

INTERNATIONAL PORTFOLIOS IN THE NEW OPEN ECONOMY MACROECONOMICS MODEL

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ABSTRACT

This thesis employs recently developed numerical approximation methods to study international portfolio diversification in the dynamic stochastic general equilibrium New Open Economy Macroeconomics (NOEM) model. The theoretical model features capital accumulation, nominal price rigidity, monetary policy shocks, and incomplete asset markets. The model can account for the observed home bias in equity portfolio. The steady state equilibrium portfolio is sensitive to the model's specifications, particularly the degree of price stickiness and the completeness of asset markets. The NOEM model with three types of shocks – investment specific technology, total factor productivity, and monetary policy – can generate sizeable volatility in portfolio holdings and asset trades. Monetary policy shocks play an important role in determining the steady state equilibrium portfolio as well as influencing portfolio dynamics. Theoretical responses of dynamic portfolio holdings are empirically tested using the Structural Vector Auto Regression framework on US data. The benchmark period is 1982:Q2 to 2007:Q4, however, the full sample from 1960:Q1 to 2007:Q4 is also examined. Empirical responses are consistent with theoretical predictions. Comparison of empirical findings of different time periods illustrates the possibility that the liberalization of financial markets has changed the nature of international asset diversification.

Table of Contents

Introduction.....	1
Chapter 1.....	5
1.1. Introduction.....	5
1.2. NOEM model with complete asset markets.....	11
1.3. Numerical iterating method and applications.....	24
1.4. NOEM model with incomplete asset markets.....	31
1.5. Conclusions and future work.....	40
Appendix.....	42
Chapter 2.....	54
2.1 Introduction.....	54
2.2 A New Open Economy Macroeconomics model.....	61
2.3 Solving the Model.....	74
2.4 Calibration and steady-state portfolios.....	79
2.5 Portfolio dynamics.....	83
2.6 Conclusions.....	93
Appendix.....	96

Chapter 3.....	118
3.1 Introduction.....	118
3.2 Structural VAR: Identification and specification.....	123
3.3 Results.....	134
3.4 Conclusions.....	144
Appendix.....	147
 Bibliography.....	 160

List of Figures

1-1 Equilibrium portfolios vs. the share of imports (trade openness)	47
1-2 Equilibrium portfolios vs. the share of labor	48
1-3 Equilibrium portfolios vs. the elasticity of substitution	49
1-4 Equilibrium portfolios vs. the degree of relative risk aversion	50
1-5 Equilibrium portfolios vs. the degree of price stickiness	51
1-6 Equilibrium equity portfolios versus the persistence and volatility of productivity shocks	52
1-7 Equilibrium equity portfolios versus volatility of monetary policy and fiscal policy shocks	53
2-1 Changes in US NFA positions between 1960:Q1 to 2007:Q4	56
2-2 Impulse responses of external positions - Home TFP shock	103
2-3 Impulse responses of external positions - Home investment specific shock	104
2-4 Impulse responses of external positions - Home monetary policy shock	105
2-5 Empirical structural responses - US Net Foreign Assets Position	106
2-6 Volume effects - Home TFP shock	107
2-7 Valuation effects - Home TFP shock	108
2-8 Volume effects - Home Investment specific shock	109
2-9 Valuation effects - Home Investment specific shock	110
2-10 Volume effects - Home Monetary policy shock	111

2-11 Valuation effects - Home Monetary policy shock	112
2-12 IRFs of selected variables to Home TFP shock	113
2-13 IRFs of selected variables to Home Embodied technology	114
2-14 IRFs of selected variables to Home Monetary policy shock	115
2-15 Real Exchange Rate	116
2-16 Net Exports	117
3-1 Changes of the US NFA position 1960:Q1-2007:Q4	119
3-2 Shares of foreign government holdings of US bonds (Author's calculation)	132
3-3 Share of Other Assets	133
3-4 Impulse responses of financial variables to an embodied technology shock	150
3-5 Impulse responses to a neutral technology shock	151
3-6 Impulse responses to an expansionary monetary policy shock	152
3-7 Impulse responses to an embodied technology shock - Trades of financial assets .	153
3-8 Impulse responses to a neutral technology shock - Trades of financial assets	154
3-9 Impulse responses to a monetary policy shock - Trades of financial assets	155
3-10 Impulse responses to shocks - Early period 1960:Q1-1982:Q1	156
3-11 Impulse responses to shocks - Full sample 1960:Q1-2007:Q4	157
3-12 Impulse responses to shocks - Relative price of equipment	158
3-13 Impulse responses to shocks - Hours worked in levels	159

List of Tables

1-1 Calibration of RBC model with complete markets	27
1-2 Iteration results for Heathcote and Perri (2008) model	28
1-3 Calibration of NOEM model with complete markets	29
1-4 Selected sensitivity analysis results for the equilibrium portfolios	30
1-5 Calibration of NOEM model with incomplete markets	34
2-1 Benchmark calibration	81
2-2 Second moments of selected macro variables	90
2-3 Predicted second moments of external balances and the real exchange rate	92
3-1 Standard deviations of net acquisitions of bonds and equities by the US	121
3-2 Variance decomposition – Asset holdings	140
3-3 Variance decomposition – Flows of asset trades	142

Introduction

The liberalization of international financial markets has expanded opportunities for international portfolio diversification. Despite the surge in cross-border capital flows, the share of foreign equities held in the portfolio of most advanced economies remains small. The international finance literature has been puzzled by this observed home bias in equity. This thesis develops a dynamic stochastic general equilibrium framework to investigate this puzzle and offers plausible explanations of the dynamics of capital flows and portfolio holdings. Furthermore, I employ the structural Vector Auto Regression to empirically study international capital movements using evidence from US markets.

Early work cannot explain the degree of home bias in equity portfolio. Indeterminacy of the deterministic equilibrium portfolio has technically prevented early theoretical framework to study endogenous portfolio choices. Following Heathcote and Perri (2007), in the first chapter, I develop a flexible and easily applicable iterating method to quantitatively study international asset portfolios in models with either complete or incomplete asset markets. This iterating method utilizes Dynare second-order simulation tools. An important contribution of this paper to the literature is that it

provides an alternative method to quantitatively examine portfolio choices in the general equilibrium framework.

The benchmark model is the New Open Economy Macroeconomics framework, which features capital accumulation, nominal price rigidity and monetary policy shocks. Home bias in equilibrium equity portfolio can arise even if there is no bias in consumption and investment under both asset market specifications. Intuitively, the correlation between domestic labor income and domestic dividends is negative in the sticky price environment. Under nominal price rigidity assumption, monetary policy shocks have significant impacts on portfolio choices. This is remarkably different from the Real Business Cycle framework, which assumes flexible prices.

Sensitivity analysis finds that the steady state equilibrium portfolio depends on the model's specifications. It is particularly very sensitive to the elasticity of substitution between domestic and imported goods. It is also important to note that sensitivity of the steady state portfolios to some parameters can change significantly under incomplete asset markets.

Although the first chapter can account for the observed home bias degree in the steady state portfolio, it does not explain the dynamics of international capital flows. The next chapter fills in this gap. I use a different numerical method, which relies on higher order approximation, to calculate theoretical impulse responses of portfolio holdings and capital flows to different sources of economic innovations. This method is developed by Devereux and Sutherland (2007, 2008). The model features three types of structural shocks: investment-specific technology, labor productivity and monetary policy shocks.

By construction, there are more types of shocks than those of financial assets; therefore, the asset markets are incomplete.

Numerical results confirm some findings of earlier papers and extend the literature by allowing an important role for monetary policy shock. I show that the responses of the net foreign asset position to shocks are consistent with theoretical intuitions. In response to economic expansionary shocks, the domestic country imports increase relatively more than its exports leading to a deterioration of the trade balance. In order to pay for its increasing imports, domestic country has to borrow abroad; hence, its net foreign asset position decreases. The calibrated benchmark model generates sizeable volatility in the net foreign asset position as well as trading flows of bonds and equities. Moreover, monetary policy shocks show significant impacts on the volatility of capital flows and asset holdings. It is an important result because the literature lacks evidence on the role of monetary policy shocks on portfolio holdings as well as capital flows.

The final chapter compliments the theoretical results by empirically investigating the dynamics of international portfolios using evidence from the US markets. The US is the largest economy and the financial center of the world. I focus exclusively on effects of three US domestic factors: the investment-specific technology, the labor productivity, and the monetary policy shocks that may drive the current fluctuations of international portfolio between the US and the rest of the world. I make extensive use of the Flows of Fund Accounts data on financial flows and holdings by different sectors of the US and the rest of the world. The structural Vector Auto Regression identification scheme and estimation procedure follow Altig, Christiano, Eichenbaum, and Linde (2005).

The benchmark period is from 1982:Q2 to 2007:Q4. I also consider the earlier period between 1960:Q1 to 1982:Q1 and the overall sample to study the possibility that the globalization of financial markets has affected international portfolio diversification since the early 1980s. Empirical responses of the net foreign asset position are consistent with theoretical predictions of the second chapter although they are only marginally statistically significant in some cases. Results show that each shock plays an important role in explaining the dynamics of international portfolio holdings. These three shocks together can account for between 10% to 45% of fluctuations in portfolio holdings and almost 29% of NFA variability over business cycle frequencies. These shocks account for smaller fractions of volatility in trading flows. Interestingly, monetary policy shocks account for a larger fraction of equity holding volatility than that of the two technology shocks, while technology shocks have more explanatory power over the dynamics of bond portfolios.

Chapter 1 considers an alternative numerical method that can solve for steady state asset portfolios in different theoretical framework. Particularly, it shows that this iterating method can apply on the New Open Economy Macroeconomics framework, which features capital accumulation, nominal rigidity, monetary policy and incomplete asset markets. The second chapter follows up the motivation and investigates the time-varying dynamics of international portfolio holdings. Finally, the third chapter empirically tests theoretical predictions using the structural Vector Auto Regression framework on US markets data.

Chapter 1

International Asset Portfolios in the New Open Economy Macroeconomics model

1.1 Introduction

Obstfeld and Rogoff (2000) put the "portfolio home bias puzzle" on their list of major puzzles in the international finance literature. Empirical studies find that the share of foreign equities held by the industrialized economies are still small. Lane and Milesi-Ferretti (2007) study OECD data and show that there is improvement in terms of diversification in equity portfolio in the last few decades but investors still hold a small share of foreign equities in their portfolio¹. Studies have found significant welfare gains from international diversification, they have not been able to explain

¹Warnock (2002) and Ahearne, Grier, and Warnock (2006) calculate and find a trend of increasing holding foreign equity in the US, but it is still small, about 12% in 2000.

why investors in most developed countries still invest a majority of their wealth in domestic equities despite the recent increasing integration of international financial markets². In this paper, we focus on building a dynamic general equilibrium model that can support the current "home bias" in equity holding as the optimal equilibrium portfolio.

Early works using standard general equilibrium Real Business Cycle (RBC) models produce contrasting results. In a two country pure exchange economy with financial integration and one traded good, Lucas (1982) shows that portfolios are perfectly diversified if residents of each country own fifty percent share of the other country's endowment. Cole and Obstfeld (1991) extend Lucas' model to have endowments of two traded goods. They find that any level of diversification can support perfect risk sharing, including financial autarky, because the terms of trade absorb all risks when preferences are log-separable. On the other hand, Baxter and Jerermann (1997) also extend Lucas' model to include production of traded goods. They find that the correlation between domestic labor income and domestic profit is positive and large, therefore, investors should "short" domestic equities to hedge against non-traded labor income risk. Thus, they claim the home bias puzzle is worse than it seems. Other papers have extended the standard RBC model to include either non-traded goods sectors, transaction costs, or asymmetric information to explain the observed level of equity diversification. Lewis (1999) reviews the literature and documents three common hypotheses which have been used in attempt to explain the international portfolio puzzle: hedging motives against home risks (nontradable

²See, for instance, Lewis (1996), Rowland and Tesar (1998), Tesar (1995), Van Wincoop (1994, 1999)

goods, non-traded labor income)³, costs of diversification (transaction, information costs)⁴, and empirical measurement errors. She finds that none of those factors alone can successfully explain the home bias phenomenon.

More recent papers have found evidence that perfect risk sharing can be achieved with home bias in equity if there is home biased preference in either consumption or investment. For instance, Kollmann (2006), and Heathcote and Perri (2008). These models assume complete asset markets and tradable goods only. Collard, Dellas, Diba and Stockman (2007) find a similar conclusion in a simple endowment model with traded and non-traded goods. They show that investors can achieve full international risk diversification if the foreign equity position matches the country's degree of openness assuming that asset markets are complete. Hnatkowska (2005) also finds evidence supporting home bias in equity in a model with production and non-traded goods. Her model features incomplete asset markets.

Although those recent RBC models have some successes in explaining the home bias puzzle, their flexible price assumption implies that monetary policy shocks have no effects on macro variables and portfolio choices. In fact, there is substantial empirical evidence that prices are not fully flexible⁵. The New Neoclassical Synthesis provides a theoretical framework to consider effects of monetary policy shocks on macroeconomic variables when there is a certain degree of nominal price stickiness. A few papers have used the richer dynamics setting of the New Open Economy Macro-

³Serrat (2001) theoretically finds a strong correlation between nontradable goods and equity home bias. Pesenti and Van Wincoop (2002) empirically find that nontradable goods effect is small

⁴Tesar and Werner (1995), Warnock (2002)

⁵Rotemberg (1982), Calvo (1983), Taylor (1983) present theoretical framework and early empirical evidence of sticky prices. Gopinath and Rigobon (2006) and references therein estimate degrees of price stickiness based on the early theoretical work. These studies find a substantial degree of inertia in price adjustment in many countries, including the US.

economics model to study endogenous portfolio choices.

Engel and Matsumoto (2006) abstract from capital in production and assume nominal price rigidity. Monetary shocks are effectively hedged by either a forward exchange position or a bond portfolio so that equity is the only means to hedge against technology shocks in their model. They show that, under sticky prices, conditional on a technology shock, the correlation between domestic labor income and profits is negative, thus investors should hold domestic equities to hedge against labor income risks. This is in contrast to the finding of Baxter and Jermann (1997). Under sticky prices, monetary policy shocks not only affect interest rates and prices but can also play an important role in portfolio choices.

Following this motivation, we embed a dynamic asset portfolio choice in a symmetric two country New Open Economy Macroeconomics model with nominal price rigidity following the Rotemberg (1982) specification. Firms can change their prices each period subject to a quadratic adjustment cost. We build a benchmark model with complete asset markets, then extend it to study international portfolio choices under incomplete asset markets. In this framework, monetary policy shocks can affect inflation rates, interest rates, output prices, profits, hence, also portfolio diversification. Price rigidity changes the way the terms of trade absorb risks in the model. Interactions between responses of macro variables to shocks in the NOEM model can generate equilibrium portfolios that are different from the international RBC framework.

Earlier literature faced one critical technical difficulty. In the deterministic case, all financial assets have the same rate of return. Since there is no risk attached, these assets are perfect substitutes. Investors are indifferent between types of assets in the

deterministic steady state so that optimal portfolios are not uniquely determined. In the stochastic environment, financial assets are differentiated by different degrees of risk attached to each asset. Optimal portfolio choices are often determined by functions of correlations and variances of stochastic factors in the economic model. Up to a first-order linear approximation of a DSGE model, all assets have the same *expected* rate of return; certainty equivalence applies so that financial assets remain perfect substitutes. Hence, a higher order approximation is required. The standard approach to solve DSGE models is to take a linear approximation around a non-stochastic steady state. Because portfolio choices are not uniquely determined in a non-stochastic steady state, there is no natural starting point to approximate around⁶. This indeterminacy problem is more acute when the asset markets are incomplete. This technical difficulty has prevented earlier work to incorporate endogenous portfolio choices in the analyses of open economy macroeconomic issues in DSGE models.

A number of papers have developed different methods to overcome the indeterminacy problem. Following Heathcote and Perri (2008), we develop a numerical iteration method to find non-stochastic equilibrium portfolios⁷. The key assumption is that households have to pay a very small portfolio adjustment cost if they deviate from the steady state equilibrium portfolio. This cost, however, is rebated to households so that the household budget constraints will not be affected by this adjustment cost in equilibrium. The best advantage of this assumption is that we can

⁶The implied optimal portfolios can be derived in a limited number of special cases; in particular, models with the complete asset markets such as Coeurdacier, Kollmann, and Martin (2008), Engel and Matsumoto (2006), Kollmann (2006)

⁷See, for example, Kollman (2006), Collard et al (2007) for models with complete asset markets. Evans and Hnatkowska (2005), Tille and van Wincoop (2006), Devereux and Sutherland (2008), and Heathcote and Perri (2008) develop methods for incomplete markets models. Heathcote and Perri (2008) implicitly use the iterating method but do not promote it as a viable numerical method to solve portfolio choices in DSGE models.

analytically pin down the non-stochastic equilibrium portfolio. Once the indeterminacy problem is resolved, we can directly apply the standard approximation methods. Under the first-order approximation, variances of shocks do not have effects due to certainty equivalence, therefore a second-order approximation is needed. We apply the second-order approximation method developed by Schmitt-Grohé and Uribe (2004) and others to study effects of shocks on equilibrium portfolio choices. We utilize the second-order stochastic simulation tools in Dynare and build an iterative algorithm to numerically find the steady state equilibrium portfolio. We apply this method on existing models and show that it can closely replicate either analytical or numerical results from other papers. Moreover, we extend the basic model to include more types of shocks and show that our method can also apply to models with incomplete asset markets.

Our paper provides two important contributions to the international portfolio literature. First, the NOEM framework has a richer dynamic and more realistic environment that enables monetary policy to have real effects on the economy. While this framework has been widely used to study various open macroeconomics issues, few have utilized this framework to study international asset portfolio choices. We fill in that gap in the literature by building a dynamic stochastic general equilibrium NOEM model with embedded endogenous asset portfolio choices. Second, we show that the numerical iteration method can be easily applied to models with different pricing and asset market structures. We present and discuss results for different model specifications, particularly the NOEM model with capital accumulation and incomplete asset markets. The NOEM model with nominal price rigidity generates different implications for international asset portfolio choices. In the sticky price environment,

monetary policy shocks have important effects on equilibrium portfolios. We consistently find a strong degree of home bias in equity in the steady state equilibrium portfolio for different specifications using empirical estimates of US data. We find that the steady state portfolio depends on numbers of structural parameters such as the degree of price stickiness, the share of labor in production, the share of imports in consumption and investment, the elasticities of substitution, and the degree of relative risk aversion. Numerical exercises also show that the sensitivity of equilibrium portfolios to structural parameters critically depends on the completeness of financial asset markets.

