frac{R^e_{t+1}}{\left(\frac{R^n_t}{1+\pi_{t+1}} \right)} \right] \tag{3.29}$$

The optimal contract problem implies that the EFP is an increasing function of the monitoring cost and cut-off productivity level:

$$efp_t = \frac{1}{(\Omega_{t+1} - \frac{\Omega'_{t+1}}{\Gamma'_{t+1}}\Gamma_{t+1})} \tag{3.30}$$

Define the τ_t as the leverage ratio of entrepreneurial assets to net worth:

$$\tau_t \equiv \frac{Q_t K_t}{NW_t} \tag{3.31}$$

Combining equations (3.30) and (3.31) delivers a condition which shows that the EFP is an increasing function of the leverage ratio and, hence, a decreasing function of the net worth of the entrepreneurs:

$$efp_t = -v_{t+1}\frac{1}{\tau_t}, \tag{3.32}$$

where $v_{t+1} = \frac{1}{\Gamma_{t+1}}\frac{\Gamma'_{t+1}}{\Omega'_{t+1}}$ is the elasticity of the external finance premium with respect to the leverage ratio. This elasticity is a decreasing function of the default probability of the entrepreneurs. If a positive shock hits the standard deviation of the productivity distribution of entrepreneurs, the distribution will become more dispersed with fatter tails and the likelihood of default perceived by the banks will rise. The banks will become more inelastic in their willingness to extend a loan for a given level of net worth.

Define V_t as the the net capital gain that the entrepreneurs obtain from investing in capital:

$$V_t = R^e_t Q_{t-1}K_{t-1} - \left(\frac{R^n_{t-1}}{1+\pi_t}\right) efp_{t-1}\left(Q_{t-1}K_{t-1} - NW_{t-1}\right). \tag{3.33}$$

Then the net worth at the end of period t is a sum of the net capital gain of the entrepreneurs who survive plus the wage received by all the entrepreneurs:

$$NW_t = s_t \chi V_t + \frac{W_t^e}{P_t}. \tag{3.34}$$

The fraction of entrepreneurs who die consume their net capital gain:

$$C_t^e = (1 - s_t \chi) V_t. \tag{3.35}$$

A shock s_t that lowers the fraction of surviving entrepreneurs would decrease the aggregate net worth in the economy but would also raise aggregate consumption because a larger fraction of entrepreneurs consume instead of investing in capital.

3.2.1.5 Monetary Policy

Monetary policy is conducted based on Taylor rules which target inflation and output growth and contains an interest rate smoothing term:

$$\frac{R_t^n}{R^n} = \left(\frac{R_{t-1}^n}{R^n}\right)^{\gamma_r} \left[\left(\frac{1+\pi_t}{1+\pi}\right)^{\gamma_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\gamma_y}\right]^{1-\gamma_r}, \tag{3.36}$$

where γ_r is the persistence of nominal interest rate changes and γ_π and γ_y are the weights that the central bank puts on inflation and output volatility. An identical condition describes the monetary policy of the foreign country.

3.2.1.6 Market Clearing

Net trade in international bonds must be zero in equilibrium which implies

$$B_{ft}^* + \frac{B_{ht}^*}{e_t^r} = 0. \tag{3.37}$$

Market clearing conditions for the home final good and the foreign final good imply the following pair of resource constraints:

$$X_{h,t} + X^*_{ht} + \mu \int_0^{\bar{a}^e_t} a_{et} dF(a_{et}) Q_{t-1} R^e_t K_{t-1} = Y_t \tag{3.38}$$

$$X_{f,t} + X^*_{ft} + \mu^* \int_0^{\bar{a}^{*e}_t} a^*_{et} dF(a^*_{et}) Q^*_{t-1} R^{*e}_t K^*_{t-1} = Y^*_t \tag{3.39}$$

Market clearing of the loanable fund market requires that the real quantity of deposits equals the volume of loans, both at Home $\frac{D_t}{P_t} = L_t$, and at Foreign $\frac{D^*_t}{P^*_t} = L^*_t$.

3.2.2 Methodology

3.2.2.1 Calibration

Most parameters are calibrated based on Faia (2007). The values of the structural parameters are reported in table 3.1. There are some parameters that are calibrated differently and some parameters that are new. Our set up differs slightly from Faia's because the entrepreneurs in our economy work and receive a wage. We will assume that the fraction of hours η of entrepreneurial labor in total labor employed by intermediate firms is 1%, a value taken from Bernanke et al. (1999). We assume a lower survival probability of entrepreneurs χ 0.95 because it lowers the persistence of our impulse responses to very persistent shocks. This does not alter the dynamics and allows us to report impulse responses more clearly and over a shorter time horizon. The elasticity of the international spread with respect to the net foreign asset position is 1% which is in accordance with estimates of Lane and Milesi-Ferretti (2004).

We assume that the Calvo fraction of firms allowed to adjust prices every period is 0.6. The persistence and the standard deviations of the credit spread shocks are calibrated based on Brzoza-Brzezina et al. (2010) who perform a similar exercise but in a closed economy setting.

3.2.2.2 Steady state and linearization

The steady state values that we use in our simulations are reported in table 3.2. The nonlinear model is log-linearized around the deterministic steady state up to the first order. The first order linearization does not detract from the dynamic analysis of responses to financial shocks because the financial accelerator mechanism creates first order effects which spillover from the external finance premium to the net worth of entrepreneurs, hence from the financial to the real sector of the economy. The list of equations describing the log-linear version of the model can be found in the appendix to chapter 3.[1]

3.3 Results

3.3.1 International transmission mechanism

3.3.1.1 Productivity shock

Before looking at the effects of financial shocks, we examine how financial frictions alter the international transmission mechanism observed in standard open economy DSGE models. In similar frameworks, Gilchrist (2003) and Faia (2007) find that the presence of a financial accelerator help to resolve the well known

[1]Only the equations descibing the behavior of the Home country are listed. The equations for the Foreign economy are identical.

output co movement puzzle and increase business cycle synchronization. Financial frictions do this by amplifying the international spillovers which increase co movement and dampens those that decrease it.

Figures 3.1-3.6 report the impulse responses to a one standard deviation negative productivity shock in the home country. We focus first on the black line simulations which show the responses with financial frictions turned off in our model. As expected a negative productivity shock at home shifts the home aggregate supply curve left which results in a fall in output and a rise in inflation. The fall in wealth, associated with the fall in output, reduces investment and consumption spending.

In our model the international transmission mechanism is dominated by movement in the terms of trade which means the home productivity shock spills over to the foreign country as a negative aggregate supply shock. Foreign output falls and inflation rises (Figure 3.4). Foreign investment and consumption also fall due to the fall in wealth. The foreign supply curve shifts left, like the home country, because of the effect the movement in the terms of trade has on the relative price of factors of production in the foreign country.

The behavior of the markets for factors of production is critical for understanding the international transmission mechanism in our model. Both capital and labor markets are experiencing simultaneous shifts in demand and supply. Figure 3.2 shows that the factor markets in the home country are dominated by supply side shocks, as prices and quantities are moving in different directions. The fall in investment indicates that capital supply shifts left resulting in an increase in the rental rate and a fall in the stock of capital. The fall in consumption raises the relative price of leisure which via a substitution effect leads to a rightward shift in labor supply resulting in a rise in the hours worked and a fall in the real wage. Figure 3.5 indicates that foreign factor markets are dominated by demand side shocks because factor prices and quantities are moving in the same direction. These shifts are driven by the increase in the terms of trade (Figure 3.3) that makes foreign goods relatively less valuable. As a result, the value of the marginal products of capital and labor falls and the demands for both foreign factors of production shift left. Figure 3.5 shows that the negative labor demand shift results in a fall in labor hours and the foreign real wage while the negative capital demand shift leads to a fall in the foreign rental rate and stock of capital.

The introduction of the financial accelerator dampens the response of output in the home country while it increases the response of output in the foreign country. The more subdued fall in the home country is mainly due to a smaller fall in capital. The financial accelerator mechanism is associated with a more inelastic capital supply as the rental rate of capital becomes more responsive to changes in the level of capital. This explains why movements in the rental rate of capital are amplified and movements in the capital stock are dampened. Less fluctuations in capital imply dampened movements in investment and output.

The presence of financial frictions amplifies the international transmission mechanism because it increases the movements in international prices. Figure 3.3 shows that the impact on the terms of trade and the real exchange rate is larger. Since domestic demand has a more muted response due to the presence of financial frictions, home imports fall by less and more of the adjustment happens through a rise in international prices. This in turn amplifies the terms of trade effect that lowers the value of the marginal products of labor and capital in the foreign country. As a result, the shift in labor demand in the foreign economy is greater and both the real wage and labor fall by a greater amount. As financial frictions lower the elasticity of capital supply, fluctuations in the foreign rental rate are amplified while the change in the capital stock is dampened. However, lower demand for capital reduces the price of capital which lowers foreign net worth and raises the foreign external finance premium. A higher premium raises the cost of borrowing and further reduces investment and output. Thus, the shift in the foreign aggregate supply curve is larger with financial frictions because the international terms of trade effect is magnified by the presence of the financial accelerator mechanism.

3.3.2 Credit Spread Shocks

3.3.2.1 Risk Shock

Figure 3.7 illustrates the positive relationship between the leverage ratio and the external finance premium generated by the introduction of a financial accelerator mechanism. The first credit spread shock that we introduce is an increase to the volatility of the productivity distribution of entrepreneurs which makes the curve in Figure 3.7 pivot anti clockwise. This means for a given leverage ratio the external finance premium is higher. This is because the shock to the volatility of the productivity distribution of entrepreneurs increases the banks perception of the probability of default and increases the level of productivity required for banks to lend since they are less willing to monitor entrepreneurs. We call it a "risk" shock because it increases the default risk of financial agents. The shock that we introduce to the dispersion of entrepreneurs is calibrated so that it results in a one standard deviation shock to the credit spread; it raises the credit spread proportionately by 0.0011. The actual spread increases from around 1.003 in steady state to 1.004.

Figures 3.8-3.11 display the impulse responses to this shock. We focus first on the impact on the domestic economy. As expected we find a strong financial multiplier effect which operates mainly through the capital market. The shock acts to reduce capital and investment because credit conditions tighten as the external finance premium charged by domestic financial intermediaries is rising. This reduces the quantity of capital demanded and lowers its price. Domestic entrepreneurs leverage ratios fall because the cost of purchasing capital is falling and net worth is rising. Over time the excess returns required by banks help increase the net worth of entrepreneurs so the shock to the external finance premium falls as both the leverage ratio declines and the shock begins to unwind. There is a reduction in domestic aggregate demand because the fall in investment is large and outweighs a shift towards higher consumption by domestic entrepreneurs and households. Entrepreneurs consumption is rising as their net worth increases and household consumption is rising because real interest rates are falling. The reduction in demand acts to reduce costs and therefore domestic and CPI inflation which the policy maker reacts to by reducing real rates.