The paper is organized as follows. Section 2 presents the basic NOEM model with complete asset markets. In section 3, we explain the iteration process and present numerical applications for models with complete asset markets. In the next section, we introduce a government spending shock to make asset markets incomplete. We present numerical equilibrium portfolios, and provide a sensitivity analysis for the incomplete markets case. Finally, section 5 concludes and suggests some possible future extensions.

1.2 NOEM model with complete asset markets

We develop a symmetric two country New Open Economy Macroeconomics model with capital accumulation and nominal price rigidity. Countries are called Home (H) and Foreign (F). Each country is populated by a representative, infinitely-lived household who consumes, works and trades financial assets.

A continuum $[0,1]$ of identical monopolistic firms produce tradable intermediate goods in each country. Intermediate firms use both labor and capital as inputs for

production. Firms maximize and pay all their profits as dividends to shareholders. Intermediate firms can adjust their output prices each period subject to an adjustment cost following the Rotemberg (1982) specification. There exists a final good bundler in each country who competitively aggregates intermediate goods into final goods for consumption and investment purposes.

Households can hold four different financial assets in their portfolios: shares of Home and Foreign intermediate firms, and two non-contingent bonds denominated in Home and Foreign currencies respectively. We first consider the case of complete asset markets with two types of shocks: technology and monetary policy.

1.2.1 Households

We consider a Home representative household's utility maximization problem. The representative household discounted lifetime preference is defined as:

$$\max \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \psi \frac{L_t^{1+\chi}}{1+\chi} \right) \quad (1.1)$$

where C_t is the consumption basket, and L_t is labor supply. $0 < \beta < 1$ is the discount factor.

The consumption basket, C_t , is a CES combination of domestic and imported final goods:

$$C_t = \left[(\mu_t)^{1/\eta} (C_t^H)^{\frac{\eta-1}{\eta}} + (1-\mu_t)^{1/\eta} (C_t^F)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (1.2)$$

where C_t^H is the consumption of domestically produced final goods, C_t^F is that of imported goods (see Final goods bundler). $\eta > 0$ is the elasticity of substitution between

final goods, and $\mu_t \in (0, 1)$ measures the share of local spending in consumption. The time subscript on μ allows us to consider demand (preference) shocks. In this paper, we assume a constant μ for simplicity. If $\mu > 0.5$, the agent is said to have a "home biased" preference in consumption.

Let P_t^H and P_t^F denote the nominal price indices of final Home and Foreign goods selling in Home denominated in Home currency. Household optimally chooses C_t^H and C_t^F such that:

$$P_t C_t = P_t^H C_t^H + P_t^F C_t^F$$

where Home consumer price index (CPI), P_t , is defined as:

$$P_t = \left[\mu_t (P_t^H)^{1-\eta} + (1 - \mu_t) (P_t^F)^{1-\eta} \right]^{\frac{1}{1-\eta}} \quad (1.3)$$

The household's optimal consumption levels of domestic and imported final goods are:

$$C_t^H = \mu_t \left[\frac{P_t^H}{P_t} \right]^{-\eta} C_t \quad \text{and} \quad C_t^F = (1 - \mu_t) \left[\frac{P_t^F}{P_t} \right]^{-\eta} C_t \quad (1.4)$$

Household supplies homogenous labor L_t to intermediate firms at the competitive nominal wage rate W_t . Labor is immobile between the two countries. Households can trade financial assets across countries for international risk sharing. Let S_{t+1} and S_{t+1}^* denote holdings of Home and Foreign firms' shares by the representative Home household at the end of period t . Shares are traded at (ex-dividend) prices Q_t and Q_t^* . Home household receives dividends D_t and D_t^* from Home and Foreign intermediate firms each period. He also can hold two non-contingent nominal bonds. Let B_{t+1} and

B_{t+1}^* denote Home holdings of domestic and foreign bonds that mature in period $t+1$. Bonds are traded at gross nominal rates of R_t and R_t^* respectively. Foreign assets are priced in Foreign currency. We assume that households pay a quadratic portfolio adjustment cost if they hold a portfolio that is different from the deterministic equilibrium portfolio⁸. Let ε_t denote the nominal exchange rate.

The representative Home household faces the following budget constraint:

$$\begin{aligned}
& P_t C_t + Q_t S_{t+1} + \varepsilon_t Q_t^* S_{t+1}^* + \frac{B_{t+1}}{R_t} + \frac{\varepsilon_t B_{t+1}^*}{R_t^*} \\
& + \frac{\gamma_1}{2} \left[Q_t (S_{t+1} - S)^2 + \varepsilon_t Q_t^* (S_{t+1}^* - S^*)^2 \right] + \frac{\gamma_2}{2} \left[\frac{P_t}{R_t} \left(\frac{B_{t+1}}{P_t} - B \right)^2 + \frac{\varepsilon_t P_t^*}{R_t^*} \left(\frac{B_{t+1}^*}{P_t^*} - B^* \right)^2 \right] \\
& = W_t L_t + S_t (Q_t + D_t) + \varepsilon_t S_t^* (Q_t^* + D_t^*) + B_t + \varepsilon_t B_t^* + T_t^r \tag{1.5}
\end{aligned}$$

where γ 's are positive portfolio adjustment cost parameters. (S, S^*, B, B^*) denote the steady state portfolio⁹. Portfolio adjustment costs are rebated to households in the equilibrium such that:

$$T_t^r = \frac{\gamma_1}{2} \left[Q_t (S_{t+1} - S)^2 + \varepsilon_t Q_t^* (S_{t+1}^* - S^*)^2 \right] + \frac{\gamma_2}{2} \left[\frac{P_t}{R_t} \left(\frac{B_{t+1}}{P_t} - B \right)^2 + \frac{\varepsilon_t P_t^*}{R_t^*} \left(\frac{B_{t+1}^*}{P_t^*} - B^* \right)^2 \right]$$

These adjustment costs help pinning down the deterministic equilibrium portfolio, hence solve the indeterminacy problem¹⁰. Portfolio adjustment costs parameters

⁸Ghironi, Lee, and Rebucci (2007) assumes shares are traded and subject to transaction costs. Here we assume that agents pay the adjustment costs if their holdings are different from a pre-determined portfolio.

⁹In the steady state, price levels are normalized to be 1. So (B, B^*) are steady state (real) values of bond holdings.

¹⁰Heathcote and Perri (2007) implicitly consider a quadratic adjustment cost structure in their

γ 's can be different across assets and countries. We assume that adjustment cost parameters are identical across assets and countries ($\gamma_1 = \gamma_2$).

The household optimally chooses consumption, labor supply and an asset portfolio to maximize its utility (1.1) subject to the budget constraint (1.5).

First-order conditions

Let λ_t be the Lagrange multiplier associated with the consumer budget constraint. The standard first-order conditions with respect to consumption and labor supply are given by:

$$\lambda_t = C_t^{-\sigma} / P_t \quad (1.6)$$

$$\frac{W_t}{P_t} = \psi L_t^\chi C_t^\sigma \quad (1.7)$$

The first-order conditions with respect to holdings of Home and Foreign equities are:

$$[1 + \gamma_1 (S_{t+1} - S)] Q_t = E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} (Q_{t+1} + D_{t+1}) \right] \quad (1.8)$$

$$[1 + \gamma_1 (S_{t+1}^* - S^*)] Q_t^* = E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{\varepsilon_{t+1}}{\varepsilon_t} (Q_{t+1}^* + D_{t+1}^*) \right] \quad (1.9)$$

These Euler equations are different from the standard Lucas asset pricing due to the portfolio adjustment cost feature. If $\gamma_1 = 0$, these conditions above are the same as standard Euler equations for asset pricing. We are interested in the case where we

numerical method for the incomplete markets extension.

assume γ_1 is a very small positive number.

Similarly, the Euler equations for bond holdings are as follows:

$$\left[1 + \gamma_2 \left(\frac{B_{t+1}}{P_t} - B\right)\right] \frac{1}{R_t} = E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \right] \quad (1.10)$$

$$\left[1 + \gamma_2 \left(\frac{B_{t+1}^*}{P_t^*} - B^*\right)\right] \frac{1}{R_t^*} = E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{\varepsilon_{t+1}}{\varepsilon_t} \right] \quad (1.11)$$

Foreign household faces an analogous utility maximization problem.

1.2.2 Firms

There is a continuum $[0,1]$ of identical monopolistic firms in the Home country which hire labor and use capital to produce distinct tradable intermediate goods. An individual firm h 's production function is:

$$Y_t^H(h) = e^{z_t} K_{t-1}^\nu(h) L_t^{1-\nu}(h) \quad (1.12)$$

where capital $K_{t-1}(h)$ and labor $L_t(h)$ are used to produce firm h 's output $Y_t^H(h)$. The production is subject to an aggregate technology shock z_t , which is normally, identically and independently distributed with mean zero and a standard deviation σ_z .

Capital is produced one-period in advance and is subject to an investment adjustment cost. A firm h purchases new investment goods $I_t(h)$ and combines them with remaining capital to produce capital for next period production. Capital is

accumulated as follows:

$$K_t(h) = (1 - \delta)K_{t-1}(h) + I_t(h) - \frac{\psi_I}{2} \left(\frac{I_t(h)}{K_{t-1}(h)} - \delta \right)^2 K_{t-1}(h) \quad (1.13)$$

where $\delta > 0$ is the depreciation rate and $\psi_I \geq 0$ is the investment adjustment cost parameter.

Investment goods production

Let I_t denote the aggregate investment goods purchased by all intermediate firms in period t such that:

$$I_t = \int_0^1 I_t(h) dh$$

We model the production of investment goods similar to the consumption basket aggregation by the representative household. An investment goods distributor buys final (domestic and imported) goods from Final goods bundlers, then combines them into final investment goods according to a CES production technology:

$$I_t = \left[(\mu^I)^{1/\eta^I} (I_t^H)^{\frac{\eta^I-1}{\eta^I}} + (1 - \mu^I)^{1/\eta^I} (I_t^F)^{\frac{\eta^I-1}{\eta^I}} \right]^{\frac{\eta^I}{\eta^I-1}} \quad (1.14)$$

where I_t^H is the investment goods distributor's demand of final domestic goods and I_t^F is that of imported ones. The share of domestic goods μ^I and the elasticity of substitution η^I are not necessarily equal to those of the consumption basket. This

setting is to accommodate empirical facts in the US data¹¹. Setting $\mu^I = \mu$ and $\eta^I = \eta$ yields the standard aggregation specification.

The investment goods distributor sells investment goods to firms at a competitive price P_t^I . Similar to the representative household, he optimally chooses a combination of final domestic and imported goods such that $P_t^I I_t = P_t^H I_t^H + P_t^F I_t^F$. The Home investment price index P_t^I , which can be different from the consumption price index (CPI), is defined as:

$$P_t^I = \left[\mu^I (P_t^H)^{1-\eta^I} + (1 - \mu^I) (P_t^F)^{1-\eta^I} \right]^{\frac{1}{1-\eta^I}}. \quad (1.15)$$

The investment distributor optimally demands the following quantities of final domestic goods and imports:

$$I_t^H = \mu^I \left[\frac{P_t^H}{P_t^I} \right]^{-\eta^I} I_t \quad \text{and} \quad I_t^F = (1 - \mu^I) \left[\frac{P_t^F}{P_t^I} \right]^{-\eta^I} I_t \quad (1.16)$$

Final goods bundler

There exists a perfectly competitive Final goods bundler who combines intermediate goods into final goods in each country. Final goods are purchased by households and investment distributors in both countries. The final Home produced good is ag-

¹¹ Erceg, Guerrieri and Gust (2005) develop a SIGMA model which incorporates the fact that the share of import in total U.S investment (~30%) is higher than the share of import in consumption (~7%)

gregated from domestic intermediate goods using the Dixit-Stiglitz aggregator:

$$Y_t^H = \left[\int_0^1 (Y_t^H(h))^{\frac{\omega-1}{\omega}} dh \right]^{\frac{\omega}{\omega-1}}$$

where $\omega > 0$ is the elasticity of substitution between intermediate goods. The bundler seeks to maximize profit

$$P_t^H Y_t^H - \int_0^1 P_t^H(h) Y_t^H(h) dh.$$

Because of perfect competition, Final goods bundler's profit is always zero in equilibrium. The maximization optimal condition yields the demand equation for individual firm's output:

$$Y_t^H(h) = \left(\frac{P_t^H(h)}{P_t^H} \right)^{-\omega} Y_t^H \quad (1.17)$$

where $P_t^H(h)$ is the price of the intermediate good h (set by firm h) at time t . The aggregate price index for final Home goods, P_t^H , is defined as:

$$P_t^H = \left[\int_0^1 (P_t^H(h))^{1-\omega} dh \right]^{\frac{1}{1-\omega}}$$

Similarly, we define a Foreign final goods bundler, who competitively combines

foreign intermediate goods into foreign final goods. Domestic agents import foreign final goods for consumption and investment.

Producer Currency Pricing with quadratic adjustment costs

Each period, every firm is able to change its price subject to a quadratic price adjustment cost as in Rotemberg (1982). For the benchmark case, we assume that nominal output prices are sticky in terms of producers' currency (PCP). It means that Home firms price their output in terms of their domestic currency. If a firm h decides to change its current period price $P_t^H(h)$ from the last period price of $P_{t-1}^H(h)$, it will incur a cost of $\frac{\psi_P}{2} \left(\frac{P_t^H(h)}{P_{t-1}^H(h)} - 1 \right)^2 P_t^H Y_t^H$, where Y_t^H is the final Home produced goods output and P_t^H is the price index defined above. Firms take nominal wage W_t and investment price index P_t^I as given. An individual firm h optimally chooses labor demand, capital, investment, and its output price to maximize its discounted profit:

$$\max_{L, I, K, P^H} E_t \sum_{i=0}^{\infty} \Gamma_{t+i} D_{t+i}(h)$$

where Γ_t is a common discount factor, and $D_t(h)$ is firm h 's profit in period t . Firms pay all profits as dividends to shareholders. Firm h 's profit is defined as

$$D_t(h) = P_t^H(h) Y_t^H(h) - W_t L_t(h) - P_t^I I_t(h) - \frac{\psi_P}{2} \left(\frac{P_t^H(h)}{P_{t-1}^H(h)} - 1 \right)^2 P_t^H Y_t^H \quad (1.18)$$

Firms can be owned by both domestic and foreign households. If Home household holds a home bias equity portfolio in equilibrium then it will represent a "median

shareholder". Hence, we assume that Home firms discount their profits by a common discount factor Γ_t , using the nominal Lagrange multiplier from the household maximization problem, defined as follows:

$$\Gamma_{t+i} = \beta^{t+i} \frac{\lambda_{t+i}}{\lambda_t}$$

Firm h 's profit maximization can be written as:

$$\max_{L,I,K,P^H} E_t \sum_{i=0}^{\infty} \beta^{t+i} \frac{\lambda_{t+i}}{\lambda_t} \left[\begin{array}{l} P_{t+i}^H(h) Y_{t+i}^H(h) - W_{t+i} L_{t+i}(h) - P_{t+i}^I I_{t+i}(h) \\ - \frac{\psi_P}{2} \left(\frac{P_{t+i}^H(h)}{P_{t+i-1}^H(h)} - 1 \right)^2 P_{t+i}^H Y_{t+i}^H \end{array} \right] \quad (1.19)$$

subject to its production technology (1.12), capital accumulation process (1.13) and output $Y_t^H(h)$ is determined by demand using (1.17).

Let λ_t^Y and λ_t^k be the Lagrange multipliers associated with the production technology and capital accumulation function respectively. The first-order conditions with respect to labor demand, investment and capital are:

$$W_t = \lambda_t^Y (1 - \nu) \frac{Y_t^H(h)}{L_t(h)} \quad (1.20)$$

$$P_t^I = \lambda_t^k \left[1 - \psi_I \left(\frac{I_t(h)}{K_{t-1}(h)} - \delta \right) \right] \quad (1.21)$$

$$\lambda_t^k = E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\lambda_{t+1}^Y \frac{\nu Y_{t+1}^H(h)}{K_t(h)} + \lambda_{t+1}^k \left[1 - \delta + \frac{\psi_I}{2} \left(\left(\frac{I_{t+1}(h)}{K_t(h)} \right)^2 - \delta^2 \right) \right] \right) \right] \quad (1.22)$$

Since there is no firm-specific idiosyncratic shock in the model, by symmetry, firms will make the same optimal decision rules regarding their choice variables so that we can drop the index (h) in the first-order conditions above. Moreover, the Rotemberg (1982) sticky price setting preserves the ex-ante identical assumption of firms. It means that Home firms also set the same output price, i.e. $P_t^H(h) = P_t^H(h') = P_t^H \forall h, h' \in [0, 1]$. The optimal price setting rule for the Home firms' output is:

$$P_t^H = \frac{\omega}{\omega-1} \lambda_t^Y - \frac{\psi_P}{\omega-1} \left(\frac{P_t^H}{P_{t-1}^H} - 1 \right) \frac{(P_t^H)^2}{P_{t-1}^H} + \frac{\psi_P}{\omega-1} E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{P_{t+1}^H}{P_t^H} - 1 \right) \frac{Y_{t+1}^H}{Y_t^H} \frac{(P_{t+1}^H)^2}{P_t^H} \right] \quad (1.23)$$

Foreign firms face an analogous maximization problem. Let $P_t^{F*}(f)$ be the price of Foreign firm f 's output denominated in Foreign currency. In the PCP case, Law of One Price holds so that the price of Foreign firm f 's output selling at Home in terms of Home currency $P_t^F(f)$ is defined as $P_t^F(f) = \varepsilon_t P_t^{F*}(f) \forall f \in [0, 1]$.

1.2.3 Monetary policy

Monetary policy in Home country follows a simple Taylor rule.

$$i_t = (1 - \alpha_i) i + \alpha_i i_{t-1} + \alpha_\pi (\pi_t - \bar{\pi}) + \zeta_t^i \quad (1.24)$$

where i_t is the (natural log) Home (gross) interest rate, i is the steady state interest rate, π_t is the (natural log) gross inflation rate, and $\bar{\pi}$ is the steady state inflation. As is standard in the literature, we assume that the steady state inflation, $\bar{\pi}$, equals

zero. The monetary shock ζ_t^i is normally, independently and identically distributed with zero-mean and a standard deviation σ_i . Foreign country monetary policy follows an analogous rule.

$$i_t^* = (1 - \alpha_i)i^* + \alpha_i i_{t-1}^* + \alpha_\pi(\pi_t^* - \overline{\pi^*}) + \zeta_t^{*i} \quad (1.25)$$

We assume that there is no correlation between monetary policy innovations.

1.2.4 Aggregation and Equilibrium

An equilibrium is a set of quantities $\{C_t, C_t^H, C_t^F, L_t, S_t, S_t^*, B_t, B_t^*, K_t, I_t, I_t^H, I_t^F, Y_t^H, D_t\}$ and prices $\{P_t^H, P_t^F, P_t, P_t^I, R_t, Q_t, W_t, \varepsilon_t\}$ for Home country and their Foreign counterparts such that, given monetary policy rules (2.24-2.25) and exogenous shock processes:

- Home representative household solves the utility maximization problem (1.1) subject to the budget constraint (1.5)
- Home firms solve their profit maximization problem (1.19) subject to the production technology (1.12), the capital accumulation process (1.13), and the demand equation (1.17),
- Foreign households and firms solve their analogous maximization problems

- Asset markets clear:

$$S_t + \hat{S}_t = 1$$

$$\hat{S}_t^* + S_t^* = 1$$

and

$$B_t + \hat{B}_t = 0$$

$$B_t^* + \hat{B}_t^* = 0$$

- Goods markets clear:

$$Y_t^H = C_t^H + C_t^{*H} + I_t^H + I_t^{*H} + \frac{\psi_P}{2} \left(\frac{P_t^H}{P_{t-1}^H} - 1 \right)^2 Y_t^H$$

$$Y_t^{F*} = C_t^F + C_t^{*F} + I_t^F + I_t^{*F} + \frac{\psi_P}{2} \left(\frac{P_t^{F*}}{P_{t-1}^{F*}} - 1 \right)^2 Y_t^{F*}$$

The last term in the goods market clearing condition represents the aggregate cost of adjusting prices in each period in units of final output of each country.

1.3 Numerical iteration method and applications

Following Heathcote and Perri (2008), we develop an iteration method to determine the steady-state equilibrium Home portfolio $\{S, S^*, B, B^*\}$. Equilibrium

Foreign portfolio is derived from Home portfolio by asset markets clearing conditions.

1.3.1 Iteration algorithm

Due to symmetry and market clearing conditions, the deterministic equilibrium portfolio can be well defined by a vector $(S, B)'$, which includes Home holdings of domestic share and bond. Using symmetry and market clearing conditions, we can show that, in the steady state, Home holding of Foreign bond B^* is equal to $-B$, and Home holding of Foreign share S^* equals $1 - S$. We use the following iteration algorithm to numerically determine the non-stochastic equilibrium portfolio $(S, B)'$. The iteration process utilizes the stochastic second-order simulation tool in Dynare.

- *Step 1:* Pick a guess for initial portfolio $(\bar{S}_0, \bar{B}_0)' \in (0, 1) \times R$. Use this initial portfolio and steady state values of non-portfolio variables (see Appendix 1.A) as the initial steady state vector.
- *Step 2:* Compute decision rules that characterize the solution to the second-order approximation of the economy around the steady state. This step follows the standard second-order approximation literature developed by Schmitt-Grohé and Uribe (2004) and others.
- *Step 3:* Simulate the model over a large number of periods and calculate the average value of decision rule for $(S_{t+1}, B_{t+1})'$. Compute the distance $\|(S_{j+1}, B_{j+1})' - (\bar{S}_j, \bar{B}_j)'\|$ where $(\bar{S}_j, \bar{B}_j)'$ is the initial portfolio of the j^{th} iteration. If $\|(S_{j+1}, B_{j+1})' - (\bar{S}_j, \bar{B}_j)'\| < \epsilon$ ($j = 0, 1, 2, \dots$) for a very small $\epsilon > 0$, then $(\bar{S}_j, \bar{B}_j)'$ is a good approximation of the long run equilibrium portfolio. Otherwise, we set the new starting portfolio $(\bar{S}_{j+1}, \bar{B}_{j+1})'$ equal $(S_{j+1}, B_{j+1})'$

and repeat from step 2 until the iteration process converges. We take the converged average portfolio to be the deterministic equilibrium portfolio of our model.

For initial values, we use Lucas (1982) complete risk sharing portfolio $(S, B)' = (0.5, 0)'$ as the initial guess for the iteration process. The iteration can start from any reasonable initial values and numerically converge to a very small neighborhood of approximated equilibrium portfolios (the magnitude of difference is in the order of 10^{-3} or less).

Let $Wealth_t$ denote the total financial wealth of Home household in period t then $Wealth_t$ is defined as:

$$Wealth_t = Q_t S_{t+1} + \varepsilon_t Q_t^* S_{t+1}^* + \frac{B_{t+1}}{R_t} + \frac{\varepsilon_t B_{t+1}^*}{R_t^*}$$

Let Λ_t^S denote the share of wealth invested in Home equity, calculated as

$$\Lambda_t^S = \frac{Q_t S_t}{Wealth_t}$$

Similarly, we define $\Lambda_t^{S^*}$, Λ_t^B , and $\Lambda_t^{B^*}$ as the shares of wealth Home household invests in Foreign equity, Home bond and Foreign bond respectively. The iteration algorithm calculates and reports (converged) equilibrium values of these shares.

1.3.2 Applications with complete asset markets

We are going to apply this method to two different types of existing models with complete asset markets. We use their calibrations, apply the iteration method, and compare results.

Application to an RBC model

Heathcote and Perri (2008) develop an RBC model, in which, the only financial assets are shares of intermediate firms. Given specific assumptions, they show that the equity portfolio is enough to complete the financial market if technology shocks are the only shocks in their benchmark model. Our benchmark NOEM setting can replicate the flexible price case by setting the price adjustment parameter equal to 0 and the monopoly markup close to 0. To match with Heathcote and Perri (2008) model, we drop bonds out of the benchmark setting, thus Euler equations for bonds and monetary policy rules are removed. Bonds are also removed from household budget constraints.

We follow Heathcote and Perri (2008) calibration for parameters and technology innovation processes. More detailed descriptions of parameters are provided in their paper. Calibrated parameters are summarized in table 1-1. The portfolio adjustment cost parameter γ_i is set equal to 0.0000015.

β	μ	$\eta(\eta^I)$	σ	χ	ψ	ν	δ	ρ_z	σ_z
0.99	0.85	1	1	1	9.7	0.34	0.025	0.91	0.006

Table 1-1: Calibration of RBC model with complete markets

Under assumptions of log utility and unitary elasticity of substitution, Heathcote and Perri (2008) are able to analytically derive equilibrium portfolios for the benchmark model specifications. They prove the existence of equilibrium portfolio by guess and verify¹². Table 1-2 shows results of the iteration method under "Iterated" columns for several values of μ . We use Heathcote and Perri (2008) analytical solutions to calculate equilibrium portfolios and report them in the "Derived" columns. Our iteration method's results are very close to their analytical equilibrium portfolios¹³.

	Iterated	Derived	Iterated	Derived	Iterated	Derived	Iterated	Derived
	$\mu = 0.5$		$\mu = 0.65$		$\mu = 0.75$		$\mu = 0.85$	
Λ^{S*}	0.5	0.5	0.3907	0.3898	0.3022	0.3012	0.1977	0.1968
Λ^S	0.5	0.5	0.6093	0.6102	0.6978	0.6988	0.8023	0.8032

Table 1-2: Iteration results for Heathcote and Perri (2008) model

Application to a NOEM model

Collard et al. (2007) provide another numerical method to solve a similar NOEM model with sticky nominal price and complete asset markets. We show that our method can generate results significantly close to theirs. A summary of the benchmark calibration used is listed in table 1-3. We also set penalty parameters γ_s equal to 0.0000015.

¹²See Heathcote and Perri (2007) for details

¹³We also perform the iteration process for different specifications to replicate Heathcote and Perri (2007) sensitivity analysis. Our results are significantly similar to theirs. Those results are omitted here but are available by requests.

β	σ	χ	ψ	$\mu(\mu^I)$	$\eta(\eta^I)$	ν	δ	ψ_I	ψ_P	ω
0.99	1.0	1	5	0.85	1.2	0.28	0.025	4.5	40	6

Table 1-3: Calibration of NOEM model with complete markets

We use the Backus, Kehoe, and Kydland (1995) specification for productivity processes.

$$\begin{bmatrix} z_t \\ z_t^* \end{bmatrix} = \begin{bmatrix} 0.906 & 0.088 \\ 0.088 & 0.906 \end{bmatrix} \begin{bmatrix} z_{t-1} \\ z_{t-1}^* \end{bmatrix} + \begin{bmatrix} \zeta_t^z \\ \zeta_t^{z^*} \end{bmatrix}$$

where $var(\zeta_t^z) = var(\zeta_t^{z^*}) = (0.00852)^2$ and $corr(\zeta_t^z, \zeta_t^{z^*}) = 0.258$.

Monetary policies follow the simple Taylor rules:

$$\begin{aligned} i_t &= (1 - 0.8)i + 0.8i_{t-1} + 2(1 - 0.8)(\pi_t - \bar{\pi}) + \zeta_t^i \\ i_t^* &= (1 - 0.8)i^* + 0.8i_{t-1}^* + 2(1 - 0.8)(\pi_t^* - \bar{\pi}^*) + \zeta_t^{i^*} \end{aligned}$$

Monetary policies are independent of each other with the standard deviation of interest rate shocks $\sigma_i(\sigma_i^*) = 0.001$.

Collard et al. (2007) method is a variation of Kollmann (2006). They iterate the consumer budget constraint and make use of the Euler conditions for asset holdings to derive a system of equations that link shares of wealth invested in each asset with the return differentials and other non-portfolio variables. Projection of this system on shocks allows us to determine asset shares. To a first-order approximation, this method delivers constant equity shares. However, it only works with complete asset markets models. We report the simulated average shares of wealth invested in each assets from the iteration process for the benchmark specification. We also

run the iteration process for different values of the share of imports, the elasticity of substitution, the degree of relative risk aversion, and the degree of price stickiness. We report results for different shares of import and degrees of risk aversion in table 1-4 (a,b). Our results are in the column labeled "Iterated", and theirs are labeled "Collard". The two methods produce similar results.

Table 4a: Equilibrium portfolios and the share of imports								
	Iterated	Collard	Iterated	Collard	Iterated	Collard	Iterated	Collard
	$\mu= 0.5$		$\mu= 0.65$		$\mu= 0.75$		$\mu= 0.85$	
Λ^{B*}	-0.0214	-0.0213	-0.0188	-0.0187	-0.0173	-0.0172	-0.0146	-0.0145
Λ^B	0.0214	0.0213	0.0188	0.0187	0.0173	0.0172	0.0146	0.0145
Λ^{S*}	0.1906	0.1902	0.1695	0.1686	0.1553	0.1535	0.1298	0.1269
Λ^S	0.8094	0.8098	0.8305	0.8314	0.8447	0.8465	0.8702	0.8731

Table 4b: Equilibrium portfolios and the degree of risk aversion								
	Iterated	Collard	Iterated	Collard	Iterated	Collard	Iterated	Collard
	$\sigma= 1.0$		$\sigma= 1.5$		$\sigma= 2.0$		$\sigma= 5.0$	
Λ^{B*}	-0.0146	-0.0145	-0.0384	-0.0382	-0.0559	-0.0557	-0.1084	-0.1083
Λ^B	0.0146	0.0145	0.0384	0.0382	0.0558	0.0557	0.1804	0.1083
Λ^{S*}	0.1298	0.1269	0.3359	0.3313	0.4879	0.4850	0.9521	0.9495
Λ^S	0.8702	0.8731	0.6641	0.6687	0.5121	0.5150	0.0479	0.0505

Table 1-4: Selected sensitivity analysis results for the equilibrium portfolios

1.4 NOEM model with incomplete asset markets

We have shown that the iteration method can be easily applied to different existing models with complete asset markets. It is able to generate results similar to methods that were specifically developed for each model. However, the main motivation of developing this method is to show that we can also apply it to models with incomplete asset markets without need of further complicated modifications.

We extend the benchmark model to study asset portfolios in the incomplete markets environment. We add in another type of shock without introducing new financial asset to effectively make the asset markets incomplete. A natural candidate is the fiscal policy shock. We apply the iteration method and study equilibrium portfolio choices in the incomplete markets case.

1.4.1 Government spending

Many papers have studied the effects of shocks to government spending on other macroeconomic variables under different economic specifications. In the fully flexible price model (for example, Baxter and King, 1993), an increase in government expenditures induces a decrease in private consumption along with an increase in labor supply, raises output and employment while lowering wage. On the other hand, Linnemann and Schabert (2003) study the effects of government spending in a New Neoclassical Synthesis model. They find that, when prices are sticky, a positive shock to government expenditure exerts two effects: an expansionary effect on output supply via increasing in labor supply and an increase in aggregate demand. While both effects tend to raise output, their effects on prices are ambiguous. In a model with capital accumulation, investment expenditure declines in response to an expansionary

fiscal policy, as higher interest rates force the shadow price of capital down. Alesina, Arganda, Perotti, and Schiantarelli (2002) empirically study fiscal policy effects in a panel of OECD countries. They find that increases in public spending increase labor costs and reduce profits. As a result, investment declines substantially in those countries. Government spending represents about twenty percent of GDP in the US and is volatile. Stochastic changes in government spending can have strong effects on other macro variables of the economy, hence, affect the equilibrium asset portfolios.

For simplicity, we assume that government purchases only final domestic goods. This assumption can be easily relaxed to allow government consume a basket of both domestic and imported final goods like in household consumption. Following the literature, we assume that bonds are in zero net supply. Government collects a lump-sum tax T_t and runs a balanced budget each period so that $P_t^H G_t = T_t$ for all t . Combining the government and household budget constraints, the consolidated household budget constraint is written as:

$$\begin{aligned}
& P_t^H G_t + P_t C_t + Q_t S_t + \varepsilon_t Q_t^* S_t^* + \frac{B_{t+1}}{R_t} + \frac{\varepsilon_t B_{t+1}^*}{R_t^*} \\
& + \frac{\gamma_1}{2} \left[Q_t (S_{t+1} - S)^2 + \varepsilon_t Q_t^* (S_{t+1}^* - S^*)^2 \right] + \frac{\gamma_2}{2} \left[\frac{P_t}{R_t} \left(\frac{B_{t+1}}{P_t} - B \right)^2 + \frac{\varepsilon_t P_t^*}{R_t^*} \left(\frac{B_{t+1}^*}{P_t^*} - B^* \right)^2 \right] \\
& = W_t L_t + S_t (Q_t + D_t) + \varepsilon_t S_t^* (Q_t^* + D_t^*) + B_t + \varepsilon_t B_t^* + T_t^r
\end{aligned} \tag{1.26}$$

In Home country, the aggregate goods market clearing condition is defined as:

$$Y_t^H = C_t^H + C_t^{*H} + I_t^H + I_t^{*H} + G_t + \frac{\psi_P}{2} \left(\frac{P_t^H}{P_{t-1}^H} - 1 \right)^2 Y_t^H \tag{1.27}$$

Government spending follows an AR(1) stochastic process with persistence ρ_g and standard deviation σ_g . Foreign government spending follows a similar process. We also assume two fiscal shocks are uncorrelated.

1.4.2 Calibration with incomplete asset markets

For the benchmark calibration, we use Canzoneri, Cumby and Diba (2007) (henceforth, CCD) specification for parameter values. The discount factor β is 0.99, which indicates an annualized interest rate of 4% in equilibrium. We also consider a log preference in consumption. We set the Frisch labor supply elasticity $1/\chi$ equal 0.33. This value is conservative and at a high end of empirical estimates between 0.05 and 0.35. Capital share in production ν is 0.25. The "home bias" preference value in consumption and investment ($\mu = \mu^I$) is set equal to 0.85. For the elasticity of substitution in final goods aggregation, we assume $\eta = \eta^I = 1.2$. Heathcote and Perri (2002) estimate the elasticity of substitution between domestic and imported goods for the US data is 0.9, while Backus, Kehoe, and Kydland (1995) find it equal 1.5. The benchmark value is in between those two estimates. For investment, the adjustment cost parameter ψ_I is 4.5, which is lower than some empirical estimates but is not numerically important to our equilibrium results. Capital depreciation rate is conventionally set at 0.025.

We use results of Keen and Wang (2007) and set the price adjustment cost parameters to be comparable with Calvo (1983) sticky price setting. The main idea is to set parameters in the Rotemberg specification so that average frequency of price adjustment matches with the Calvo setting. The benchmark values for price rigidity parameters are $\psi_P = 60$ and $\omega = 6$, which indicates the average duration of price

adjustment is about 4 quarters (i.e., it is equivalent to set the Calvo price setting parameter equal to 0.75). The elasticity of substitution between alternative intermediate goods $\omega = 6$ means the monopoly markup is 20%. The portfolio adjustment penalty parameters (γ_i) are set at 0.0000025. This guarantees that the iteration process will run properly without (numerically) encountering nonstationarity problem. A summary of benchmark parameters value is listed in table 1-5.

β	σ	χ	ψ	$\mu(\mu^I)$	$\eta(\eta^I)$	ν	δ	ψ_I	ψ_P	ω
0.99	1.0	3	1	0.85	1.2	0.25	0.025	4.5	60	6

Table 1-5: Calibration of NOEM model with incomplete markets

The persistence and volatility of productivity shocks will be important for our numerical results. For the benchmark specification, we adopt a productivity process used in CCD, which has persistence and volatility $(\rho_z, \sigma_z) = (0.923, 0.0086)$. There is no correlation between the two countries' shocks.

For monetary policy, we consider a simple Taylor rule that reacts to the past interest rate and current inflation. We use CCD estimate of the US data over the Volcker and Greenspan years (1979.3 - 2003.2).

$$i_t = 0.222 + 0.824i_{t-1} + 0.356\pi_t + \zeta_t^i \quad (1.28)$$

The interest rate shock, ζ_t^i , has a standard error σ_i equal to 0.00245. Foreign monetary authority follows a similar rule. We assume that monetary policies are independent.

Government spending G_t follows an AR(1) process:

$$\ln(G_t) = \bar{g} + 0.973 \ln(G_{t-1}) + \zeta_t^g \quad (1.29)$$

The Home fiscal policy shock, ζ_t^g , is normally, independently and identically distributed with a standard error σ_g equal to 0.01. The constant \bar{g} will be calibrated such that $G/Y = 0.20$ in the steady state. Foreign government spending follows an analogous process. Fiscal policy shocks are not correlated across countries.

1.4.3 Results

For the benchmark specification, result shows that the steady state equilibrium portfolio exhibits strong home bias in equity. Households put around 91.5% of their financial wealth in domestic equity and merely 8.5% in foreign equity in equilibrium. Domestic agents also borrow abroad (short foreign bond) and invest at home (long position in domestic bond). Gross value of domestic bond holding is about 3% of total financial wealth. We then perform sensitivity analysis to study how the equilibrium portfolio is affected by key parameters of the model, in particular, the share of imports, the share of labor in production, the degree of risk aversion, and the elasticity of substitution. We also consider the importance of shocks' persistence and volatility. In addition, we study how different degrees of price stickiness, which is the special feature of the NOEM model, affect the steady state equity portfolio.