What are the spillover effects to the second country? Our results suggest that the international transmission is dominated by changes in the terms of trade. There is terms of trade appreciation since domestic prices fall by less than foreign prices denominated in domestic currency. This means there is a real appreciation of the domestic currency and a substitution of demand away from domestic goods towards foreign goods. As a result the foreign economy benefits from traditional expenditure switching effects and domestic net exports fall. These increase demand for foreign output over time.

But there is output co-movement across the two countries in the first few periods. This is because the appreciation of the terms of trade is having an effect on supply in the foreign economy. The appreciation of the terms of trade lowers the real output value of the marginal products of foreign capital and labor in terms of domestic output. As a result the demands for foreign capital and labor fall and overall foreign output falls. This fall in output has knock on consequences for foreign consumption and investment spending.

However, we find little evidence of co-movement between cross country financial variables. There is a muted response of the foreign external finance premium and correspondingly small response erosion of foreign capital in comparison to the domestic responses. There is also little evidence of co-movement across financial variables as the external finance premium is falling in the foreign economy compared to the rise in the external finance premium in the domestic economy. So in our framework the main international spillover seems to be dominated by the effects of movements in the terms of trade.

3.3.2.2 Survival Probability Shock

The second credit spread shock that we introduce is a negative shock to the survival rate of domestic entrepreneurs. The spillover effects of this shock are mainly driven by changes to the net worth of domestic financial agents. The fall in the fraction of surviving entrepreneurs lowers aggregate net worth because entrepreneurs become more impatient and choose to consume more today given the higher probability that they will not survive to the next period. Therefore this type of shock acts like a "net worth" shock which provides an interesting comparison to our "risk" shock. We are now able to compare whether different types of credit spread shocks have different real economy spillovers in our framework.

Figures 3.12-3.15 report the impulse responses to this type of shock. The shock to the survival rate of domestic entrepreneurs acts to reduce domestic investment and capital. Entrepreneurs falling net worth has two direct effects; first it leads to an increase in the external finance premium, second it increases the leverage ratio of borrowers. Over time there is a fall in the price of capital because the demand for investment goods is falling and net worth rises as the shock dies away both of these helps to reduce the external finance premium. Unlike the "risk" shock, here the fall in investment is outweighed by the rise in entrepreneurs consumption. This means that in the first few periods following the shock there is a rise in domestic output and inflation driven by the increase in overall aggregate demand. Consumption by the financial agent crowds out households consumption but domestic households increase their supply of labor because the fall in consumption means that leisure is relatively more valuable which means that output rises to meet increased demand from domestic entrepreneurs. Essentially since dying entrepreneurs demand more final goods, the aggregate demand curve shifts right and home inflation rises.

The international spillovers are similar to the "risk" shock which highlights the importance of the terms of trade on international spillovers. There is terms of trade appreciation because the rise in domestic inflation is greater than the rise in foreign inflation. This means there is a real exchange rate appreciation of the domestic currency and expenditure switching towards the foreign economy. So domestic net exports fall and these act like a positive demand shock for the foreign economy where output and inflation rise.

There is also not much evidence of co-movement across financial variables with the shock to the survival rate of entrepreneurs. The response of foreign financial variables to the domestic financial shock as muted and there is a fall in the external finance premium in the foreign economy whilst it is rising in the domestic economy.

3.3.2.3 Comparison of Credit Spread Shocks

The impact of the survival probability shock is not only different in direction but also in magnitude. Figures 3.16-3.19 show the relative impulse responses to the two financial shocks where the impulse responses of the variables are scaled by the standard deviation of each shock. The impact of the survival probability shock is significantly larger and lasts longer than the impact of the external finance premium shock. This is true in both countries. These suggest that a "net worth" shock might be more important for international business cycle fluctuations than a "risk" shock.

3.4 Conclusion

We build a two-country DSGE model with a financial accelerator in order to analyze international spillovers from credit spread shocks originating in the foreign country. We find that the international transmission mechanism is amplified by the presence of financial frictions because movements in international prices are larger. We look at the international spillovers of two types of credit spread shocks, a "risk" shock and "net worth" shock. Our results indicate that the international spillovers resulting from the two types of shocks are significant and persistent but differ both qualitatively and quantitatively. A shock that raises the riskiness of entrepreneurs raises the credit spread and results in negative aggregate demand shift in the home economy due to a fall in investment spending. The spillover to the foreign economy is in the form of a rising terms of trade that lowers the relative values of the marginal products of capital and labor, induces a negative shift in capital and labor demand and leads to a leftward shift in the foreign aggregate supply curve. A shock that lowers the fraction of surviving entrepreneurs leads to a fall in the quantity of home net worth and a fall in consumption and investment spending. However, it results in a higher fraction of entrepreneurs consuming and shifts the aggregate demand curve to the right. The spillover to the foreign country is in the form of a rising terms of trade that makes foreign goods relatively cheaper and leads to a rightward shift in the foreign aggregate demand curve. The impacts of the two shocks also differ in magnitude. A "net worth" shock has a relatively larger impact than a "risk" shock. Our findings imply that shocks to the net financial wealth contribute more to international business cycle fluctuations than "risk" shocks.

Our short-term agenda is to extend our model in a way that helps think about international financial contagion. Currently, the entrepreneurs' balance sheets are not exposed to foreign financial assets or liabilities. The financial shocks spill over to the foreign country only through standard trade channels. We intend to add an international financial channel and see whether it enhances international spillovers. We plan to open the balance sheets of entrepreneurs in a number of ways and analyze how international spillovers change. We aim to compare how different types of financial exposure affect international spillovers. The exposure could be on the liabilities side by allowing entrepreneurs to borrow from a foreign bank, or it could be on the asset side by letting the entrepreneurs rent out capital to foreign intermediate firms.

3.5 Tables and Figures

Table 3.1: Calibration of Structural Parameters

Parameter	**Description**	**Baseline Value**	**Source**
γ	Home Bias	0.7	Faia (2007)
ε	Substitution elasticity of varieties	6	Faia (2007)
ϕ	Inverse of Frisch labor supply elasticity	0.33	Faia (2007)
β	Discount factor	0.99	Faia (2007)
δ	Depreciation rate	0.025	Faia (2007)
α	Capital share in production	0.35	Faia (2007)
η	Entrepreneurial share in total hours	0.01	Bernanke et al. (1999)
ε_{ik}	Elasticity of capital price to investment capital ratio	0.25	Faia (2007)
pr	Elasticity of foreign bond spread	0.01	Lane and Milesi-Ferretti (2004)
χ	Survival probability	0.95	Assumed
μ	Monitoring cost	0.12	Faia (2007)
σ_{a^e}	Volatility of E shock	0.28	Faia (2007)
υ	Elasticity of EFP to leverage ratio	0.05	Faia (2007)
a	Elasticity of substitution between home and foreign goods	1.5	Faia (2007)
ω	Fraction of firms not allowed to adjust every period	0.6	Faia (2007)
ϖ	Sensitivity parameter of ν to σ_{a^e}	0.12	Implied
γ_{r^n}	Persistence of nominal interest rate in monetary rule	0.8	Brzoza-Brzezina et al. (2010)
γ_π	Weight on inflation	1.5	Brzoza-Brzezina et al. (2010)
γ_y	Weight on output	0.5	Brzoza-Brzezina et al. (2010)
ρ_A	Persistence of the productivity shock	0.9	Faia (2007)
ρ_f	Persistence of the risk shock	0.83	Brzoza-Brzezina et al. (2010)
ρ_s	Persistence of the survival shock	0.84	Brzoza-Brzezina et al. (2010)
σ_A	Standard deviation of the productivity shock	0.008	Faia (2007)
σ_f	Standard deviation of the risk shock	0.012	Brzoza-Brzezina et al. (2010)
σ_s	Standard deviation of the survival shock	0.06	Brzoza-Brzezina et al. (2010)

Table 3.2: Calibration of Steady State Values

Steady State Variable	Description	Value	Source
$\frac{B^*}{e^r}$	Net foreign asset position	0	Assumed
Y	Output	1	Assumed
X	Aggregate demand	1	Implied
R^F	Gross real interest rate on foreign bonds	1.01	Implied
K	Capital stock	7.116	Implied
N	Labor	0.348	Implied
I	Investment	0.178	Hall (2002)
$\frac{R^k}{P}$	Rental rate on capital	0.0381	Implied
$\frac{W}{P}$	Real wage	1.8699	Implied
R^e	Entrepreneurial return on capital	1.0131	Implied
τ	Leverage ratio	2.1	Implied
NW	Net worth	3.3886	Implied
L	Real value of loans	3.7274	Implied
$\frac{D}{P}$	Real value of deposits	3.7274	Implied
C	Consumption	0.768	Hall (2002)
C^e	Entrepreneurial consumption	0.0541	Hall (2002)
W^e	Wage of entrepreneurs	0.0065	Implied
e^r	Real exchange rate	1	Assumed
TOT	Terms of trade	1	Assumed
a^e	Cut-off productivity of entrepreneurs	0.52	Implied

Figure 3.1: IRFs to a One Standard Deviation Negative Productivity Shock in the Home Country