Diversification and the share of import

We first look at the importance of trade openness to the equilibrium portfolio since it is the focus of many papers in the literature. In the benchmark specification with incomplete markets, government spending is assumed to consist of only final domestic goods and account for 20% of domestic output in equilibrium. The equilibrium total share of imports, therefore, is smaller than the equilibrium share of imports in consumption and investment aggregation, $1-\mu$. The benchmark value $\mu(=\mu^I) = 0.85$ implies the equilibrium import share of 12%, which is around the empirical estimate for US data. Numerical results of equilibrium portfolios are plotted in Figure 1-1. We find that home bias in consumption or investment, at most, partially explains the biased preference in equity. As seen from results, the equilibrium portfolio is strongly biased toward domestic equity for all values of import share considered, even in the case $\mu < 0.5$, i.e., there is a counterfactual "foreign bias" preference in consumption and investment. However, the larger the import share is, the smaller is the home bias. It is consistent with findings of other papers in the literature and is robust to either complete or incomplete asset markets.

Diversification and the labor share

We consider different shares of labor in production by adjusting the Cobb-Douglas parameter ν , ranging from 0.25 up to 0.40 so that the labor share is between 52% and 70%. In a model with *one* traded goods and flexible prices, Baxter and Jerermann (1997) find that domestic agents hold foreign equity to hedge against domestic labor income risks, thus, a larger share of labor leads to less domestic equity in the equilibrium portfolio. Heathcote and Perri (2008) find the opposite in a model with

flexible price and *two* traded goods. They find that larger share of labor means larger home bias in equity. We also find similar results in a NOEM model with complete markets. In contrast, when asset markets are incomplete, results show that the larger the share of labor is, the *smaller* is home bias in equity (see Figure 1-2).

Diversification and the elasticity of substitution

The benchmark value for the elasticity of import substitution is in between two empirical estimates for US data by Heathcote and Perri (2002) and Backus, Kehoe and Kydland (1995). We also take other values of the elasticity into consideration. Figure 1-3 plots equilibrium shares of domestic equity against the elasticity. It shows that the elasticity of substitution has a negative effect on home bias in equity. The more easily goods are substituted, the smaller home bias in equity is. For a very high elasticity ($\eta > 3.5$), we find that domestic household actually shorts domestic equity (i.e., "foreign bias" in equity). On the other hand, Heathcote and Perri (2008) find that, under flexible prices, higher elasticity of substitution (for values of the elasticity $\eta \leq 4$) leads to stronger home bias in equity.

Diversification and the relative risk aversion

Another parameter considered here is the degree of relative risk aversion. Increasing degree of risk aversion affects consumers through a lower inter-temporal elasticity of substitution. We find that the more risk averse households are, the less domestic equity they hold in the equilibrium portfolio (Figure 1-4). The sensitivity of equity portfolios on the relative risk aversion greatly diminishes for degrees of risk aversion larger than 3. Moreover, we perform a similar analysis in the benchmark

NOEM model with complete markets. We also find that degree of risk aversion has a negative effect on home bias in equity. This finding is similar to Engel and Matsumoto (2006) with sticky prices, but is opposite to Heathcote and Perri (2008) result with flexible prices. Thus, the sensitivity of home bias in equity on the degree of risk aversion is robust to asset markets structures, but changes dramatically when prices are sticky.

Diversification and nominal rigidity

One key feature of the NOEM model is the presence of nominal price stickiness. We study how different specifications of price stickiness affect equilibrium portfolios. We consider different price adjustment parameters (ψ_P) so that the average duration of price adjustment ranges between 2 to 5 quarters. We also consider other combinations of the monopoly mark-up ratio and price adjustment parameter such that the average duration of price adjustment remains at about 4 quarters. Figure 1-5 plots the equilibrium equity portfolios against the nominal rigidity parameters. We find that when the average duration of price adjustment increases (in other words, prices are stickier), home bias in equity actually decreases in the incomplete asset markets case. On the contrary, under complete asset markets, price stickiness is positively correlated with home bias in equity, which is consistent with Engel and Matsumoto (2006) finding. Moreover, when intermediate firms have less market power (i.e., smaller monopoly markup), households also tend to hold less domestic equity for a given duration of price adjustment.

Importance of shocks' persistence and volatility

Finally, we consider how persistence and variances of shocks affect equilibrium portfolios. Figure 1-6 plots how shares of domestic equity in equilibrium portfolios correlate with the persistence and volatility of productivity shocks. For the persistence of productivity shocks, we use values between 0.843 and 0.95. It shows that if productivity shocks are more persistent, domestic agents hold less domestic equity. Moreover, more volatile productivity also reduces home bias in equity portfolio. Values on the x -axis are the ratios of standard deviations to the benchmark value.

Regarding to monetary shocks, we find that increasing the volatility of monetary policy shocks reduces home bias in equity in equilibrium. This is in stark contrast with Engel and Matsumoto (2006). In their model, money shocks have no effect on equilibrium equity portfolios. On the other hand, the volatility of fiscal policy shocks is positively correlated with home bias in equity (Figure 1-7).

In summary, home bias in equity is robust to all specifications of structural parameters taken in consideration here, except for cases with very high elasticity of substitution between domestic and imported goods. Domestic agents increase holdings of foreign equity in order to hedge against more volatile productivity and monetary shocks, which reduces home bias in equity portfolios. On the other hand, government spending volatility induces stronger home bias. The general equilibrium effect depends on the relative strengths of shocks. In all cases considered in this paper, the share of domestic bond always negatively co-moves with the share of domestic equity, suggesting that there is a trade-off between types of financial assets. Domestic agents often hold a long position in domestic bonds and short foreign bonds, except

the case of inelasticity of substitution between domestic and imported goods¹⁴. In this paper, we pay more attention to explain the puzzle in equity portfolio but this framework can be used to study bond portfolio as well.

Sensitivity analysis shows that the assumption of asset market completeness is critical in determining the sensitivity of equity position to structural parameters. It also shows that sticky prices have important impacts on equilibrium equity portfolios. Moreover, the analysis also makes suggestions how each type of shocks may affect equilibrium equity positions. Importantly, we find that numerical results can be sensitive to combinations of parameter values.

1.5 Conclusions and future work

This paper studies international asset portfolio choices in a dynamic NOEM model with nominal price rigidity and incomplete asset markets. It provides another dimension to explain the home bias puzzle in the existing international finance literature. For the benchmark calibration, our model generates a strong degree of home bias in equity in the steady state. We also find that domestic agents invest a small share of wealth in domestic bond and borrow from abroad. Setting aside the case of very high elasticity of import substitution, numerical results consistently show that domestic agents invest more than 50% of their wealth in domestic equity. With the presence of nominal rigidity, monetary policy shocks can have impacts on the equilibrium asset portfolios. Quantitatively, increasing the volatility of monetary policy shocks reduces the share of domestic equity while fiscal policy volatility generate a stronger home bias degree in the equilibrium equity portfolio. Existence of nominal

¹⁴Coeurdacier, Kollmann and Martin (2007) also find domestic households short domestic bonds if the substitution elasticity is less than one.

rigidity is also critical to the sensitivity of equilibrium equity portfolio on several key parameters. Results show that there is a possible trade-off between equity and bond by households, although shares of domestic bond in wealth is much smaller than domestic equity. Numerical analysis shows that implications of structural parameters on equilibrium portfolios critically depend on whether asset markets are complete or incomplete.

Although the paper cannot fully provide analytical explanations of the general equilibrium effects on endogenous international asset portfolio choices, it provides a flexible quantitative framework for incomplete markets models, which can be used for future work. Results from this paper suggest some interesting extensions. One possible extension is to implement different pricing rules, such as local currency pricing and/or price indexation¹⁵. This paper focuses on explaining the equity puzzles and assumes bonds are in zero net supply for simplicity. However, a future work which includes non-zero bond will provide more realistic asset portfolios. Furthermore, we would like to extend this framework to study the dynamics of international portfolios in the NOEM model.

¹⁵Local Currency Pricing rules are presented in Appendix 1.B.

APPENDIX

1.A Steady State Equations

Steady state values are symmetric by assumption. The following set of equations solves the steady state values for non-portfolio variables of Home, which do not depend on the steady state value of asset portfolio, given by $\{S, S^*, B, B^*\}$. Foreign variables have the same values as their Home counterparts.

$$P = P^H = P^F = 1 \tag{1.30}$$

$$\varepsilon = 1 \tag{1.31}$$

$$Y = C^H + C^{H*} + I^H + I^{H*} + (G) \tag{1.32}$$

$$Y = K^v L^{1-v} \tag{1.33}$$

$$C^H = \mu C \tag{1.34}$$

$$C^F = (1 - \mu)C \tag{1.35}$$

$$I^H = \mu^I I \tag{1.36}$$

$$I^F = (1 - \mu^I)I \tag{1.37}$$

$$\lambda = C^{-\sigma} \tag{1.38}$$

$$\lambda^Y = \frac{\omega - 1}{\omega} \quad (1.39)$$

$$\lambda^K = 1 \quad (1.40)$$

$$\frac{K}{L} = \left[\frac{1/\beta - (1 - \delta)}{v \frac{\omega - 1}{\omega}} \right]^{\frac{1}{v-1}} = \left(\frac{Y}{L} \right)^{1/v} \quad (1.41)$$

$$I = \delta K \quad (1.42)$$

$$W = \lambda^Y (1 - v) \frac{Y}{L} \quad (1.43)$$

$$C = Y - I - (G) \quad (1.44)$$

$$\frac{D}{L} = v \frac{Y}{L} - \frac{I}{L} \quad (1.45)$$

$$L = \left[\frac{W}{\psi \theta (\frac{C}{L})} \right]^{\frac{1}{\theta + \alpha}} \quad (1.46)$$

$$Q = \frac{\beta}{1 - \beta} D \quad (1.47)$$

$$G/Y = 0.2 \quad (1.48)$$

1.B Local Currency Pricing or Price to Market

Gopinath and Rigobon (2007) empirically find that prices are sticky in the currency which they are priced. Evidence show that there is local currency pricing

for US imports and producer currency pricing for US exports. Engel and Matsumoto (2005) present their case with local currency pricing (LCP). Bergin (2004) models a hybrid case in which, he allows a fraction of firms use LCP strategy and the rest prices output in domestic currency. He empirically estimates that about 99% of firms actually use LCP strategy. We modify our model to consider the Local currency pricing strategy. Under Local currency pricing, firms in each country have to make two decisions regarding their output prices. Each firm has to set two different prices: one for domestic market and another one for export market. Price of exports is denominated in Foreign currency. The Law of One Price is no longer hold except in the steady state. We describe the optimal rules for prices as follows.

Optimal price setting rules

Let $P_t^H(h)$ denote price of goods produced by Home firm h sell in Home country denominated in domestic currency and $P_t^{H*}(h)$ be price of its exports denominated in foreign currency. Each firm h has two demands, domestic $Y_t^H(h)$ and exports $Y_t^{H*}(h)$. We assume a similar aggregation technology like in the case with producer currency pricing, except that there are two different types of final aggregated goods, one for domestic demand and the other for exports. Demands for firm h output in each market can be similarly defined as in (1.17) with relative prices $\frac{P_t^H(h)}{P_t^H}$ and $\frac{P_t^{H*}(h)}{P_t^{H*}}$ in Home and Foreign market respectively. Firm h 's output $Y_t(h)$ equals its total demands.

$$Y_t(h) = Y_t^H(h) + Y_t^{H*}(h) \tag{1.49}$$

Home firm h is facing an analogous quadratic adjustment cost for each price $P_t^H(h)$ and $P_t^{H*}(h)$. For simplicity, we assume that both prices have the same degree

of stickiness. Home firm h dividend is now calculated as:

$$D_t(h) = P_t^H(h)Y_t^H(h) + \varepsilon_t P_t^{H*}(h)Y_t^{H*}(h) - W_t L_t(h) - P_t^I I_t(h) - \frac{\psi_P}{2} \left(\frac{P_t^H(h)}{P_{t-1}^H(h)} - 1 \right)^2 P_t^H Y_t^H - \frac{\psi_P}{2} \left(\frac{P_{t+i}^{H*}(h)}{P_{t+i-1}^{H*}(h)} - 1 \right)^2 \varepsilon_t P_t^{H*} Y_t^{H*} \quad (1.50)$$

Firm's total output is now defined as in (1.49) and dividend is calculated in (1.50). The firm's maximization problem is similar to the case of Producer currency pricing except with different price setting equations. The optimal LCP price setting rules are defined as:

$$P_t^H = \frac{\omega}{\omega-1} \lambda_t^Y - \frac{\psi_P}{\omega-1} \left(\frac{P_t^H}{P_{t-1}^H} - 1 \right) \frac{(P_t^H)^2}{P_{t-1}^H} + \frac{\psi_P}{\omega-1} E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{P_{t+1}^H}{P_t^H} - 1 \right) \frac{Y_{t+1}^H}{Y_t^H} \frac{(P_{t+1}^H)^2}{P_t^H} \right] \quad (1.51)$$

$$P_t^{H*} = \frac{\omega}{\omega-1} \frac{\lambda_t^Y}{\varepsilon_t} - \frac{\psi_P}{\omega-1} \left(\frac{P_t^{H*}}{P_{t-1}^{H*}} - 1 \right) \frac{(P_t^{H*})^2}{P_{t-1}^{H*}} + \frac{\psi_P}{\omega-1} E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{P_{t+1}^{H*}}{P_t^{H*}} - 1 \right) \frac{Y_{t+1}^{H*}}{Y_t^{H*}} \frac{\varepsilon_{t+1}}{\varepsilon_t} \frac{(P_{t+1}^{H*})^2}{P_t^{H*}} \right] \quad (1.52)$$

Foreign firms face an analogous maximization problem in both cases. Prices of Foreign produced goods are denoted with $(^F)$ for goods selling in Home and with $(^{F*})$ for goods selling in Foreign country. The optimal price setting rules are similar to what described above for Home firms.

Goods markets clearing conditions for the local currency pricing case for Home

country are

$$Y_t^H = C_t^H + I_t^H + \frac{\psi_P}{2} \left(\frac{P_t^H}{P_{t-1}^H} - 1 \right)^2 Y_t^H + G_t \quad (1.53)$$

$$Y_t^F = C_t^F + I_t^F + \frac{\psi_P}{2} \left(\frac{P_t^F}{P_{t-1}^F} - 1 \right)^2 Y_t^F \quad (1.54)$$

$$Y_t = Y_t^H + Y_t^{H*} \quad (1.55)$$

where Y_t^H and Y_t^{H*} are aggregate domestic and export demands for Home output, and Y_t^F is aggregate import demand by Home agents. There are similar conditions for Foreign country.

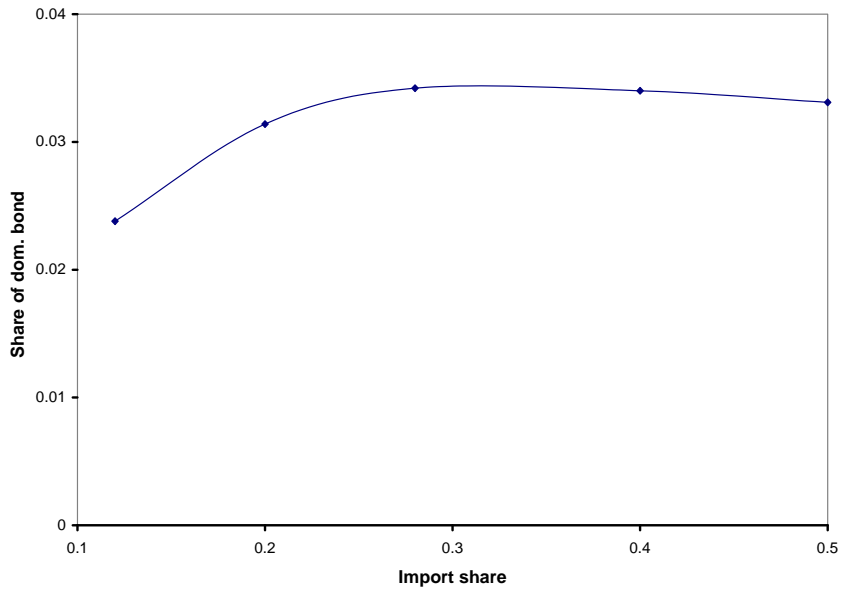
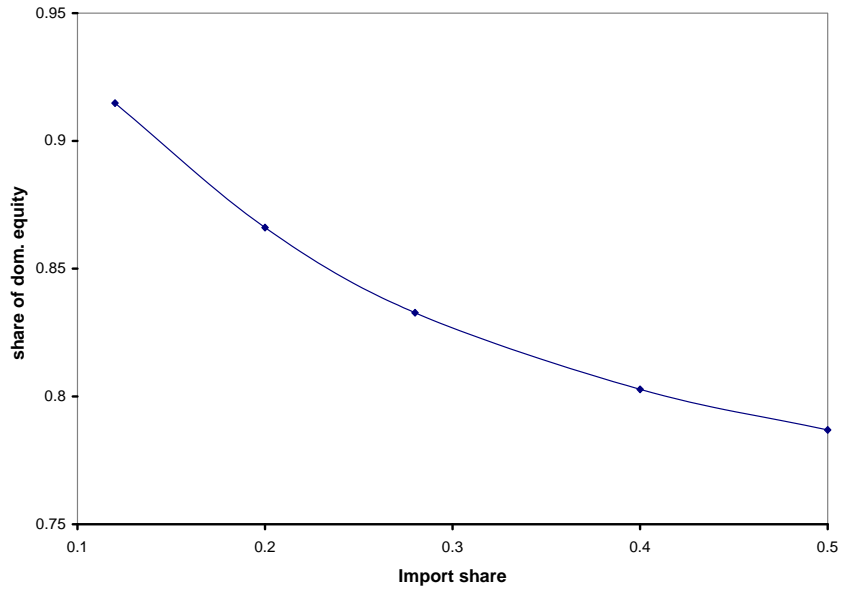


Figure 1-1: Equilibrium portfolios vs. the share of imports (trade openness)