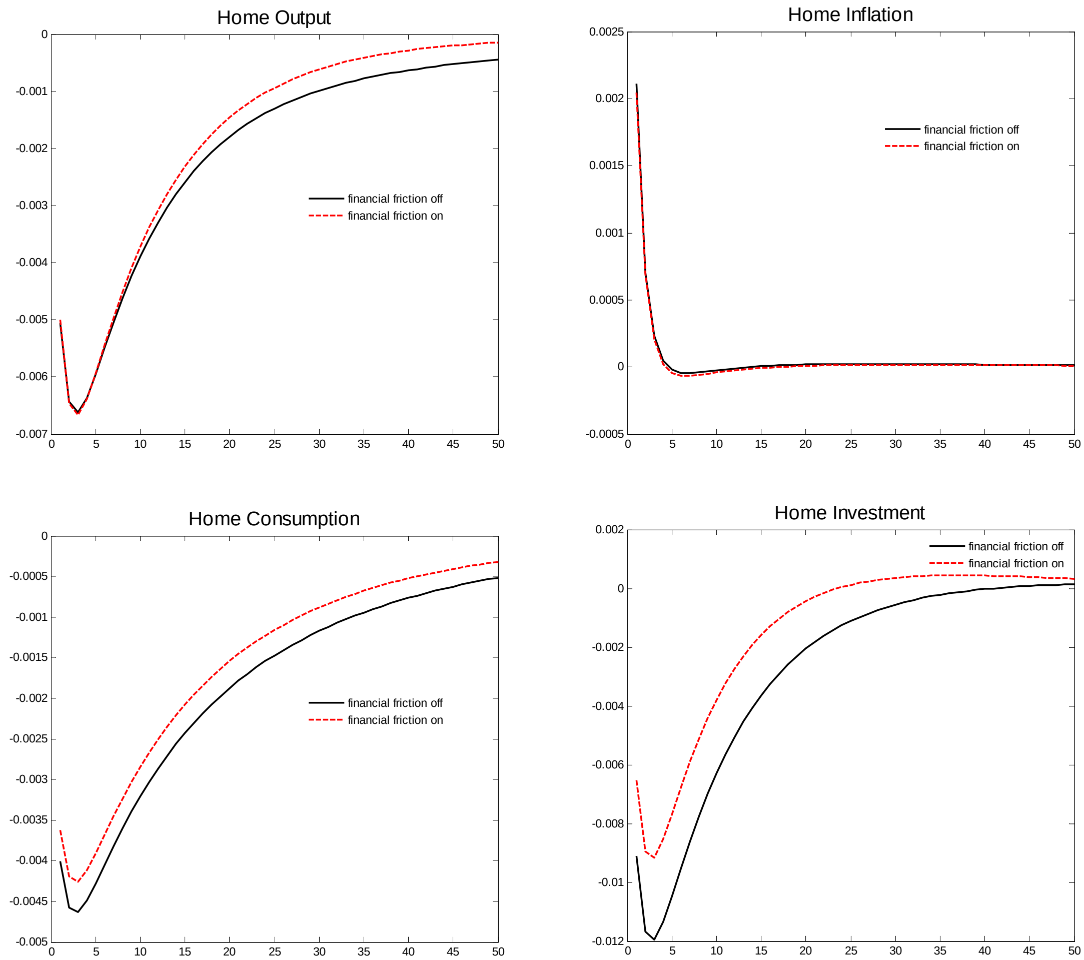


Figure 3.2: IRFs to a One Standard Deviation Negative Productivity Shock in the Home Country

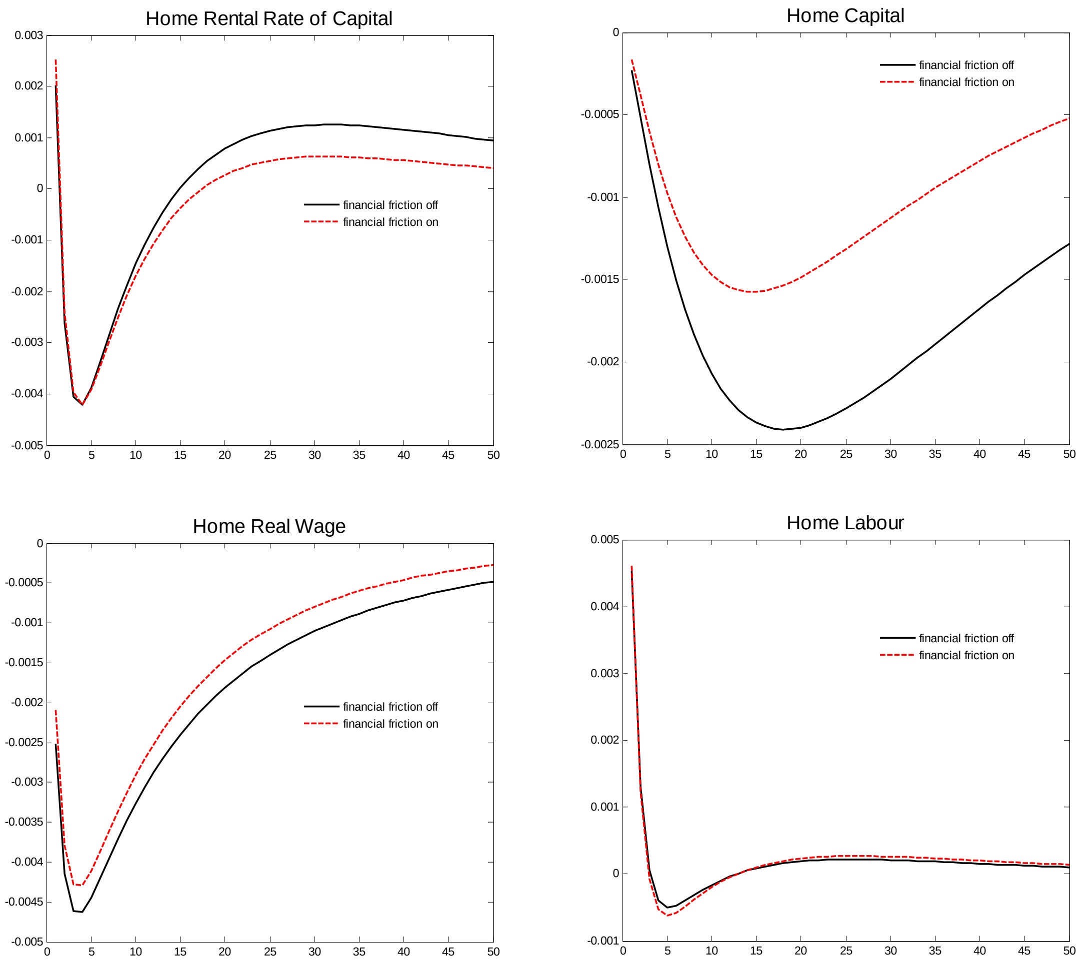


Figure 3.3: IRFs to a One Standard Deviation Negative Productivity Shock in the Home Country

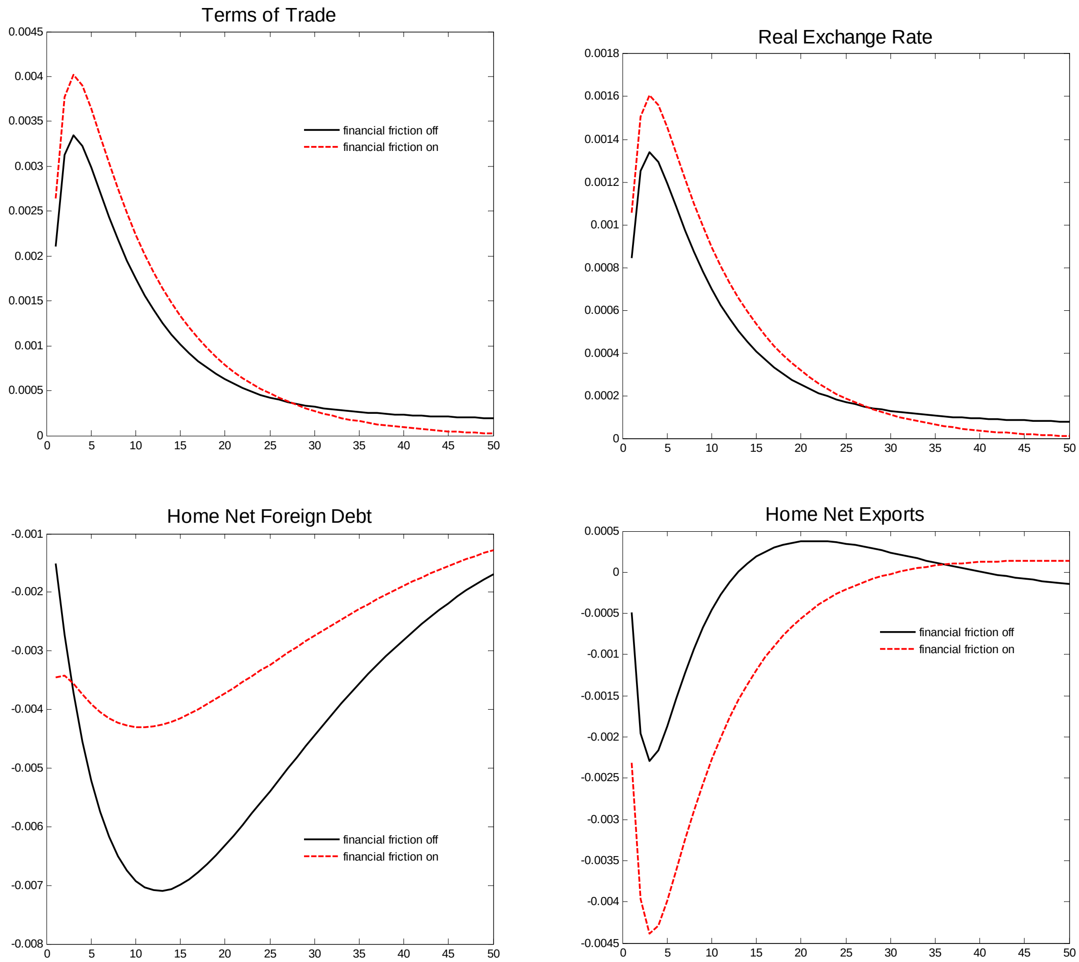


Figure 3.4: IRFs to a One Standard Deviation Negative Productivity Shock in the Home Country

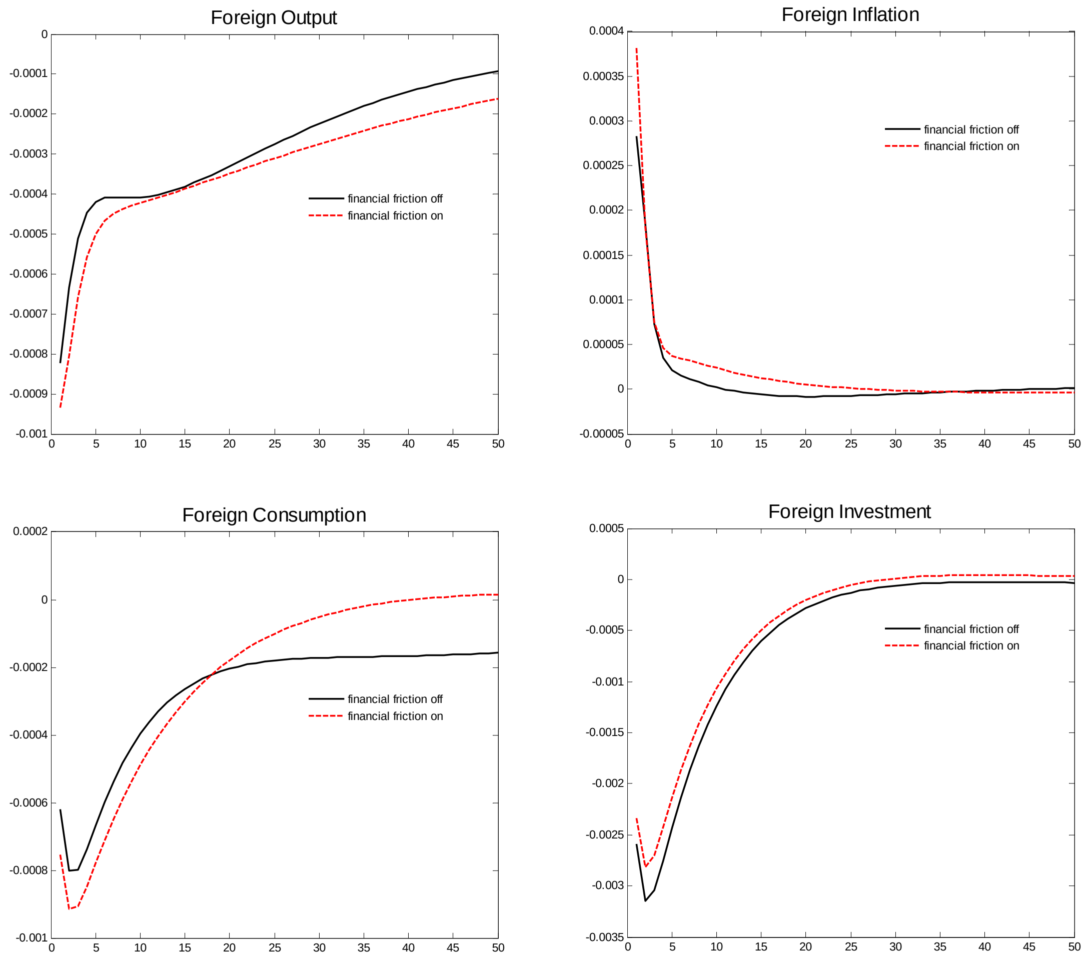


Figure 3.5: IRFs to a One Standard Deviation Negative Productivity Shock in the Home Country