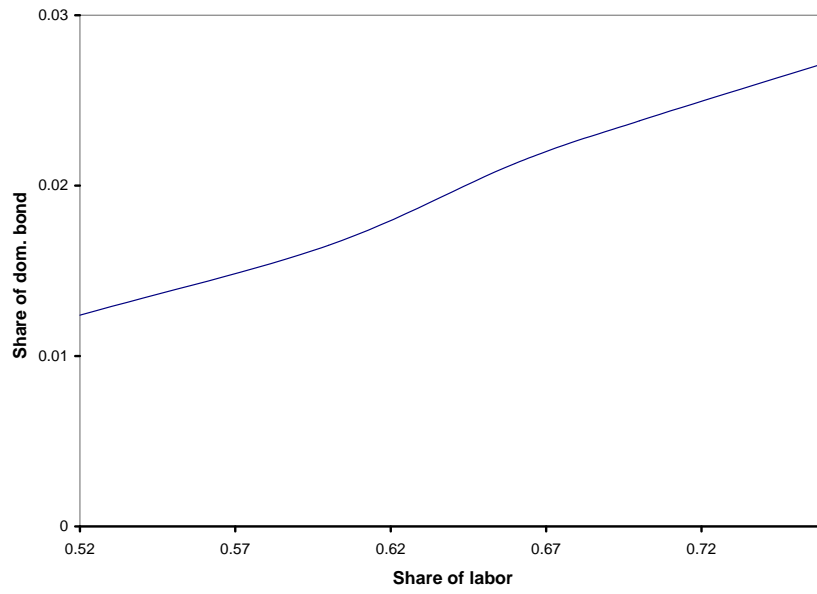
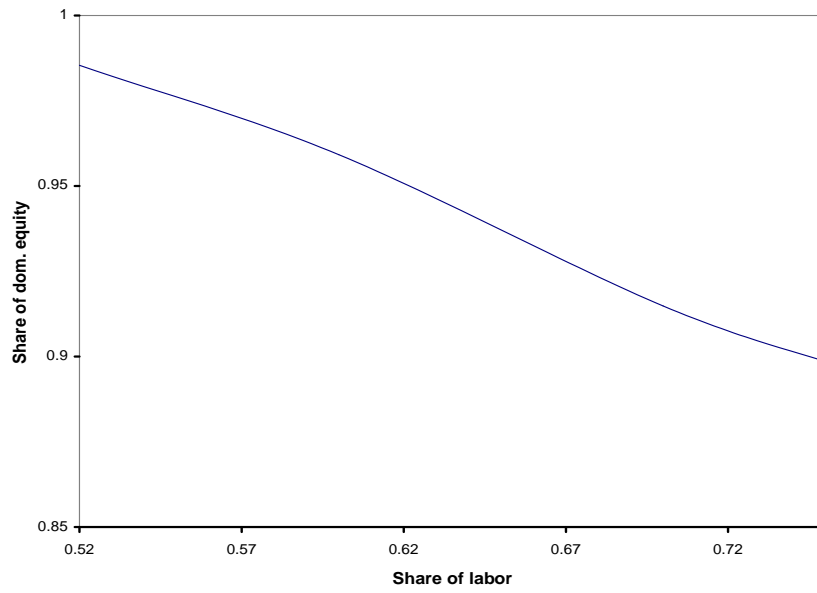


Figure 1-2: Equilibrium portfolios vs. the share of labor

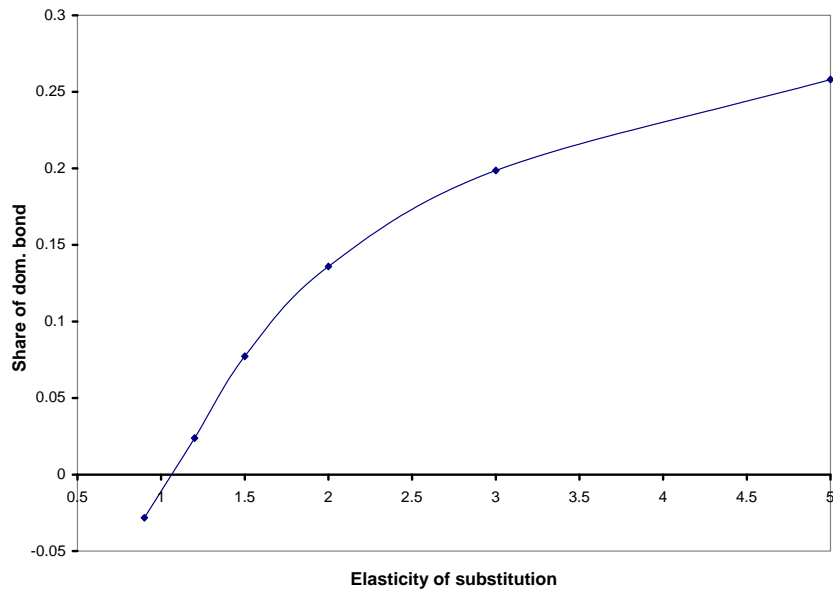
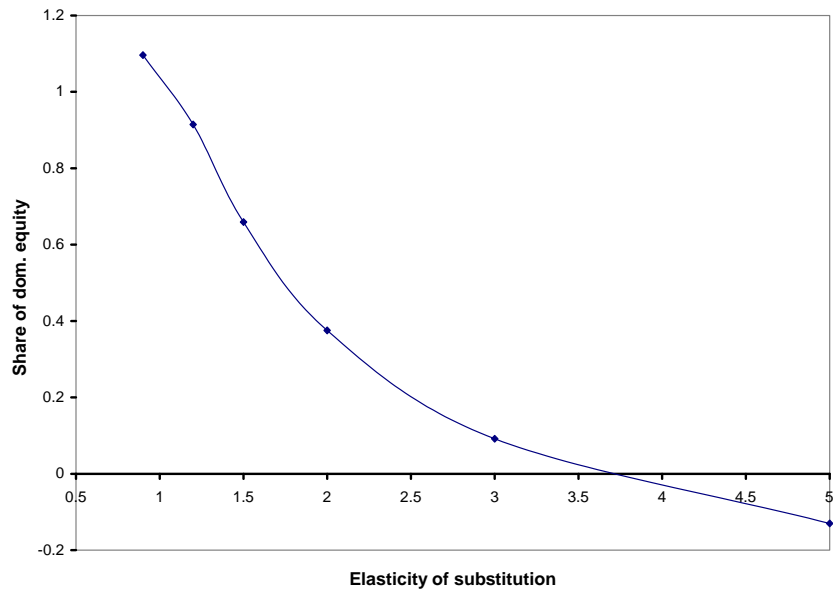


Figure 1-3: Equilibrium portfolios vs. the elasticity of substitution

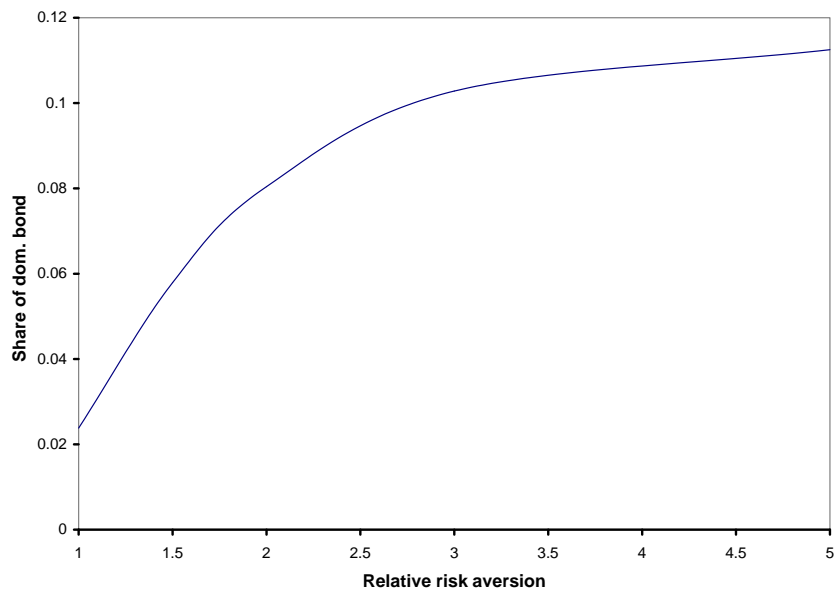
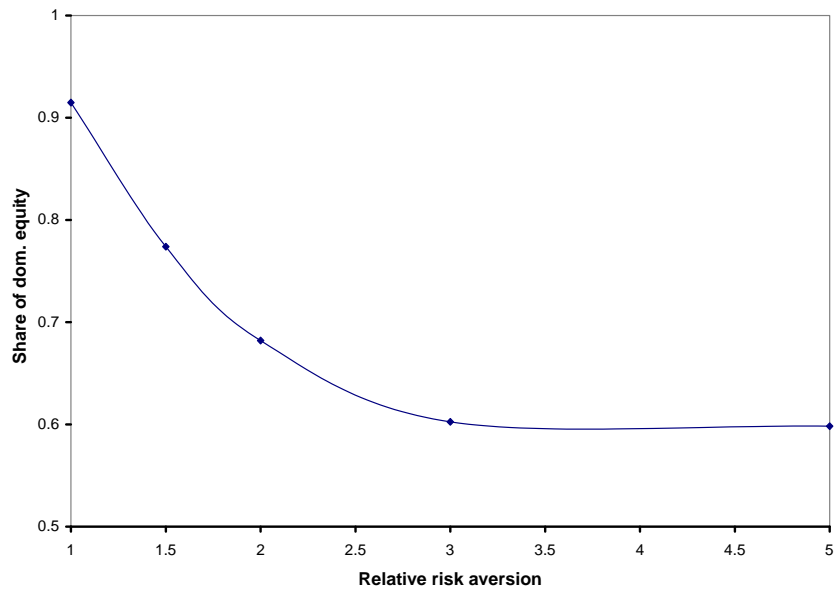


Figure 1-4: Equilibrium portfolios vs. the degree of relative risk aversion

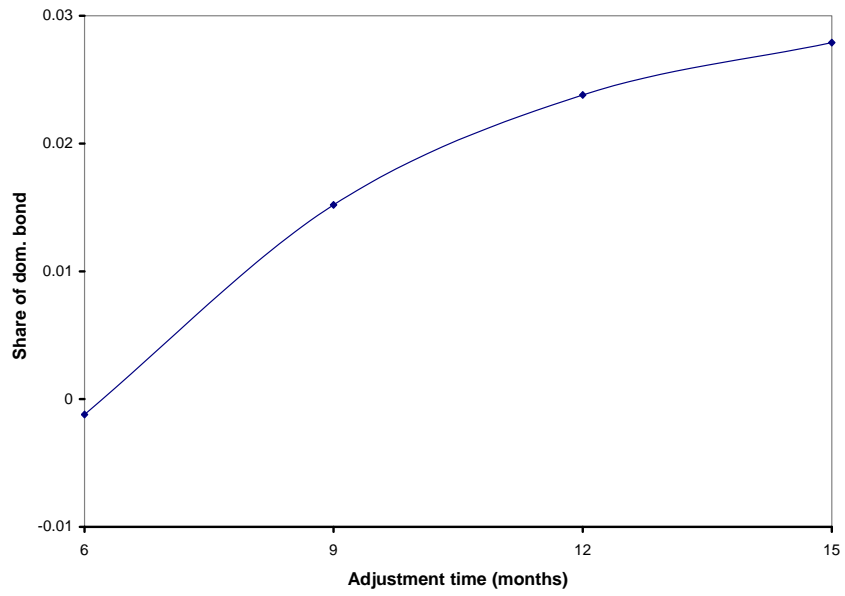
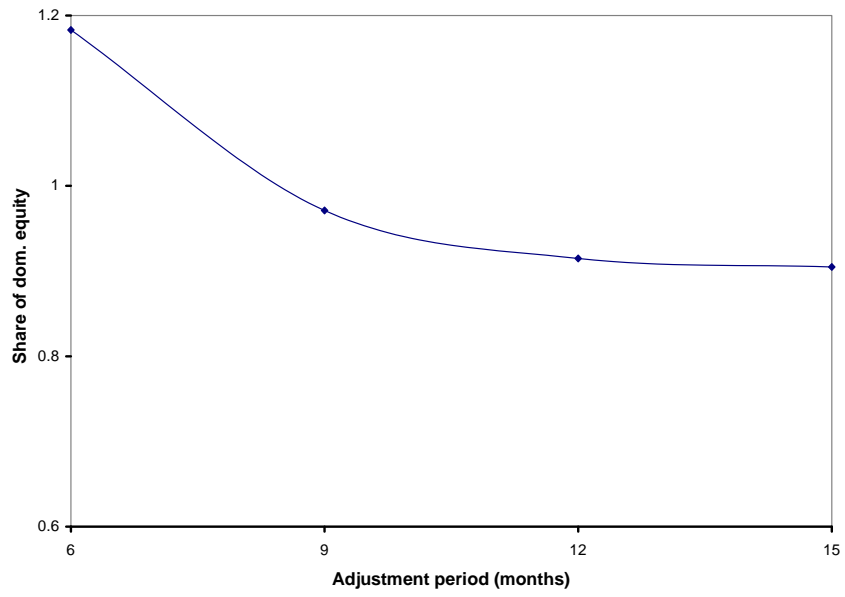


Figure 1-5: Equilibrium portfolios vs. the degree of price stickiness

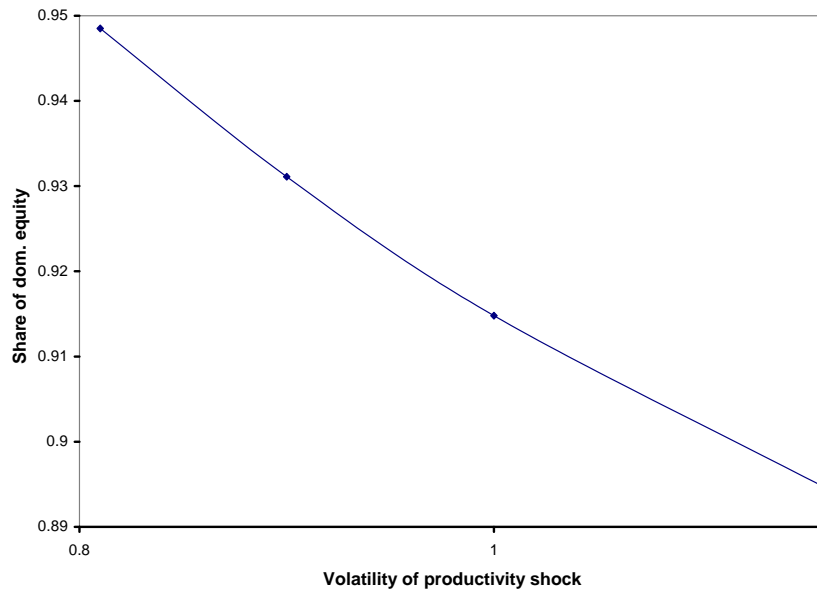
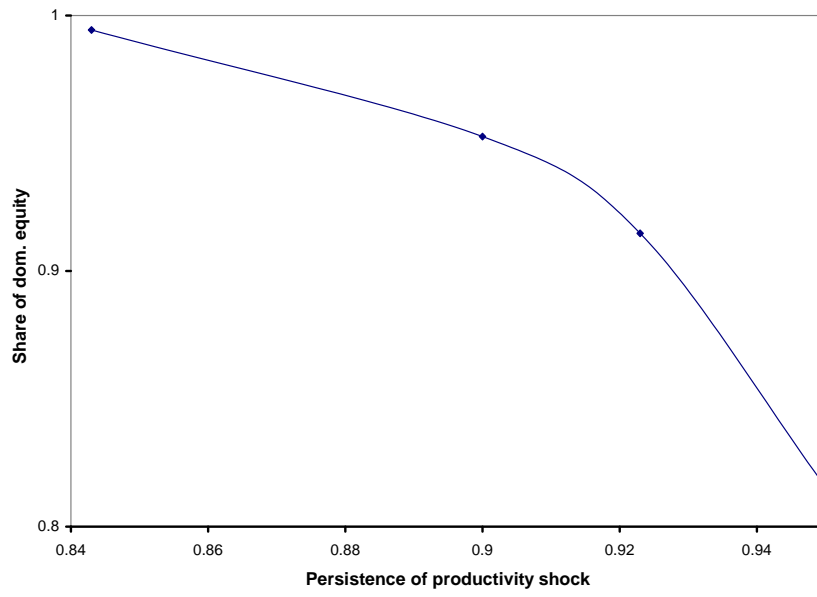


Figure 1-6: Equilibrium equity portfolios vs. persistence and volatility of productivity shocks

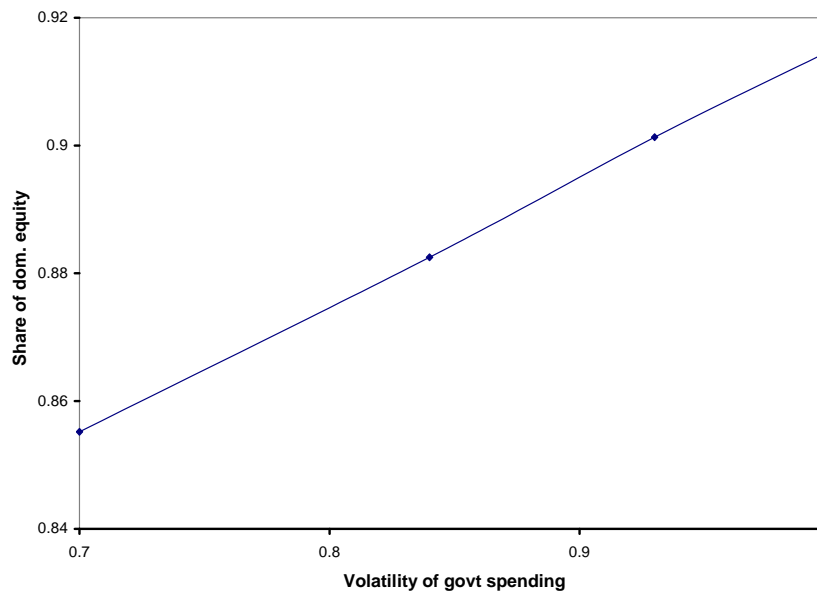
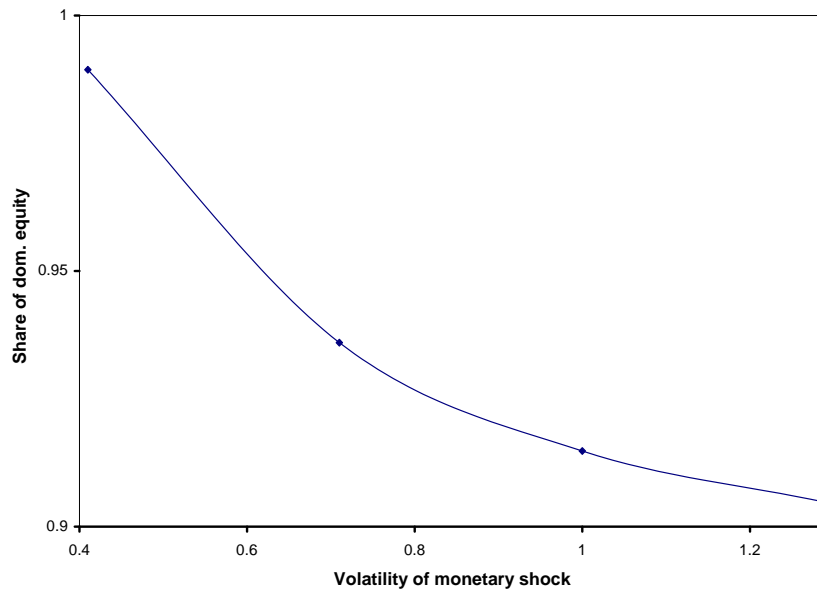


Figure 1-7: Equilibrium equity portfolios vs. volatility of monetary policy and fiscal policy shocks

Chapter 2

International Portfolio Dynamics in the New Open Economy Macroeconomics model

2.1 Introduction

The liberalization of international financial markets has expanded opportunities for investors to diversify their portfolios across borders. Lane and Milesi-Ferretti (2003, 2007) empirically study international capital flow data and find that gross holdings have reached unprecedented levels and that capital flows across borders have also increased dramatically. With gross external asset and liability positions as large as or larger than GDP in most advanced economies, changes in the exchange rate or asset prices in response to macroeconomic shocks can generate large changes in the external wealth positions (Gourinchas and Rey, 2005). These changes, in turn, may affect the international business cycles and the international transmission of shocks.

Figure 2-1 shows the flows of US external assets and liabilities and net foreign asset positions (normalized by nominal GDP) between 1960:Q1 to 2007:Q4¹. There is an obvious trend of increasing fluctuations of those positions since the late 1970s. These empirical facts raise a number of important questions for open economy macroeconomic analyses. Which macroeconomic factors drive these movements? How do optimal portfolios respond to each type of shock? There is a big gap in the literature that can identify those macroeconomic factors and study their effects on the optimal asset holdings and trades. This paper is aimed to fill in that gap.

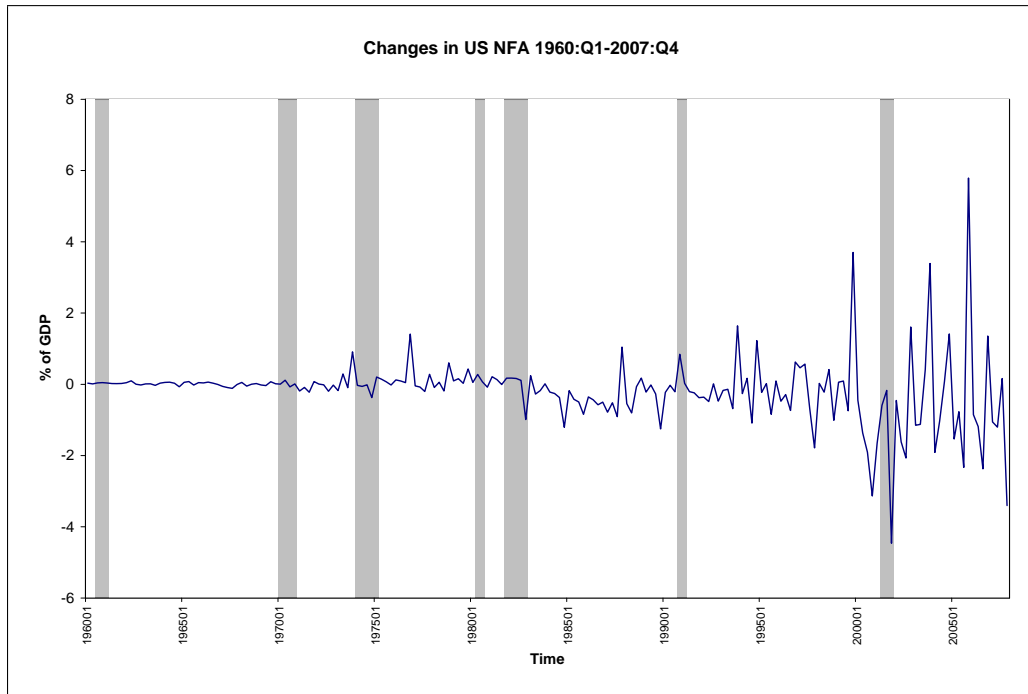


Figure 2-1: Changes in US NFA position - 1960:Q1 - 2007:Q4

Almost all papers in the related international finance literature focus only on

¹Data source: The Flow of Funds Accounts at the end of June, 2007 (author's calculation)

explaining the steady state optimal portfolio choices². The purpose of this paper, on the other hand, is to study the time-varying *dynamics* of international asset portfolios in response to theoretical economic shocks in a complex dynamic stochastic general equilibrium (DSGE) environment. Based on my knowledge, this is the first paper to examine the dynamics of asset holdings and external balances in the DSGE model, which features capital accumulation, two different types of technology shocks, nominal price rigidity and monetary policy innovations, and more importantly with incomplete asset markets. Employing recently developed numerical approximation methods, I calculate the implied impulse responses of international portfolio allocation to different types of shocks. One of the most important findings is that monetary policy shocks have strong impacts on the dynamics of portfolio holdings and asset trades, such that they should be considered in conjunction with other types of innovations in any open economy macroeconomics model which incorporates endogenous portfolio choices.

Earlier literature often abstracts from endogenous portfolio choices because of a critical technical difficulty. In a deterministic case, all financial assets pay the same rate of return. Since there is no risk attached, these assets are perfect substitutes. Households are indifferent between types of assets in the deterministic steady state; thus, optimal portfolios are not uniquely determined. In a stochastic environment, financial assets are differentiated by different degrees of risk attached to each asset. Optimal portfolio choices are often determined by functions of correlations and vari-

²With the notable exception of Coeurdacier, Kollmann, and Martin (2008) discussed below, the literature has focused on steady state equity portfolios. This relates to the "home bias in equity" puzzle named by Obstfeld and Rogoff (2000), according to which investors have a strong preference toward domestic equity in most of the industrialized economies. This puzzle has attracted a large number of papers in the last few decades.

ances of stochastic factors in the economic model. Up to a first-order linear approximation of a DSGE model, all assets have the same expected rate of return; certainty equivalence applies so that financial assets remain perfect substitutes. Hence, a higher order approximation is required. The standard approach to solve DSGE models is to take a linear approximation around a non-stochastic steady state. Because portfolio choices are not uniquely determined in a non-stochastic steady state, there is no natural starting point to approximate around³. This indeterminacy problem is more acute when the asset markets are incomplete. This technical difficulty has prevented earlier work to incorporate endogenous portfolio choices in the analyses of the open economy macroeconomic issues in DSGE models with incomplete asset markets.

This paper makes use of recently developed numerical approximation methods to calculate the dynamics of international portfolios in a model with incomplete asset markets. The method used in this paper is described in Devereux and Sutherland (2007, 2008). While their solution procedure is novel, the general principles rely on results of earlier work in the literature, which state that in order to derive the solution for portfolio holdings up to N -th order accuracy; one has to approximate the portfolio choices' Euler equations up to $(N+2)$ -th order. Therefore, in order to derive the time-varying dynamics of portfolio holdings, a third-order approximation of the Euler equations is needed. Devereux and Sutherland (2007) show that the dynamics of portfolio holdings can be derived from the solution of a second-order linear approximation of the model's non-portfolio variables. This solution can be derived using several available algorithms. In this paper, I use the Schmitt-Grohé

³The implied optimal portfolios can be derived in a limited number of special cases; in particular, models with the complete asset markets such as Coeurdacier, Kollmann, and Martin (2008), Engel and Matsumoto (2006), Kollmann (2006)

and Uribe (2004) algorithm and the accompanying Matlab package. The Devereux and Sutherland (2007, 2008) method is very flexible and easily applicable to solve different types of DSGE models including the complicated model used in this paper⁴.

Most of the work in the earlier literature exclusively focuses on explaining the home bias in equity puzzle, therefore, those models often abstract from bonds. There are few papers that have considered stocks and bonds together; but the bond portfolio is often specially constructed to fully absorb a certain source of risk in those models. For instance, Engel and Matsumoto (2006) consider a forward exchange position that completely hedges against a money supply shock. Coeurdacier, Kollmann, and Martin (2008) assume bonds' payoffs are denominated in produced goods so that they fully absorb terms of trade risk in their model. This paper assumes two nominal bonds whose payoffs are in each country's currency. This assumption makes the bond structure in this model more realistic and generates considerable diversification across types of assets in response to economic shocks.

A related work to the one considered here is Coeurdacier et al. (2008), in which, they study the dynamics of international portfolio diversification under complete asset markets. In their model, they assume capital accumulation, two types of technology shocks: investment-specific and total factor productivity, flexible prices and trades in bonds and equities. Bonds are denominated in units of produced goods and completely hedge against the terms of trade risk. Coeurdacier et al. (2008) investigate the covariances and variances of portfolio holdings and trades and their correlations

⁴Tille and Van Wincoop (2007) develop a similar method which also relies on higher order approximation to numerically obtain portfolio choices via an iterative algorithm. Evans and Hnatkovska (2005) propose a numerical method that relies on a combination of perturbation, projection and continuous-time approximation techniques. Their method is also capable of analyzing time variation in portfolio choices but it is very complex and represents a significant departure from standard DSGE solution methods

with macro variables.

In this paper, I extend Coeurdacier et al. (2008) framework in a number of directions to take advantages of the New Open Economy Macroeconomics model features. First, I assume two nominal non-contingent bonds are denominated in their respective currencies. This bond portfolio is more realistic and empirically relevant. Bonds and equities are traded internationally without intermediation costs. Second, I introduce nominal rigidity following the Rotemberg (1982) setting. Monetary policy is assumed to follow a Taylor-type rule subject to a random shock. Engel and Matsumoto (2006) find that under nominal rigidity, monetary policy shocks can impact the steady state equity portfolio. It is thus important to understand how monetary policy shocks affect the dynamics of the optimal portfolio holdings. Finally, this additional source of risk makes the asset markets incomplete. In order to analyze the effects of shocks on the portfolio dynamics, I investigate both the impulse response functions and the second moments of portfolio holdings and macro variables.

For the benchmark specification, the model can account for the observed home bias in equity in the US data. Around this benchmark steady state, I calculate and investigate the impulse responses of macroeconomic variables and asset holdings to domestic positive technology shocks and expansionary monetary policy innovations. The calculated impulse responses of the net foreign asset position are consistent with theoretical intuition. Improved domestic productivity or a domestic expansionary monetary policy increases domestic output relative to foreign output. A combination of responses of (relative) consumption, investment and the real exchange rate leads to a decrease in net exports. In order to pay for its imports, the domestic country has to borrow abroad; therefore, its net foreign asset position worsens.

A detailed analysis of the impulse responses of asset holdings to those shocks shows that foreign investors acquire more domestic assets (bonds plus equities) than their domestic counterparts do with foreign assets. Results also suggest that there is a certain degree of diversification across types of assets in addition to the usual cross-border diversification. These movements of asset holdings can also be further divided into sub-components in order to study the “valuation effects” due to changes in asset prices and the (real) exchange rate. The valuation effects of equities are much larger than those of bonds; however, they are often offset by relatively large movements in net equity purchases so that the total changes are smaller and dependent on a particular type of shock and asset. The model is able to generate a substantial degree of volatility in the asset holdings and asset trades. The model’s predicted moments of external balances and capital flows are also in line with the empirical literature.

Most importantly, in the sticky prices environment, monetary policy shocks can affect the real rates of return of financial assets. In the model, monetary policy shocks have sizeable effects on the dynamics of the net foreign asset positions and trading flows of both bonds and equities. Although monetary policy shocks generate smaller valuation effects (and volume effects), their total effects on the net foreign asset position are almost as large as the effects of two technology shocks. The magnitudes of these net effects of monetary policy are sizeable given that the calibrated standard deviation of monetary policy shocks is smaller than those of technology shocks⁵. This finding clearly suggests that monetary policy should always be considered in any open economy macroeconomics model that may concern the optimal international portfolio

⁵The standard deviation of monetary policy shocks is calibrated to match with the volatility of quarterly averages of the effective Federal funds rate. Its magnitude is 1.5 and 3.5 times smaller than the standard deviations of the embodied and neutral technology shocks respectively.

allocations and their dynamic consequences on macroeconomic performance. While empirical responses to technology shocks are comparable with the model's predictions, the empirical response of the NFA position to an interest rate shock is counterfactual. This result is of interest for future research.

The paper is structured as follows. Section 2 provides the description of the symmetric two-country NOEM model with capital accumulation, price rigidity, shocks and structure of asset markets. A brief summary of approximation methods used in the paper is presented in section 3. The benchmark specification and the corresponding steady state equilibrium portfolio are described in the next section. Section 5 discusses the dynamics of portfolio holdings generated by this benchmark model's parameterization. Section 6 concludes the paper.

2.2 A New Open Economy Macroeconomics model

I develop a symmetric two country New Open Economy Macroeconomics model, which can be considered as an extended version of a combination of the Devereux and Sutherland (2007) and Coeurdacier et al. (2008). There is a "Home" and a "Foreign" country, with each country specializing in producing a range of differentiated tradable goods. Each country is populated by a representative household who consumes, works, and trades a portfolio of financial assets to maximize its utility over an infinite horizon. Production of goods requires both labor and capital inputs and is subject to a neutral (i.e., total factor productivity or TFP) technology shock. Capital accumulation process is subject to an investment efficiency (embodied) technology shock. Firms can reset output prices subject to a quadratic adjustment cost following the Rotemberg (1982) setting. I assume that firms set prices in their domestic

currency, i.e. using a Producer Currency Pricing (PCP) strategy. Monetary policy is introduced in terms of a simple Taylor rule.

The international asset portfolio includes two types of securities: stocks and bonds. The menu of assets includes two equities issued by domestic and foreign firms and two nominal bonds denominated in their respective currencies; all assets are traded internationally without intermediation costs. The total amount of equities is normalized to unity while bonds are assumed to be in zero net supply⁶. This assumption makes the model more tractable but it also makes the bond structure much simpler than in the reality. Since nominal bonds cannot be used to completely hedge against any source of risk, this asset structure creates more dynamics in asset reallocation in response to economic shocks. In this model, there are more shocks than the number of financial assets so that the international asset markets are incomplete.

2.2.1 Consumers

A home representative agent has the utility function of the form:

$$U = E_0 \sum_{t=0}^{\infty} \beta_t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\psi}}{1+\psi} \right) \quad (2.1)$$

⁶Devereux and Sutherland (2007, 2008) assume all financial assets are in zero net supply. In section 3, I show that their solution method is still applicable in this case with a minor modification of the consumer's budget constraint

where $\sigma > 0$, $\psi > 0$. C_t is a final consumption basket consisting of domestic and imported goods, defined as

$$C_t = \left[(\mu)^{1/\eta} (C_{H,t})^{\frac{\eta-1}{\eta}} + (1-\mu)^{1/\eta} (C_{F,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (2.2)$$

in which, C_H and C_F are consumption of home and foreign produced final goods. The parameter η in (2.2) is the elasticity of substitution between domestic and imported goods. The parameter $\mu \in (0, 1)$ measures the share of local spending in consumption. If $\mu > 0.5$, the agent is said to have a "home bias" preference in consumption.

The endogenous discount factor β_t evolves according to:

$$\beta_{t+1} = \beta_t \Upsilon(C_t), \beta_0 = 1 \quad (2.3)$$

where C_t is aggregate home consumption and $0 < \Upsilon(C_t) < 1$, $\Upsilon'(C_t) < 0$. If $\Upsilon(C_t)$ is a constant (i.e. $\Upsilon'(C_t) = 0$) then the discount factor is exogenous. It is well known that, in this case, the incompleteness of financial markets implies a non-stationary wealth distribution in the first-order approximation to the model. Although the solution method does not require doing so, it may be useful to eliminate the unit root (by setting $\Upsilon'(C_t) < 0$) to solve other problems than portfolio allocations. In this paper, I assume the following functional form of $\Upsilon(C_t)$:

$$\Upsilon(C_t) = \tilde{\beta} C_t^{-\nu} \quad (2.4)$$

where $0 \leq v < \sigma$ and $0 < \tilde{\beta}C_t^{-v} < 1$. Following Schmitt-Grohé and Uribe (2003), I assume that the impact of consumption on the discount factor is not internalized, and C_t is the aggregate consumption.

The domestic aggregate consumer price index, P_t , is defined as:

$$P_t = [\mu(P_{H,t})^{1-\eta} + (1-\mu)(P_{F,t})^{1-\eta}]^{\frac{1}{1-\eta}} \quad (2.5)$$

where P_H and P_F are the nominal price indices of final home and foreign goods selling at "Home" denominated in terms of home currency.

Home households supply homogenous labor L_t to firms at the competitive wage W_t . Agents can trade two equities and two nominal bonds denominated in their respective currencies. Let $\alpha_{k,t-1}$ represent the real holdings of asset k , where $k = \{E, E^*, B, B^*\}$, brought into period t from the end of period $t-1$, and $r_{k,t}$ is the period t real return on this asset. Let Ω_t denote the value of net wealth of home agents in period t in units of home consumption such that $\Omega_t = \sum \alpha_{k,t-1}$. Real rates of return on all financial assets are also defined in units of home consumption. I use the domestic bond as the benchmark asset with the real rate return of $r_{B,t}$.

A representative home household maximizes its utility subject to a budget constraint, written in nominal terms, as follows:

$$\begin{aligned} P_t C_t + Q_t E_{t+1}^H + S_t Q_t^* E_{t+1}^F + \frac{B_{t+1}^H}{R_t} + \frac{S_t B_{t+1}^F}{R_t^*} \\ = W_t L_t + E_t^H (Q_t + D_t) + S_t E_t^F (Q_t^* + D_t^*) + B_t + S_t B_t^F \end{aligned}$$

where S_t is the nominal exchange rate.

Let define the home agent's real holdings of financial assets:

$$\begin{aligned}\alpha_{E,t} &= \frac{Q_t E_{t+1}^H}{P_t} & \alpha_{E^*,t} &= \frac{\varepsilon_t Q_t^*}{P_t^*} E_{t+1}^F \\ \alpha_{B,t} &= \frac{1}{R_t} \frac{B_{t+1}^H}{P_t} & \alpha_{B^*,t} &= \frac{1}{R_t^*} \frac{\varepsilon_t B_{t+1}^F}{P_t^*}\end{aligned}$$

and the real returns on these assets:

$$\begin{aligned}r_{E,t} &= \frac{(Q_t + D_t)/P_t}{Q_{t-1}/P_{t-1}} & r_{E^*,t} &= \frac{\varepsilon_t(Q_t^* + D_t^*)/P_t^*}{\varepsilon_{t-1}Q_{t-1}^*/P_{t-1}^*} \\ r_{B,t} &= R_{t-1} \frac{P_{t-1}}{P_t} & r_{B^*,t} &= R_{t-1}^* \frac{\varepsilon_t}{\varepsilon_{t-1}} \frac{P_{t-1}^*}{P_t^*}\end{aligned}$$

All real variables are defined in units of home consumption and $\varepsilon_t = \frac{S_t P_t^*}{P_t}$ is the real exchange rate.