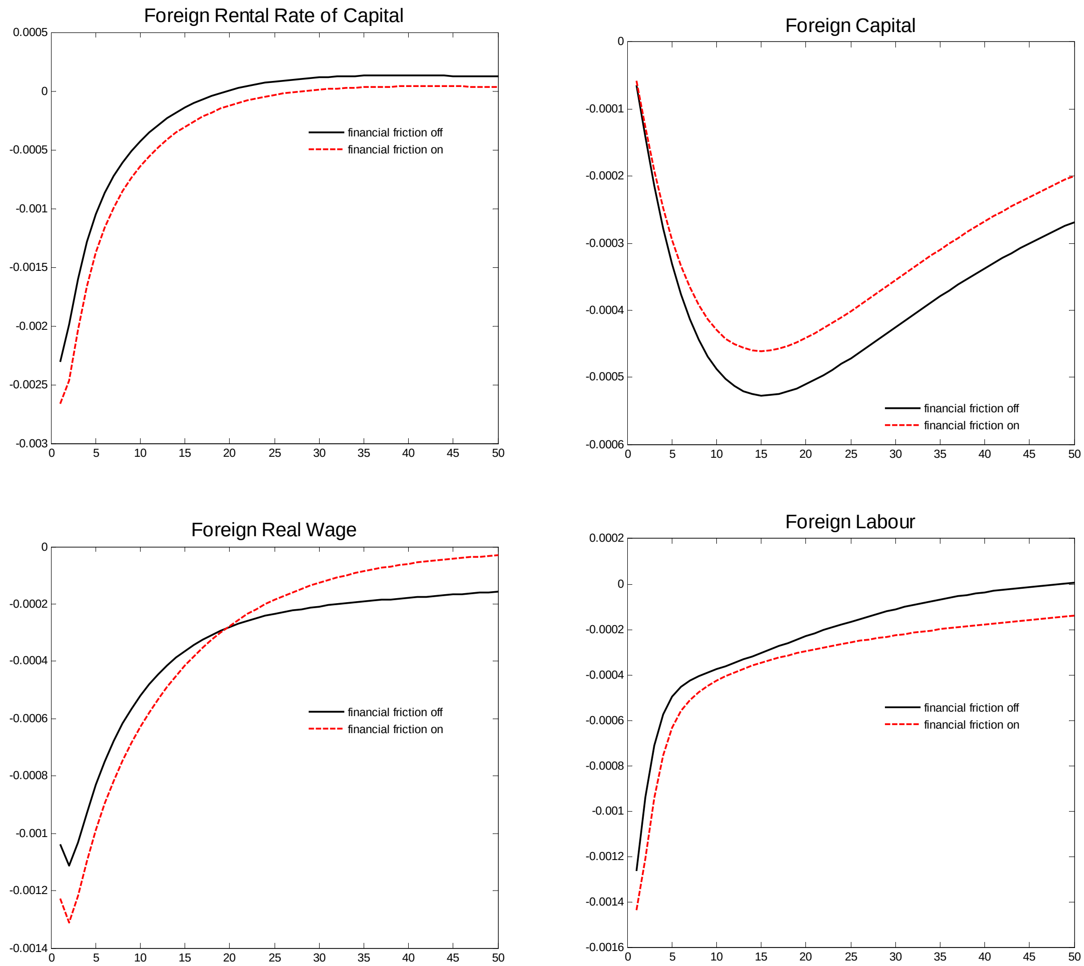


Figure 3.6: IRFs to a One Standard Deviation Negative Productivity Shock in the Home Country

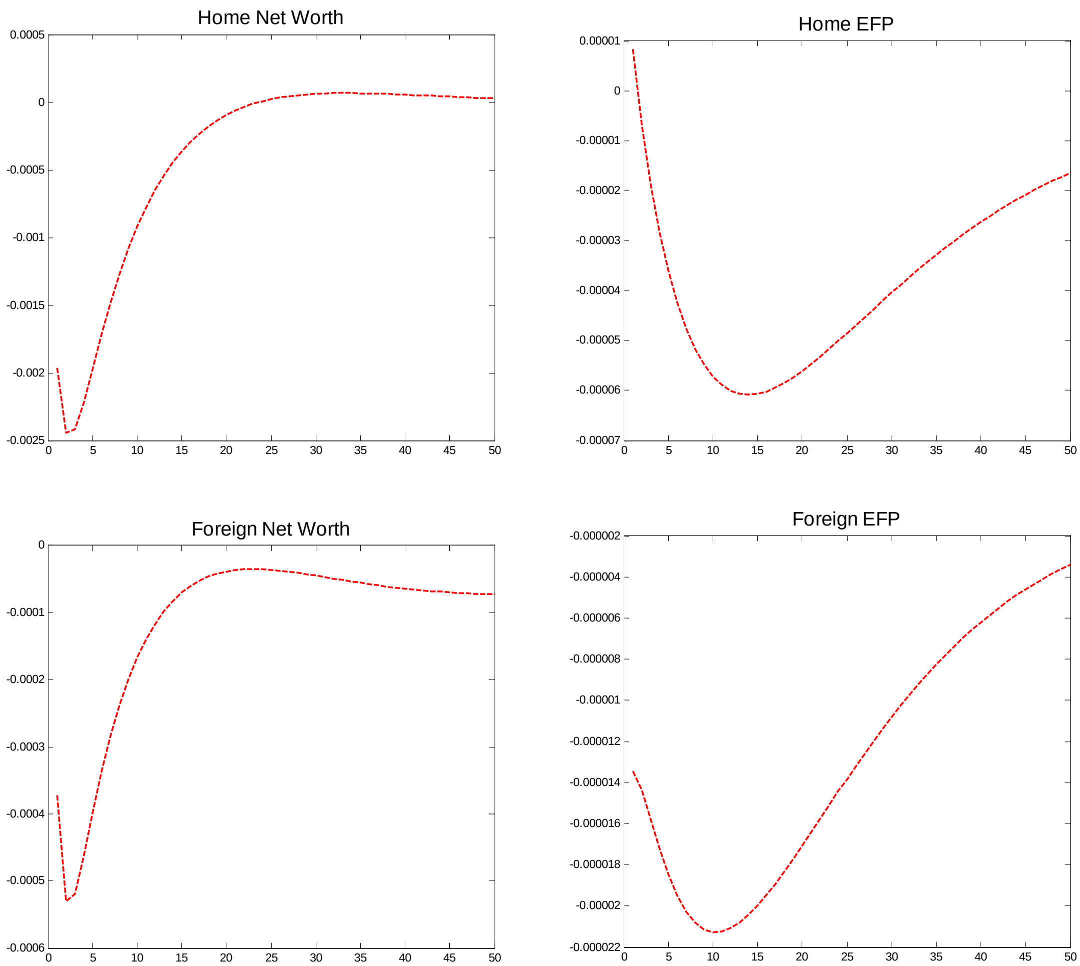


Figure 3.7: Effect of Risk Shock

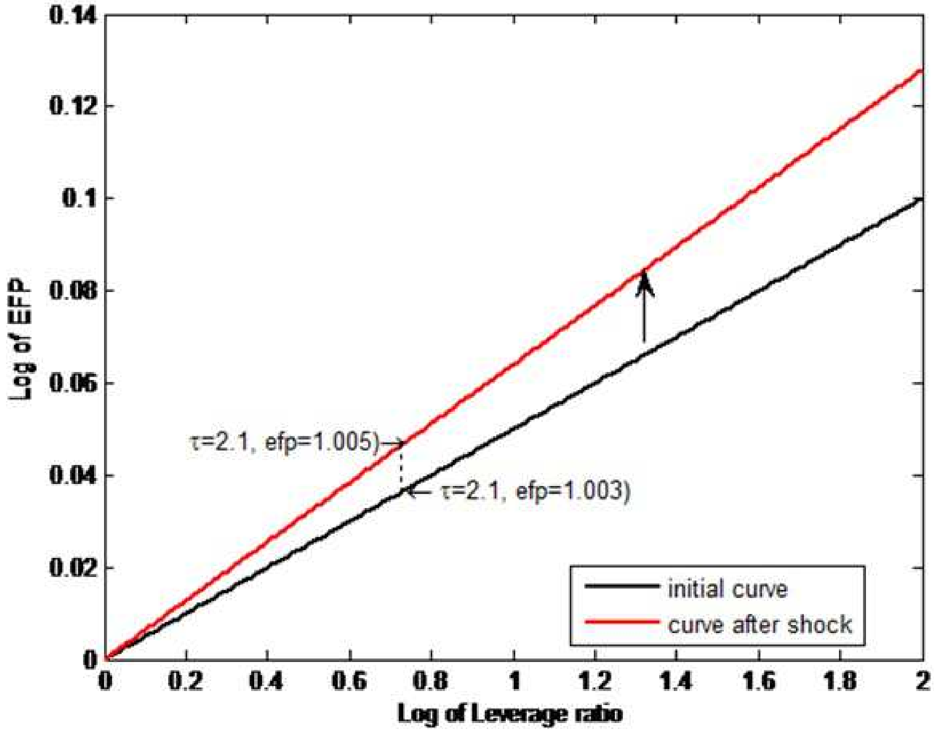


Figure 3.8: IRFs to a One Standard Deviation Positive Risk Shock in the Home Country