It is simple to show that the budget constraint in real terms can be written as⁷:

$$C_t + \Omega_{t+1} = w_t L_t + r_{B,t} \Omega_t + \alpha'_{t-1} r_{x,t} \quad (2.6)$$

⁷See Appendix 2.A for more details on the definitions of returns and holdings, and the derivation of the budget constraints

where:

$$\begin{aligned}\alpha'_{t-1} &= [\alpha_{E,t-1} \ \alpha_{E^*,t-1} \ \alpha_{B^*,t-1}] \\ r'_{x,t} &= [(r_{E,t} - r_{B,t}) \ (r_{E^*,t} - r_{B,t}) \ (r_{B^*,t} - r_{B,t})]\end{aligned}$$

Households' optimal consumption levels of home and foreign goods are:

$$C_{H,t} = \mu \left[\frac{P_{H,t}}{P_t} \right]^{-\eta} C_t \quad C_{F,t} = (1 - \mu) \left[\frac{P_{F,t}}{P_t} \right]^{-\eta} C_t \quad (2.7)$$

First-order conditions for consumption and labor supply are:

$$\lambda_t = C_t^{-\sigma} \quad (2.8)$$

$$\lambda_t w_t = L_t^\psi \quad (2.9)$$

Euler equations with respect to wealth and portfolio choices imply the following conditions:

$$C_t^{\nu-\sigma} = \tilde{\beta} E C_{t+1}^{-\sigma} r_{B,t+1} \quad (2.10)$$

$$E_t [\Lambda_{t+1} (r_{k,t+1} - r_{B,t+1})] = 0 \quad k = \{E, E^*, B^*\} \quad (2.11)$$

where the consumption based discount factor Λ_{t+1} is defined as $\Lambda_{t+1} = \Upsilon(C_t) \frac{U_c(C_{t+1})}{U_c(C_t)}$

2.2.2 Firms

Monopolistic firms produce a $[0,1]$ range of differentiated products. The production function of an individual firm $i \in [0, 1]$ is:

$$Y_{H,t}(i) = Z_t [K_t(i)]^\kappa [L_t(i)]^{1-\kappa} \quad (2.12)$$

where Z_t is an aggregate productivity shock. It is assumed that the productivity shock follows an AR(1) process:

$$\log Z_t = \rho_z \log Z_{t-1} + u_{z,t} \quad (2.13)$$

where $0 \leq \rho_z \leq 1$ and $u_{z,t}$ is an i.i.d shock with $E_{t-1}[u_{z,t}] = 0$ and $std(u_{z,t}) = \sigma_z$.

The law of motion of capital accumulation is:

$$K_{t+1}(i) = (1 - \delta)K_t(i) + \chi_t I_t(i) \quad (2.14)$$

where $0 < \delta < 1$ is the depreciation rate of capital, $I_t(i)$ is firm i 's demand of home investment good (defined below) at date t . Investment is subject to an exogenous investment-efficiency shock χ_t which is assumed to follow an AR(1) process:

$$\log \chi_t = \rho_\chi \log \chi_{t-1} + u_{\chi,t} \quad (2.15)$$

where $0 \leq \rho_\chi \leq 1$ and $u_{\chi,t}$ is an i.i.d shock with $E_{t-1}[u_{\chi,t}] = 0$ and $std(u_{\chi,t}) = \sigma_\chi$. I also assume that there is no correlation between productivity and investment-specific shocks.

The aggregated home output is defined by a Dixit-Stiglitz aggregation over all intermediate outputs by a perfectly competitive bundler:

$$Y_{H,t} = \left[\int_0^1 (Y_{H,t}(i))^{\frac{\omega-1}{\omega}} di \right]^{\frac{\omega}{\omega-1}}, \quad \omega > 1 \quad (2.16)$$

The final investment good is generated by an investment bundler using home and foreign aggregated outputs:

$$I_t = \left[(\mu^I)^{1/\eta^I} (I_{H,t})^{\frac{\eta^I-1}{\eta^I}} + (1 - \mu^I)^{1/\eta^I} (I_{F,t})^{\frac{\eta^I-1}{\eta^I}} \right]^{\frac{\eta^I}{\eta^I-1}} \quad (2.17)$$

where I_H and I_F are amounts of home and foreign goods used for investment in home respectively. The home bias preference and the elasticity of substitution between domestic and imported goods may be different for investment and consumption⁸. In other words, it is possible to allow that $\mu^I \neq \mu$, $\eta^I \neq \eta$. The investment bundler is perfectly competitive and makes zero profit in equilibrium. Thus, the associated

⁸This idea follows the SIGMA model developed by Erceg, Guerrieri and Gust (2005) which takes into account differences in the aggregation for consumption and investment

nominal investment price index, P_t^I , is equal to:

$$P_t^I = \left[\mu^I (P_{H,t})^{1-\eta^I} + (1 - \mu^I) (P_{F,t})^{1-\eta^I} \right]^{\frac{1}{1-\eta^I}} \quad (2.18)$$

Firms optimally demand home and foreign goods:

$$I_{H,t} = \mu^I \left[\frac{P_{H,t}}{P_t^I} \right]^{-\eta^I} I_t \quad I_{F,t} = (1 - \mu^I) \left[\frac{P_{F,t}}{P_t^I} \right]^{-\eta^I} I_t \quad (2.19)$$

where $I_t = \int_0^1 I_t(i) di$ is the aggregated demand for investment good by home firms.

Each firm maximizes profits by hiring labor and accumulating capital, and re-setting output prices following the Rotemberg pricing specification. It is assumed that prices are set in the producers' currency. I also assume that domestic firms discount their profits using the discount factor of the domestic households. Because the model produces home bias in equity, the representative domestic household is the absolute majority shareholder in home firms, so that this assumption is acceptable. Firms pay all profits to shareholders as dividends.

Firm i 's nominal profit is defined as

$$D_t(i) = P_{H,t}(i) Y_{H,t}(i) - P_t w_t L_t(i) - P_t^I I_t(i) - \frac{\psi_P}{2} \left(\frac{P_{H,t}(i)}{P_{H,t-1}(i)} - 1 \right)^2 P_{H,t} Y_{H,t} \quad (2.20)$$

where $Y_{H,t}(i)$ is firm i 's output which depends on its relative price and aggregate

output:

$$Y_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\omega} Y_{H,t} \quad (2.21)$$

and $Y_{H,t}$ and $P_{H,t}$ are the aggregated home output and nominal price index. Let us define the real price of firm i 's output as $p_t^H(i) = \frac{P_{H,t}(i)}{P_t}$, which is in units of home final consumption. Firm i 's profit maximization can be written in real terms as:

$$\max_{L_t, I_t, K_{t+1}, p_t^H} E_t \sum_{j=0}^{\infty} \Lambda_{t+j} \left[\begin{aligned} & p_{t+j}^H(i) Y_{H,t+j}(i) - w_{t+j} L_{t+j}(i) - \frac{P_{t+j}^I}{P_{t+j}} I_{t+j}(i) \\ & - \frac{\psi_P}{2} \left(\frac{p_{t+j}^H(i)}{p_{t+j-1}^H(i)} \pi_t - 1 \right)^2 p_{t+j}^H Y_{H,t+j} \end{aligned} \right] \quad (2.22)$$

subject to its production technology (2.12), law of motion for capital (2.14), and demand function (2.21). The CPI inflation rate is defined as $\pi_t = \frac{P_t}{P_{t-1}}$ as usual.

Let λ_t^Y and λ_t^k respectively be the Lagrange multipliers associated with the production function and capital accumulation process. The first-order conditions with respect to labor demand, investment and capital are:

$$w_t = \lambda_t^Y (1 - \kappa) \frac{Y_t^H(i)}{L_t(i)} \quad (2.23)$$

$$\frac{P_t^I}{P_t} = \lambda_t^k \chi_t \quad (2.24)$$

$$\lambda_t^k = E_t \left[\Lambda_{t+1} \left(\lambda_{t+1}^Y \frac{\kappa Y_{t+1}^H(i)}{K_{t+1}(i)} + \lambda_{t+1}^k \chi_{t+1} \right) \right] \quad (2.25)$$

Since there is no firm-specific shock in the model, by symmetry, firms will make the same optimal decisions regarding their choice variables so that we can drop the

index i in the first-order conditions above. Moreover, the Rotemberg sticky price setting preserves the ex-ante identical assumption of firms. It means that all home firms set the same output price, i.e: $p_t^H(i) = \frac{P_{H,t}(i)}{P_t} = \frac{P_{H,t}}{P_t} = p_t^H \forall i \in [0, 1]$. Let the define π_t^H as $\pi_t^H = \frac{p_t^H}{p_{t-1}^H} \cdot \frac{P_t}{P_{t-1}}$. The optimal rule for setting real price of home firms' output can be written as:

$$p_t^H = \frac{\omega}{\omega-1} \lambda_t^Y - \frac{\psi_P}{\omega-1} (\pi_t^H - 1) \pi_t^H p_t^H + \frac{\psi_P}{\omega-1} E_t \left[\Lambda_{t+1} (\pi_{t+1}^H - 1) \pi_{t+1}^H \frac{Y_{H,t+1}}{Y_{H,t}} p_{t+1}^H \right] \quad (2.26)$$

2.2.3 Monetary policy

Monetary policy is assumed to follow a simple Taylor-type reaction function. Monetary authorities follow a policy that smooths the rate of return on nominal bonds of the respective currency which is subject to a stochastic shock. The home monetary rule is defined as:

$$\log R_{t+1} = (1 - \gamma_R) \log \bar{R} + \gamma_R \log R_t + \gamma_\pi \log \pi_t + \gamma_Y \log(y_t/\bar{y}) + m_t \quad (2.27)$$

where $\bar{R} = 1/\beta$ and \bar{y} are the steady state nominal interest rate and output, respectively. Monetary policy innovation m_t is an i.i.d shock to the Central Bank's preference such that $E_{t-1}[m_t] = 0$ and $std(m_t) = \sigma_m$.

The role of m_t is to allow a simple way of introducing a non-productivity related shock in the model. Monetary policy shock is an important source of uncertainty particularly in models with nominal rigidity. I assume that the nominal interest rate is adjusted for CPI inflation, which is different than Devereux and Sutherland (2007)

who use PPI inflation. Devereux and Engel (2003) show that it is equivalent to consider either type of inflation, so I follow the literature and use the CPI inflation.

2.2.4 Foreign economy

The model assumes a symmetric structure so that the foreign economy has an analogous representation to the home economy. Thus, foreign consumers choose consumption, labor supply and portfolio holdings to maximize their utility subject to the following budget constraint:

$$C_t^* + \frac{1}{\varepsilon_t} \Omega_{t+1}^* = w_t^* L_t^* + \frac{1}{\varepsilon_t} r_{B,t} \Omega_t^* + \frac{1}{\varepsilon_t} \alpha_{t-1}^* r_{x,t} \quad (2.28)$$

where ε_t denotes the real exchange rate and $\varepsilon_t = \frac{S_t P_t^*}{P_t}$. The real exchange rate appears in the foreign consumer budget constraint because wealth, portfolio holdings, and returns are all defined in units of the Home consumption. The similar first-order optimal condition with respect to wealth for the foreign household is:

$$C_t^{*v-\sigma} = \tilde{\beta} E_t \left[C_{t+1}^{*-\sigma} \frac{\varepsilon_t}{\varepsilon_{t+1}} r_{B,t+1} \right]$$

Foreign Central Bank also follows a similar monetary policy rule to smooth the rate of return on foreign nominal bonds

$$\log R_{t+1}^* = (1 - \gamma_R) \log \bar{R} + \gamma_R \log R_t^* + \gamma_\pi \log \pi_t^* + \gamma_Y \log(y_t^*/\bar{y}) + m_t^* \quad (2.29)$$

It is assumed that there is no monetary policy coordination between two countries.

2.2.5 Market-clearing conditions

Foreign agents solve similar maximization problems. The corresponding variables and parameters for foreign agents are denoted with the asterisk (*). Since Law of One Price holds, the price of imported goods sold in the home country is $P_{F,t} = S_t P_{F,t}^*$, where $P_{F,t}^*$ is the price of foreign goods set by foreign producers in foreign currency and S_t is the nominal exchange rate. Domestic output is determined by demand from home and foreign consumption and capital investment. A similar condition is used for the foreign output:

$$Y_{H,t} = C_{H,t} + C_{H,t}^* + I_{H,t} + I_{H,t}^* + \frac{\psi_P}{2} \left(\frac{p_t^H}{p_{t-1}^H} \pi_t - 1 \right)^2 Y_{H,t} \quad (2.30)$$

$$Y_{F,t}^* = C_{F,t} + C_{F,t}^* + I_{F,t} + I_{F,t}^* + \frac{\psi_P}{2} \left(\frac{p_t^{*F}}{p_{t-1}^{*F}} \pi_t^* - 1 \right)^2 Y_{F,t}^* \quad (2.31)$$

It is easy to show that asset market clearing conditions for equities are:

$$\alpha_{E,t} + \alpha_{E,t}^* = q_t \quad (2.32)$$

$$\alpha_{E^*,t} + \alpha_{E^*,t}^* = \varepsilon_t q_t^* \quad (2.33)$$

where $q_t(q_t^*)$ is the ex-dividend real price of home (foreign) equities and the number of outstanding equities in each country is normalized to be unity.

Similarly, market clearing conditions for bonds are:

$$\alpha_{B,t} + \alpha_{B,t}^* = 0 \quad (2.34)$$

$$\alpha_{B^*,t} + \alpha_{B^*,t}^* = 0 \quad (2.35)$$

Finally, the variance-covariance matrix of shocks is denoted Σ . Correlations of shocks across types or countries can be different from zero depending on particular calibrations. However, this assumption does not affect the solution method.

2.3 Solving the Model

It is well known in the open economy macro literature that portfolio choice α_t is indeterminate up to a first order approximation around a non-stochastic steady state, because all assets are perfect substitutes at the first-order level of approximation. Standard approximation methods are not able to overcome this indeterminacy problem. However, a sequence of papers by Devereux and Sutherland (2007, 2008) provides a generally simple approximation method for characterizing steady-state and time-varying equilibrium portfolios in a two country DSGE model. Their work shows that to solve for the steady-state and the time-varying equilibrium portfolios, higher order approximation is needed. Although an analytical solution can be derived in special and simple cases, it is not immediately available for this complicated model. Hence, I rely on numerical results to study dynamic equilibrium portfolio choices.

The solution to the model is described by sequences of quantities $\{C_t, C_t^*, L_t, L_t^*, I_t, I_t^*, Y_{H,t}, Y_{F,t}^*, K_t, K_t^*, D_t, D_t^*\}$, prices $\{W_t, W_t^*, R_t, R_t^*, Q_t, Q_t^*, P_t, P_t^*, P_{H,t},$

$P_{F,t}^*$, S_t, ε_t , rates of returns $\{r_{E,t}, r_{E^*,t}, r_{B,t}, r_{B^*,t}\}$, and the vector of asset holdings $\{\alpha_{E,t}, \alpha_{E^*,t}, \alpha_{B,t}, \alpha_{B^*,t}\}$ for home agents (foreign agents' vector of asset holdings can be easily derived from market clearing conditions) which:

- Solve households' utility maximization problem (2.1) subject to the budget constraint (2.6), and satisfy equilibrium conditions (2.8-2.11) and analogous conditions for foreign country (only one budget constraint equation is needed due to Walras' law).
- Solve firms' profit maximization problem (2.22), and satisfy equilibrium conditions (2.23-2.26), and their foreign counterparts
- Satisfy monetary policy rules (2.27-2.29) and market clearing conditions for goods and asset markets (2.30-2.35).

The following subsections are quick summaries of solution methods. For details, see Devereux and Sutherland (2007, 2008).

2.3.1 "Zero-order" steady state portfolios

There are other solution methods for portfolio choices in a model with incomplete asset market that also employ higher-order approximation to compute steady state portfolios (see also Bui (2008), Tille and van Wincoop (2007), Heathcote and Perri (2008), Evans and Hnatkovska (2005), Hnatkovska (2005)). I choose to follow Devereux and Sutherland (2008) because calculating steady state portfolios is the first step of their later work, which provides a general framework to compute time-varying characteristics of equilibrium portfolios. I also use the iteration method described in

my other paper (Bui, 2008) to calculate and compare the steady state portfolios with results of Devereux and Sutherland (2008) method.

The solution method considered in this paper has two important properties that allow it to be used for general forms of models. First, the deviation of portfolio holdings around the approximation point does not have any effects in the dynamics of first-order approximation of non-portfolio variables in the model. The second important property is that only the first-order approximation of non-portfolio parts of the model is needed to solve for the steady state portfolios. The sufficient conditions and solution of the steady state portfolio choice are derived from the second-order approximation of Euler equations of asset holdings. Moreover, if the variance-covariance matrix Σ is constant then the optimal portfolio is non-time-varying up to the level of approximation considered.

Devereux and Sutherland (2008) develop a solution formula for steady state portfolio assuming net-zero wealth. To comply with their solution procedure, I define the following variables (in real terms):

$$\begin{aligned} NFA_{t+1} &\equiv \alpha_{E^*,t} - \alpha_{E,t}^* + \alpha_{B,t} + \alpha_{B^*,t} \\ NX_t &\equiv w_t L_t + d_t - C_t \end{aligned}$$

Combining these definitions with the asset market clearing conditions, I can re-write the home budget constraint as:

$$NFA_{t+1} = NX_t + r_{B,t} * NFA_t + \xi_{H,t} \tag{2.36}$$

where

$$\xi_{H,t} = \alpha_{E^*,t-1}(r_{E^*,t} - r_{B,t}) - \alpha_{E,t-1}^*(r_{E,t} - r_{B,t}) + \alpha_{B^*,t-1}(r_{B^*,t} - r_{B,t}) \quad (2.37)$$

The variable $\xi_{H,t}$ represents the "excess return" of investing in assets other than domestic bonds. By construction, Net Foreign Asset (NFA_t) equals zero in equilibrium. This modification allows me to directly adopt their solution formula (equation 43 in Devereux and Sutherland, 2008)⁹.

2.3.2 "First-order" time-varying portfolios

In order to compute time-variation equilibrium portfolios, higher orders of approximation are needed. The third-order approximation of Euler equations and the second-order of the non-portfolios part are needed. As in the case of the steady state portfolio, portfolio decisions only enter the non-portfolio parts of the model through the second-order approximation of the budget constraint (only one budget constraint is needed due to Walras' Law).