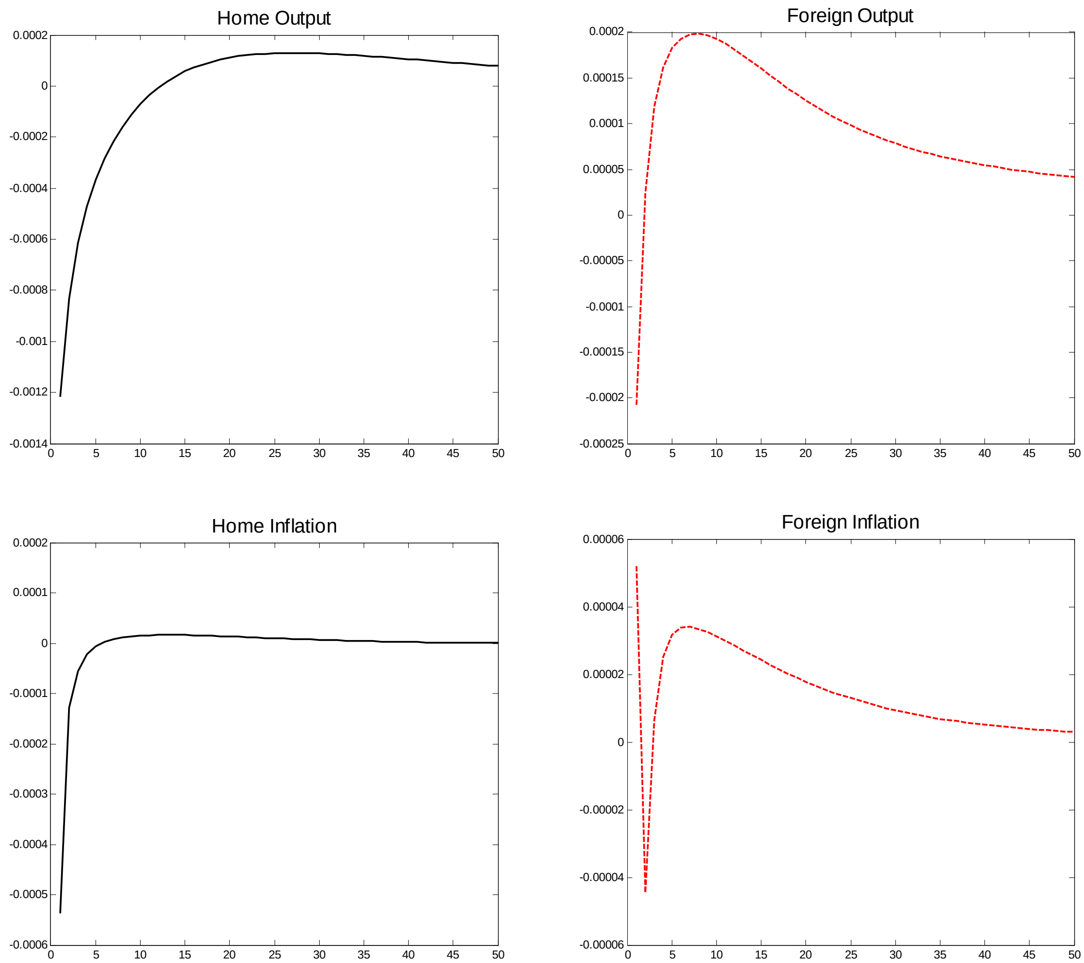


Figure 3.9: IRFs to a One Standard Deviation Positive Risk Shock in the Home Country

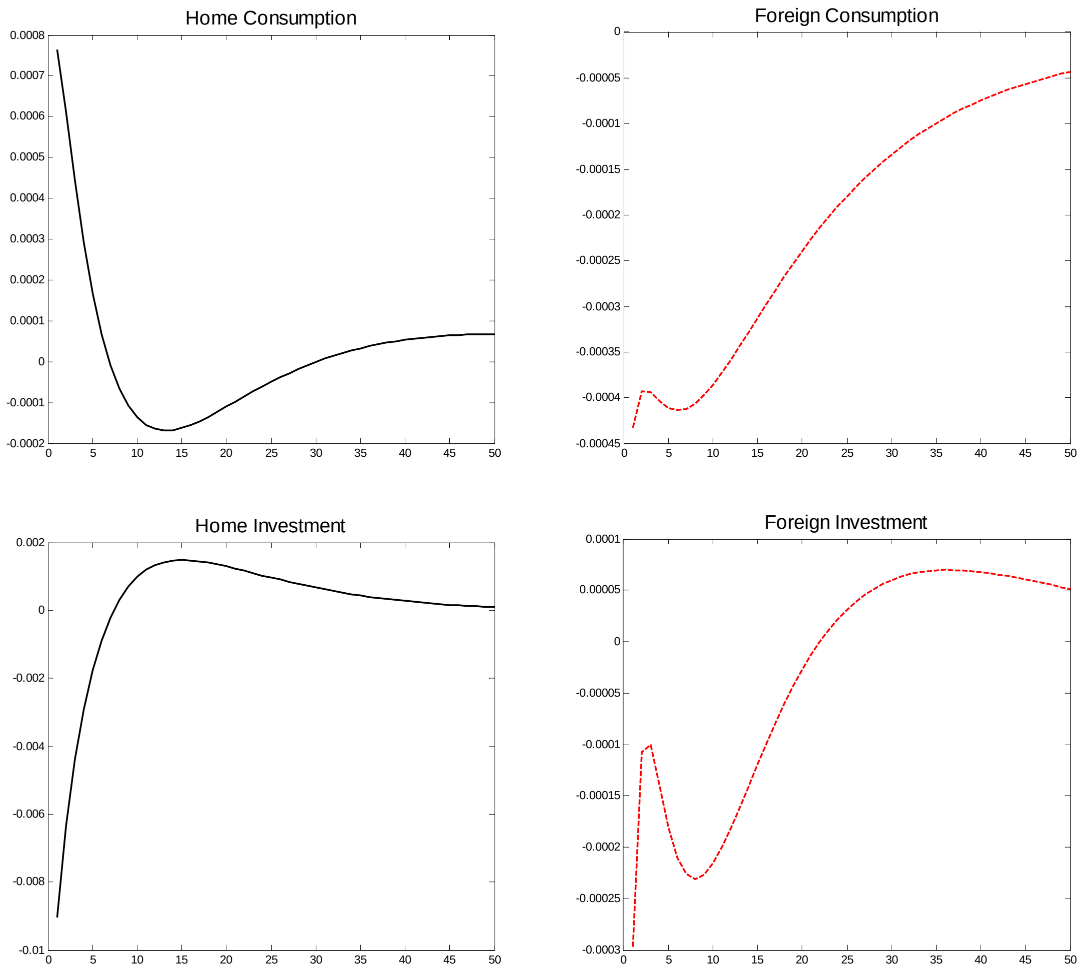


Figure 3.10: IRFs to a One Standard Deviation Positive Risk Shock in the Home Country

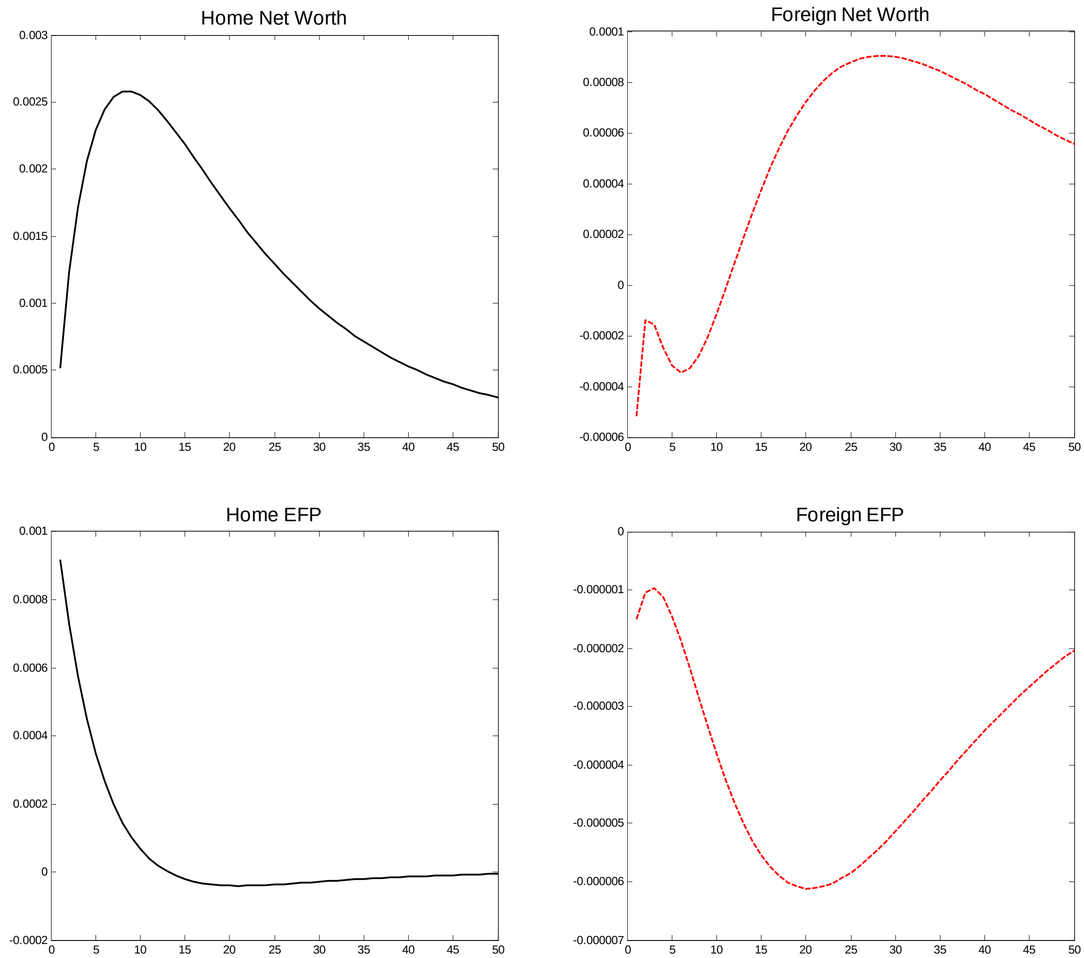


Figure 3.11: IRFs to a One Standard Deviation Positive Risk Shock in the Home Country

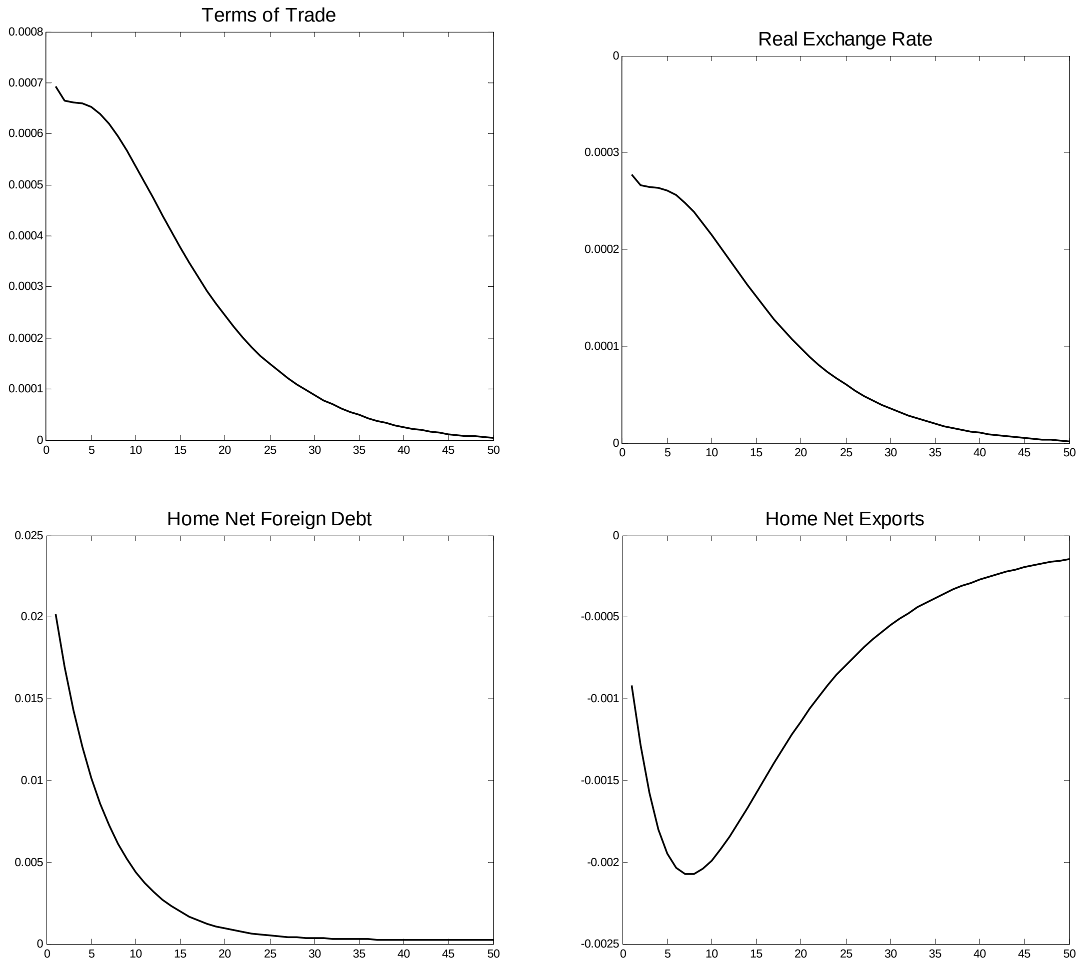


Figure 3.12: IRFs to a One Standard Deviation Negative Survival Shock in the Home Country

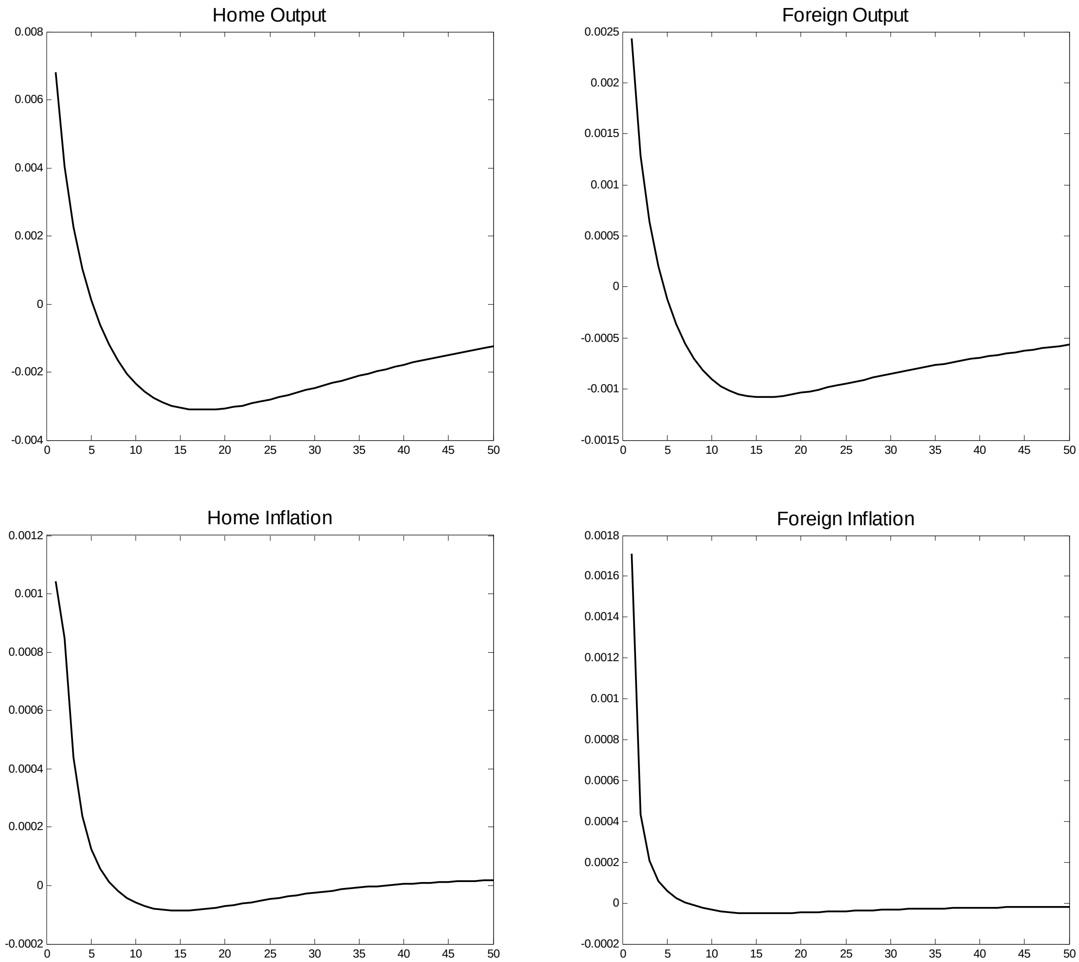


Figure 3.13: IRFs to a One Standard Deviation Negative Survival Shock in the Home Country

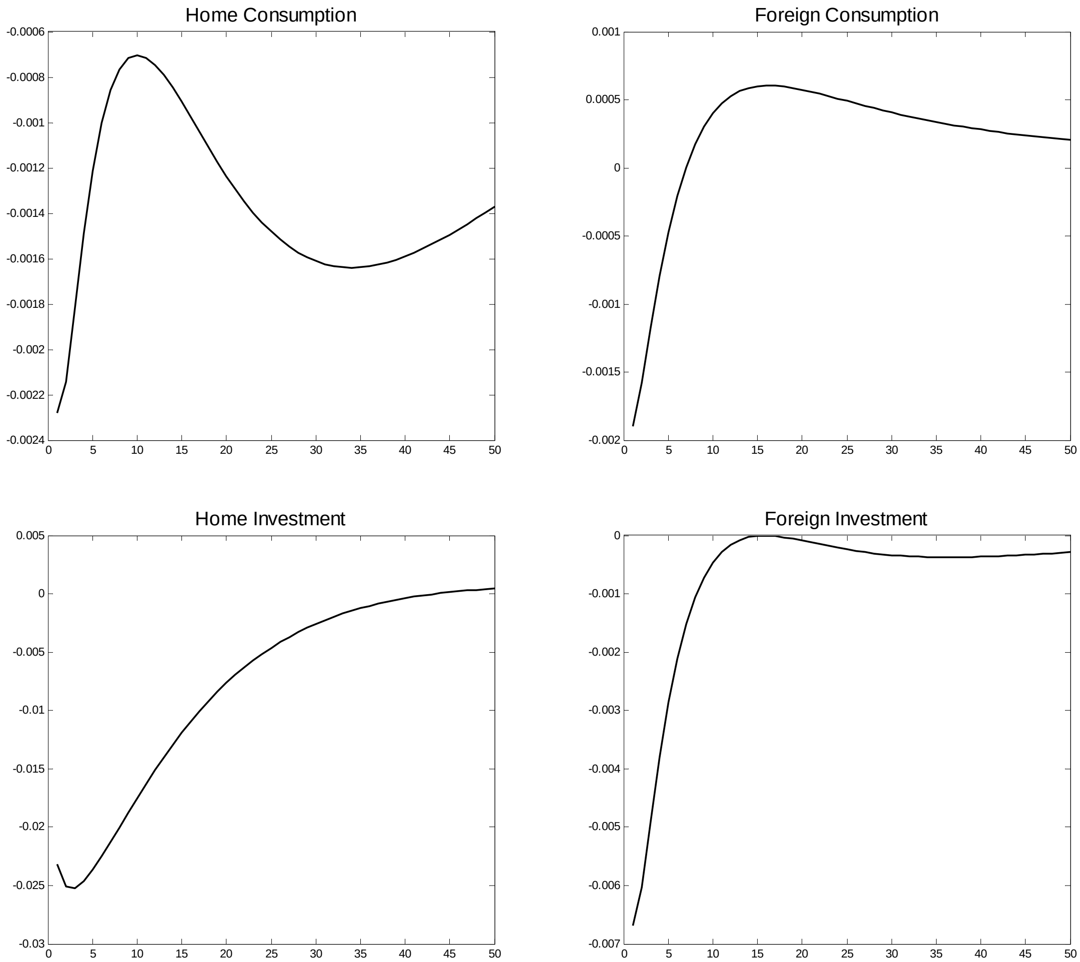


Figure 3.14: IRFs to a One Standard Deviation Negative Survival Shock in the Home Country

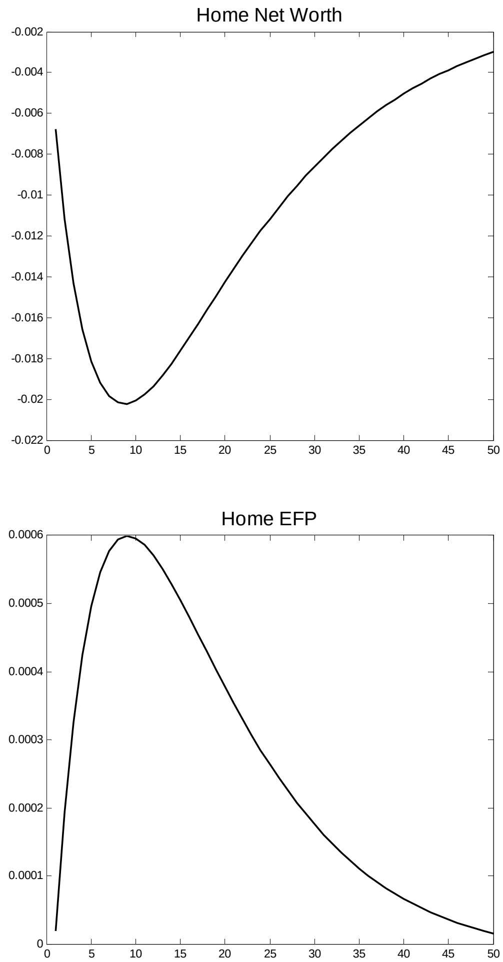


Figure 3.15: IRFs to a One Standard Deviation Negative Survival Shock in the Home Country

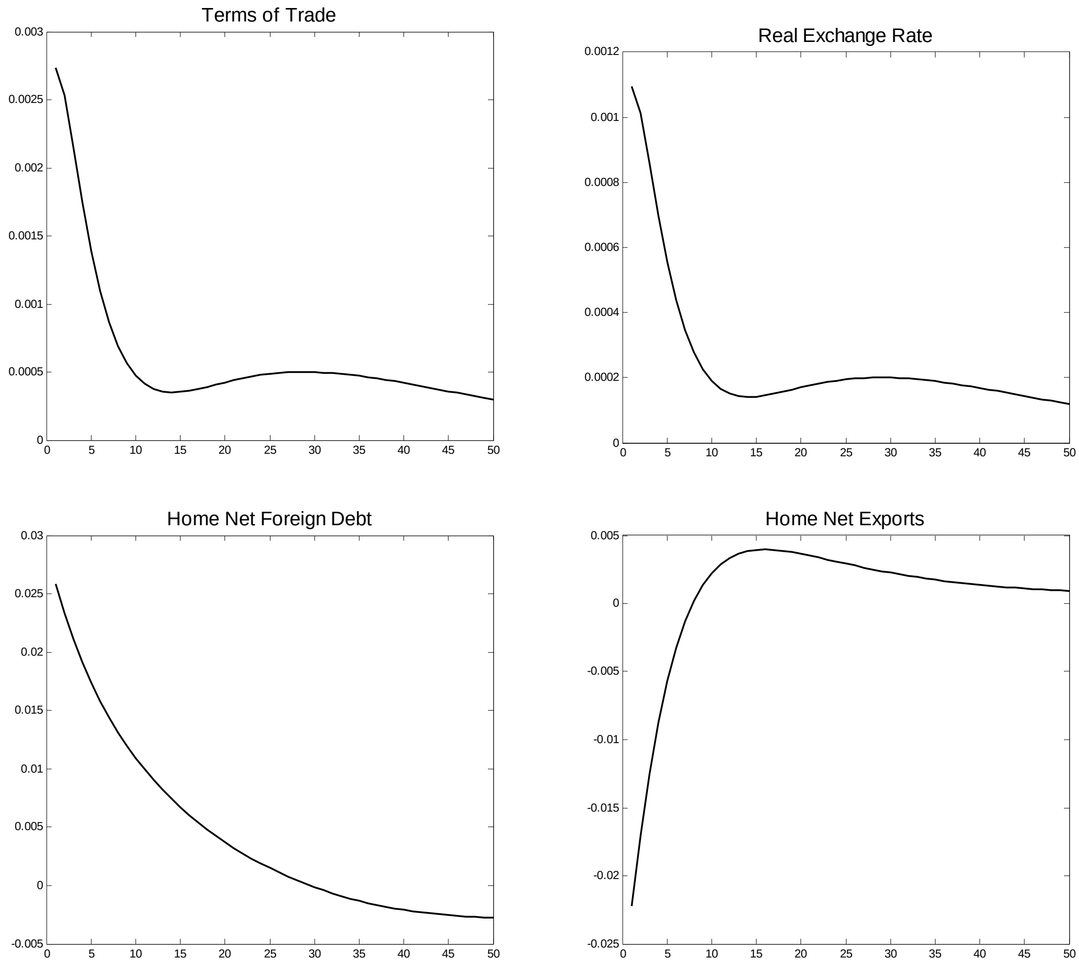


Figure 3.16: Relative IRFs to Credit Spread Shocks in the Home Country

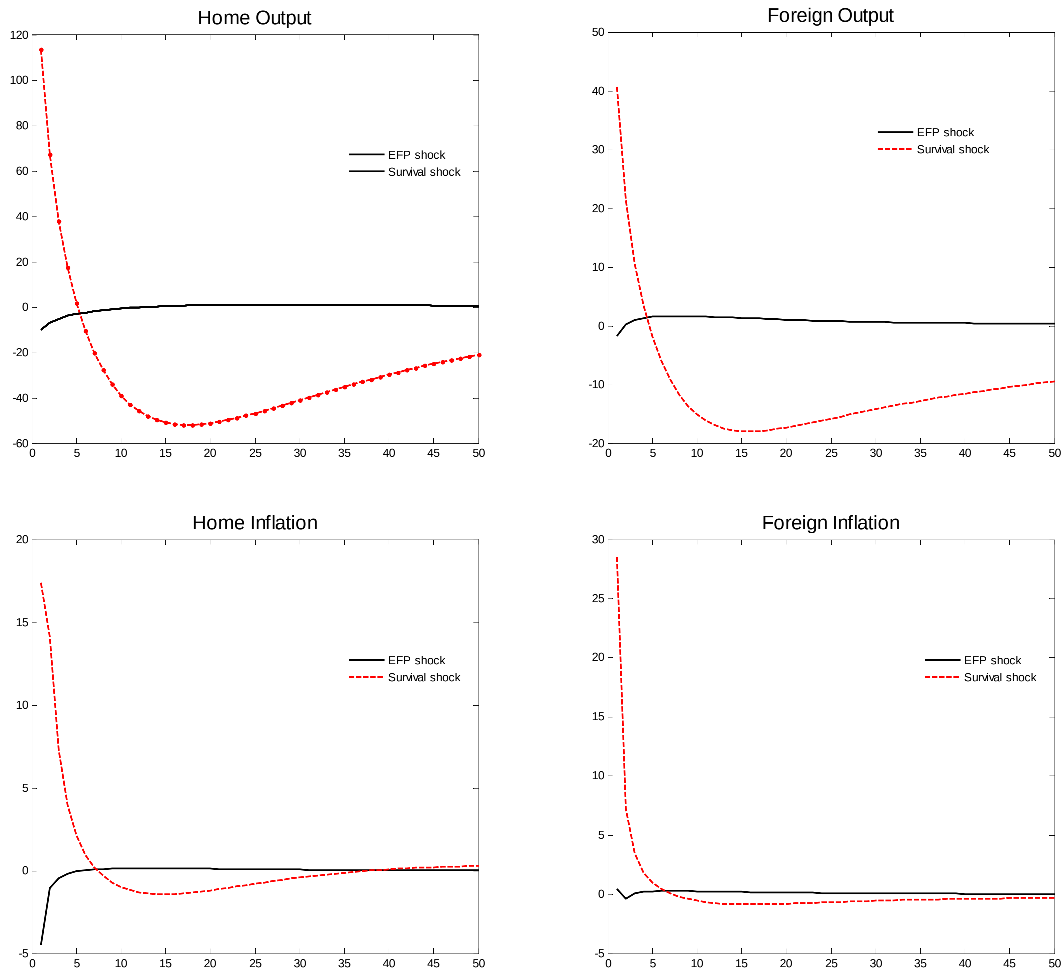


Figure 3.17: Relative IRFs to Credit Spread Shocks in the Home Country

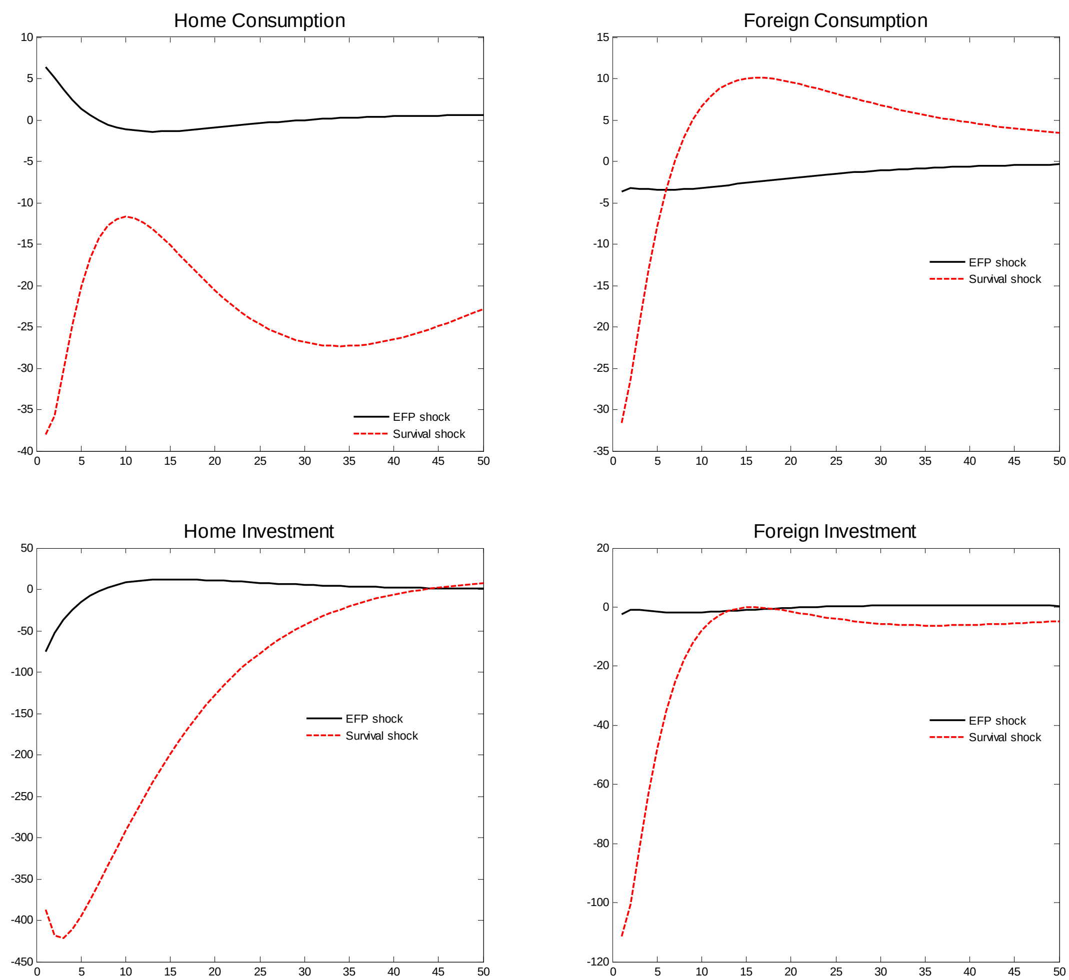


Figure 3.18: Relative IRFs to Credit Spread Shocks in the Home Country

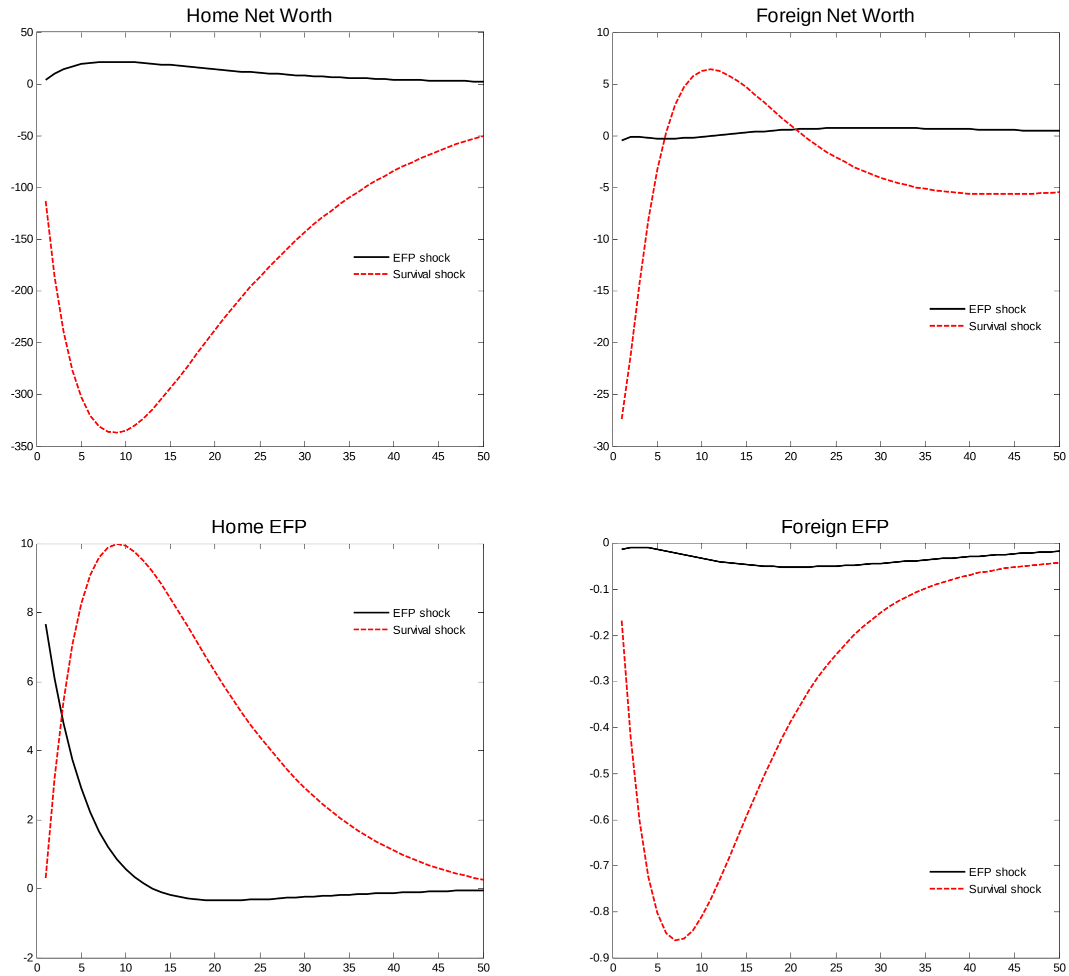
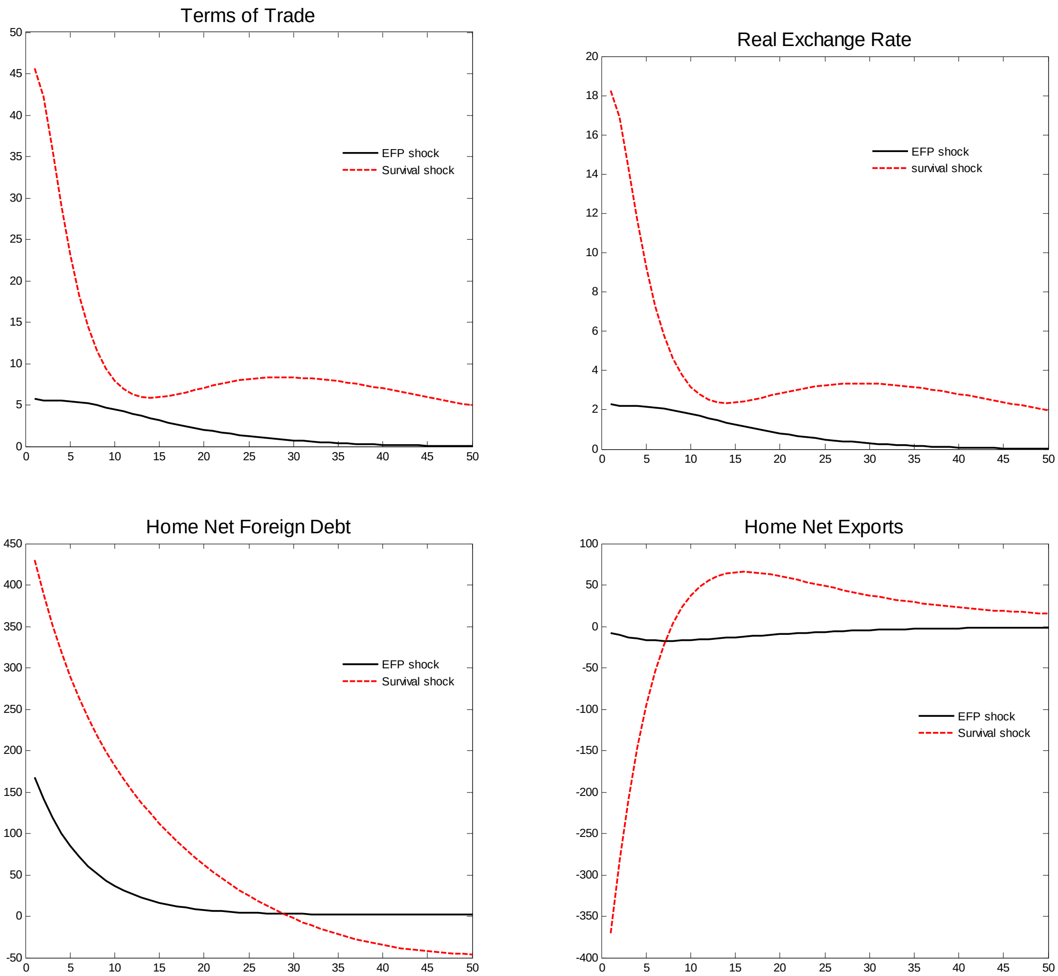


Figure 3.19: Relative IRFs to Credit Spread Shocks in the Home Country



3.6 Appendix

Log linear model with a financial accelerator.

Variables with a hat and a time subscript are in log deviation from the steady state, or $\hat{x}_t = \log X_t - \log X$. Foreign country variables are denoted with an asterisk

$$g_t = \rho_g \, g_{t-1} + \varepsilon_{gt} \tag{3.40}$$

$$A_t = \rho_A A_{t-1} - \varepsilon_{At} \tag{3.41}$$

$$s_t = \rho_s \, s_{t-1} - \varepsilon_{st} \tag{3.42}$$

$$f_t = \rho_f f_{t-1} + \varepsilon_{ft} \tag{3.43}$$

$$ef\hat{p}_t = r^e_{t+1} - (r^n_t - \pi_{t+1}) \tag{3.44}$$

$$\hat{\tau}_t = \hat{q}_t + \hat{k}_t - n\hat{w}_t \tag{3.45}$$

$$\hat{q}_t = \varepsilon_{ik} \left(\hat{\imath}_t - \hat{k}_{t-1} \right) \tag{3.46}$$

$$r^e_{t+1} - (r^n_t - \pi_{t+1}) = \upsilon\hat{\tau}_t \; + \varpi \, log\,(\tau) \; f_t \tag{3.47}$$

$$NWn\hat{w}_t = \chi R^e NW \left(s_t + r^n_{t-1} - \pi_t + e\hat{f}p_{t-1} + n\hat{w}_{t-1} \right) + w^e \hat{w}^e_t \tag{3.48}$$

$$C^e {c^e}_t = R^e NW \left(r^n_{t-1} - \pi_t + e\hat{f}p_{t-1} + n\hat{w}_{t-1} \right)$$

\

$$-\chi R^e NW \left(s_t + r^n_{t-1} - \pi_t + e\hat{f}p_{t-1} + n\hat{w}_{t-1} \right) \tag{3.49}$$

$$r^e_t = \frac{1-\delta}{R^e}\hat{q}_t - \hat{q}_{t-1} + \frac{r^k}{R^e}\hat{r}^k_t \tag{3.50}$$

$$\hat{w}^e_t = \hat{mc}_t + \frac{(1-\gamma)\, tot^{a-1}}{\gamma + (1-\gamma)\, tot^{a-1}} \hat{tot}_t + \hat{y}_t \tag{3.51}$$

$$l\,\hat{l}_t = K\left(\hat{q}_t + \hat{k}_t \right) - NWn\hat{w}_t \tag{3.52}$$

$$\hat{x}_t = \frac{1-\gamma}{1-\gamma+\gamma\, tot^{1-a}}\,\hat{x}_{ft} + \frac{\gamma}{\gamma + (1-\gamma)\ tot^{a-1}}\,\hat{x}_{ht} \tag{3.53}$$

$$\hat{x}_t = \frac{C}{X}\,\hat{c}_t + \frac{C^e}{X}\hat{c}^e_t + \frac{I}{X}\hat{\imath}_t \tag{3.54}$$

$$\hat{x}_{ht} - \hat{x}_{ft} = (-a)\ tot_t \tag{3.55}$$

$$C\,\hat{c}_t + d\,\hat{d}_t + B^*_t - B^* = wN\ (\hat{w}_t + \hat{n}_t) + \frac{d}{\beta}\left(\beta r^n_{t-1} - \pi_t + \hat{d}_{t-1} \right) + R\left(B^*_{t-1} - B^* \right)$$

$$+R\,B^{*}r_{t-1}+\frac{Y}{\left(\gamma+(1-\gamma)\ tot^{a-1}\right)^{\frac{1}{1-a}}}\left(tot_t\,\frac{(1-\gamma)\ tot^{a-1}}{\gamma+(1-\gamma)\ tot^{a-1}}+\hat{y}_t\right)$$

$$-\frac{Y}{\left(\gamma+(1-\gamma)\ tot^{a-1}\right)^{\frac{1}{1-a}}}\,\frac{b-1}{b}\left(\hat{y}_t+\ \frac{(1-\gamma)\ tot^{a-1}}{\gamma+(1-\gamma)\ tot^{a-1}}\hat{tot}_t+\hat{mc}_t\right) \qquad (3.56)$$

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