Following Devereux and Sutherland (2007), the system of second-order approximation equations of the non-portfolio part of the model can be written in the following

⁹Additionally, I apply the iteration method to calculate steady state portfolios using the second order approximation of the whole model. This method is presented in my other paper (Bui, 2008). The two methods generate approximately the same steady state portfolios. Results of the iteration method are not reported here but are available upon request.

state-space representation:

$$A_1 \begin{bmatrix} s_{t+1} \\ E_t[c_{t+1}] \end{bmatrix} = A_2 \begin{bmatrix} s_t \\ c_t \end{bmatrix} + A_3 x_t + A_4 \Lambda_t + A_5 \xi_t + O(\epsilon^3) \quad (2.38)$$

$$x_t = N x_{t-1} + u_t \quad (2.39)$$

$$\Xi_t = vech \left(\begin{pmatrix} \begin{bmatrix} x_t \\ s_t \\ c_t \end{bmatrix} \begin{bmatrix} x_t & s_t & c_t \end{bmatrix} \end{pmatrix} \right) \quad (2.40)$$

where s_t is a vector of predetermined state variables, c_t is a vector of endogenous choice (jump) variables, and x_t is a vector of exogenous forcing variables which follows the AR(1) process described in (2.39). The second-order effects come through Ξ_t ¹⁰. The variable ξ_t represents the realized excess return on the time-varying part of the portfolio, which is defined as $\xi_t = \widehat{\alpha}_{t-1} \widehat{r}_t$, where the hat ($\widehat{\cdot}$) denotes the variable's first-order deviation from its corresponding steady-state value. Devereux and Sutherland (2007) show that up to a second-order approximation, ξ_t is an exogenous i.i.d random variable with zero-mean. The innovation covariance matrix Σ is defined above. A_1 , A_2 , A_3 , A_4 , A_5 are coefficient matrices of the second-order approximation equations derived from the system of equilibrium conditions of the model.

This system of equations can be solved using any of the available solution methods for linear rational expectation models such as Sims (2000), Schmitt-Grohé and

¹⁰The $vech(\cdot)$ operator converts a symmetric matrix into a vector by stacking the column of its upper triangle. See Lombardo and Sutherland (2005) and Devereux and Sutherland (2007) for more details.

Uribe (2004), and Lombardo and Sutherland (2007). For this paper, I use the algorithm developed by Schmitt-Grohé and Uribe (2004) to compute the solution. As mentioned by Devereux and Sutherland (2007), users of any of these methods need to be careful with the transformation of the solution into a correct format. Solution of this step is a vector of coefficients Γ , such that the time-varying portfolio can be calculated as $\hat{\alpha}_t = \Gamma' z_{t+1}$ where $z'_{t+1} = [x_t \ s_{t+1}]$.

2.4 Calibration and steady-state portfolios

In the international macroeconomic literature, it is common to assume the US as the home country. Following the literature, I calibrate the benchmark model using available empirical estimates of US quarterly data.

2.4.1 Benchmark calibration

The endogenous discount factor is calibrated so that in the steady state $\tilde{\beta} C^{-\nu} = \bar{\beta} = 0.99$, where C is the value of steady state consumption. This implies an annualized steady state nominal interest rate of 4%. I assume $\nu = 0.01$ and calibrate $\tilde{\beta}$ accordingly¹¹. For households' utility preference I assume a logarithm preference in consumption. The Frisch labor supply elasticity $1/\psi$ is set equal to 0.33, which is well in range of empirical estimates.

I set the consumption home bias $\mu = 0.85$, with the elasticity of substitution $\eta = 0.9$ following Heathcote and Perri (2002). This setting is reasonable because in this model I do not differentiate between traded and non-traded goods. The presence of nontraded goods in the data implies smaller substitution elasticity between domestic

¹¹The parameter ν determines the convergent speed of NFA. Steady state portfolios are not very sensitive to values of ν .

and imported goods. I assume that investment is less home biased and more elastic than consumption. This follows the arguments from the SIGMA model developed by Erceg, Guerrieri, and Gust (2005). For the benchmark calibration, I set $\mu^I = 0.75$ and $\eta^I = 1.2$.

Capital share in firms' production function κ is set equal to 0.28¹². The depreciation rate of capital is 2.5% which is commonly used for US quarterly data. This specification implies that the share of consumption in output is 83% and the share of investment is 17%. The steady state ratio of import to GDP is 16.7%. These numbers are in line with the literature, in which there is no government spending.

For the Rotemberg pricing specification, I use results of Keen and Wang (2007) to calibrate the price adjustment cost parameters. The benchmark values are $\psi_P = 36$ and $\omega = 7$. This is equivalent to setting the Calvo price parameter equal to 0.67, which indicates that the average duration of price change is about 3 quarters.

For the productivity shock Z_t , I use estimation results of Canzoneri, Cumby and Diba (2007), such that

$$\log Z_t = 0.923 \log Z_{t-1} + u_{z,t}$$

and $\sigma_z = 0.00861$. I assume that $\text{corr}(u_{z,t}, u_{z^*,t}) = 0$.

The literature on investment specific technology shocks has used the real investment price index to estimate the investment specific (embodied) technology shock (for instance, Fisher (2003, 2006), Altig, Christiano, Eichenbaum, and Linde (2005)). I

¹²Given that monopolistic markup is 17% in the benchmark, this specification implies that the share of capital in final output is one-third, which is commonly used in the literature.

follow the literature and estimate an AR(1) process for the embodied technology shock using US quarterly data. Data are taken from the appropriate sub-series of National Income and Product Accounts database from 1960:I to 2007:IV. The real investment price index is computed as the ratio of gross private investment price index to the GDP deflator. Series are logged and Hodrick-Prescott filtered using smoothing parameter $\lambda = 1600$. I estimate that the autoregression coefficient is $\rho_\chi = 0.85$ and the standard deviation $\sigma_\chi = 0.0036$. I assume there is no correlation between the two countries' embodied technology shocks.

For monetary policy rules, I adopt the benchmark Taylor rule estimated by Canzoneri et. al. (2007) as follows:

$$\log R_{t+1} = 0.824 \log R_t + (1 - 0.824)[\log \bar{R} + 2.02 \log \pi_t + 0.184 \log(y_t/\bar{y})] + m_t$$

where \bar{y} and \bar{R} are steady state values of output and nominal interest rate. Monetary policy shock m_t has a standard error $\sigma_m = 0.00245$. Foreign central bank follows a similar rule. Monetary policies are independent between the two countries.

β	v	σ	κ	ψ	μ	μ^I	η	η^I	δ	ψ_P	ω
0.99	0.01	1.0	0.28	3	0.85	0.75	0.9	1.2	0.025	36	7

Table 2-1: Benchmark calibration

2.4.2 Steady-state portfolios under incomplete asset markets

For the benchmark calibration, the steady state portfolio implies that domestic households hold 89.8 percent of total domestic equity and 10.2 percent of foreign

equity in their portfolio¹³. Steady state holding of domestic bond is valued at 30 percent of output. The market clearing condition for bonds implies that domestic households borrow abroad (i.e., issue bonds denominated in foreign currency) of the same magnitude.

While there is broad consensus in the literature that a "good" model of portfolio choice should imply home bias in the optimal equity portfolio, the literature has produced contrasting results for equilibrium bond holdings. Theoretical models generate a wide range of equilibrium bond holdings depending on the particular model's specification. Coeurdacier et al. (2007) show that, in a particular circumstance under incomplete asset markets, it is efficient for each agent to hold a "short" (negative) position in domestic currency bonds and a long (positive) position in foreign bonds (given that there is equity home bias). Devereux and Sutherland (2007b) find that under flexible prices and complete markets, money is fully neutral in the economy where both bonds and equities are traded. In that economy, they find that the optimal portfolio consists of "full diversification" equity portfolio and *no* bonds. On the other hand, Coeurdacier et. al. (2008) find that households hold home bias in equity and positive domestic bond position in the steady state. Their model assumes flexible prices and complete markets.

Empirically, bonds are not in zero net supply as they are commonly assumed to be in the macro literature and in this paper. Furthermore, there exists the forward market which is not modeled here. The bond position is however not fully determined in the empirical studies due to the complexity and lacking of data. Though the bond portfolio in the model is not as realistic as it should be, it still provides a good

¹³The current report of US international portfolio holdings shows that US investors were holding approximately 88.7% of total US equities at the end of June, 2007.

proxy for consideration of asset diversification. The existence of nominal bonds in the model generates another channel for diversification by allowing investors to not only reallocate wealth across countries (as in models with equities only) but also to reallocate across types of securities (bonds versus stocks).

2.5 Portfolio dynamics

This step applies the approximation method developed by Devereux and Sutherland (2007) to calculate the time-varying responses of the equilibrium portfolio around the benchmark steady state. Impulse response functions of portfolio holdings are calculated using the coefficient vector Γ such as $\hat{\alpha}_t = \Gamma' \cdot [x_t \ s_{t+1}]$ where $\hat{\alpha}$ is a vector of deviations from steady-state values of gross portfolio holdings $\hat{\alpha}_t = [\hat{\alpha}_{B^*,t}, -\hat{\alpha}_{E^*,t}, \hat{\alpha}_{E^*,t}]'$ and $z_{t+1} = [x_t \ s_{t+1}]$ is a vector of deviations from steady-state of exogenous and pre-determined state variables. Given that portfolio decisions are made at the end of period t for holdings of assets into period $t + 1$, the time varying portfolio $\hat{\alpha}_t$ will depend on the value of state variables observed at time t , i.e. z_{t+1} is the values of exogenous shocks x_t and endogenous state s_{t+1} prior to the realization of time $t + 1$ shocks, u_{t+1} . Impulse response functions are calculated for a positive one-standard-deviation increase in each shock. This step utilizes the second-order approximation algorithm of Schmitt-Grohé and Uribe (2004) and uses a Matlab code which transforms solutions of Schmitt-Grohé and Uribe procedure to conform with Devereux and Sutherland (2007) solution formulas¹⁴.

¹⁴This code was generously provided by Alan Sutherland.

2.5.1 Net Foreign Asset position and its components

Recall that $NFA_{t+1} = \alpha_{B,t} + \alpha_{B^*,t} - \alpha_{E^*,t} + \alpha_{E,t}$, thus the time varying response of domestic bond holding $\widehat{\alpha}_{B,t} = \alpha_{B,t} - \overline{\alpha}_B$ can be calculated as:

$$\widehat{\alpha}_{B,t} = \widehat{NFA}_{t+1} - (\widehat{\alpha}_{B^*,t} - \widehat{\alpha}_{E^*,t} + \widehat{\alpha}_{E,t})$$

From the market clearing condition for domestic bond, I can find the responses of foreign households' holding of the domestic bond as follows:

$$\widehat{\alpha}_{B^*,t} = -\widehat{\alpha}_{B,t}$$

The home Net Foreign Asset position can be divided into two components: gross external assets and gross external liabilities, therefore, changes of the home NFA position also can be divided into changes in gross external assets and liabilities.

$$\widehat{NFA}_{t+1} = (\widehat{\alpha}_{B^*,t} + \widehat{\alpha}_{E^*,t}) - (\widehat{\alpha}_{E,t} + \widehat{\alpha}_{B,t}) = \widehat{gxa}_t - \widehat{gxl}_t$$

Figure ?? shows the responses of home net foreign asset position and gross external assets and liabilities (expressed as percentages of steady state output) to a positive domestic TFP shock. Increased domestic labor productivity worsens the home NFA position. A positive domestic technology shock increases domestic output and consumption relative to foreign output and consumption. The real exchange rate depreciates and net exports decrease. Gross external liabilities increase more than

gross external assets. In response to a positive domestic TFP shock, real (relative) returns (compared to the benchmark domestic bond) of other assets decrease; of these, foreign bond return decreases the least while return on foreign equity drops the most. Both domestic holdings of foreign bond and equity slightly increase while foreign households move away from domestic equity and into domestic bond. The net effect of these changes leads to a decrease in the home NFA position.

Figure 2-3 shows the responses of the NFA position and its two components to a positive increase in domestic investment efficiency. Improvement in investment efficiency at home leads to increases in consumption and output, and an appreciation in the real exchange rate. The net effect increases the trade deficit and worsens the home NFA position. The gross external asset position decreases upon impact while gross external liabilities increase by a small amount. In addition, investors move away from domestic bonds and into domestic equities a few periods after the realization of shock. In general, external positions and asset holdings respond to an improved investment efficiency in a similar pattern to their responses to an increase labor productivity.

Responses of the NFA position to a domestic expansionary monetary policy are shown in Figure 2-4. Similarly, output and consumption increase and the real exchange rate depreciates due to an expansionary home monetary policy. Net exports decrease and the home NFA position worsens. Monetary policy shocks have an immediate impact on the NFA position (impacts of technology shocks on the NFA position peak between 5-10 periods after shocks are realized). Upon the realization of an interest rate shock, gross assets drop relative more than gross liabilities. Notably, under sticky prices, a monetary policy shock has strong effects on both bond and

equity holdings. In response to a domestic expansionary monetary policy, foreign investors increase domestic equity holding and decrease their holding of domestic bond while both domestic holdings of foreign bond and equity decrease. This pattern of foreign investors' responses is different from their responses to improved domestic productivity.

These theoretical impulse responses are empirically testable by estimating the Structural Vector Autoregression (SVAR) framework and using available data series. The identification scheme is described in Altig et al. (2005) and is also used by Bems, Dedola, and Smets (2007). This framework can be used to examine effects of structural shocks on the NFA position and its components, which essentially is the focus of Bui (2009). Figure 2-5 shows the point estimates and 95 percentile confidence intervals of empirical responses of the US NFA position to three identified US shocks: the TFP, the investment-specific technology, and the monetary policy¹⁵. While empirical impulse responses of the NFA position to technology shocks are comparable with theoretical predictions, the empirical response of the NFA position to a monetary policy shock is not. In the model, in response to an expansionary monetary policy shock, the home NFA position worsens. In contrast, the empirical estimates may suggest that the NFA position may respond positively to an expansionary monetary policy. Although empirical results are inconclusive because of the large confidence interval, this finding is still of interest for further extensions of the theoretical model and more empirical work.

¹⁵See Appendix 2.B for the description of data source and the identification scheme.

2.5.2 Valuation effects versus Net purchases

The discussion in the subsection above analyzes the effects of domestic shocks on total changes of gross values of (real) assets and liabilities (normalized by steady state output) in the model. In fact, movements of the NFA position and its components can be further broken down into two components: volume and asset price movements. Gourinchas and Rey (2007) find that changes due to asset prices and exchange rate movements or the "valuation effects" have important roles in explaining the dynamics of a country's NFA position and current account. Other papers also try to examine these "valuation effects" and their effects on global external imbalances, such as Ghironi, Lee, and Rebucci (2007), Coeurdacier et al. (2008), Devereux and Sutherland (2008b), and Nguyen (2009). In this paper, I only present theoretical impulse responses of these effects and leave further discussion for future extensions. It is important to have a theoretical framework that can disentangle those effects in a complex dynamic environment.

Recall that real values of home holdings of foreign equity and bond are $\alpha_{E^*,t} = \varepsilon_t q_t E_{t+1}^F$ and $\alpha_{B,t} = \frac{\varepsilon_t}{R_t^*} b_{t+1}^F$. Therefore I can divide the total changes of them into volume and price movements as follows:

$$\hat{\alpha}_{E^*,t} = \varepsilon q^* E^F (\hat{q}_t^* + \hat{\varepsilon}_t) + \varepsilon q^* (E_{t+1}^F - E^F)$$

and

$$\hat{\alpha}_{B^*,t} = \frac{b^F}{R^*} (\hat{\varepsilon}_t - \hat{R}_t^*) + \frac{1}{R^*} (b_{t+1}^F - b^F)$$

The first component in the right hand side of the equations above represents the

valuation effects due to changes in asset prices and the real exchange rate. The second component represents the net purchases or the volume effects of each asset. Similarly, changes in home gross external liabilities can also be decomposed into changes in volumes and asset prices.

Figures 2-6 to 2-11 show changes of each asset holdings due to volume and price movements in response to domestic shocks in the model. Movements due to either net purchases or price changes of equities are significantly larger than for bonds and account for most of these changes in the NFA position and its components. In response to each shock, volume effects offset valuation effects so that the net effect on external positions is small despite large changes due to net purchases and asset price adjustments.

Upon impacts of domestic expansionary shocks, volume effects lead to an increase in the NFA position in response to improved investment efficiency and expansionary monetary policy but to a decrease in the NFA position as a result of higher labor productivity (TFP). These changes in the NFA position can be broken into changes of gross assets and liabilities positions, or into changes of holdings of each type of assets. Changes due to net purchases (sales) of assets in the NFA components are mainly driven by equities. In response to shocks, domestic and foreign investors' cross-country equity acquisitions are positively correlated. Hence, the (net) volume effect of the NFA position is smaller than those of its asset and liability components. Notably, the analysis of net purchases in response to an expansionary monetary policy suggests that investors are increasingly biased toward domestic equity from an already strong home bias steady state equity portfolio.

Moreover, results show that the conditional correlations (on each type of shocks)

between domestic (relative) labor income and domestic (relative) dividends are negative. Engel and Matsumoto (2006) consider portfolio choices in a simpler model with sticky prices. They find that, in the sticky prices environment, investors are driven toward home bias in equity because the correlation between domestic firms' dividends and domestic labor income conditional on TFP shocks is negative so that domestic equity provides a better hedge against non-tradable labor income. In this paper, I find that the correlation is negative conditional on each type of shock, thus, the unconditional correlation is also negative. This finding extends the Engel and Matsumoto (2006) intuition. The negative correlation, conditional and unconditional, between domestic labor income and domestic dividends is the key explanation of the home bias in the optimal equity portfolio.

Valuation effects move in the opposite direction to volume effects; thus, the total changes of asset positions are much smaller than changes due to each movement - valuation effects and net purchases. Bond returns are affected by monetary policy rules with a strong degree of interest rate smoothing; the nominal interest rates (i.e. the inverses of bond prices) move much less than prices of equities. Moreover, the shares of wealth invested in equities are much larger than those invested in bonds in the steady state. Therefore, valuation effects linked with bonds are insignificant compared to those of equities in response to shocks.

More importantly, under sticky prices, monetary policy shocks have effects on real returns of bonds and equities, and consequently, have effects on asset prices and portfolio holdings. Valuation effects of equities due to an expansionary monetary policy shock are smaller than those of the two technology shocks; but they are still considerably larger than the valuation effects of bonds. This result is worth empha-

sizing because, based on my knowledge of the literature, not many papers consider the valuation effects of monetary policy, either theoretically or empirically.

2.5.3 Predicted correlations and variances

This subsection examines the simulated second moments of selected variables predicted by the model. The standard deviations, correlations, and autocorrelations are calculated using a Monte-Carlo simulation. I simulate the economy for 500 periods, drop the first 100 periods, and calculate those moments. This is repeated 1000 times. Average values of simulated moments are reported.

Moments	Model	BKK ^a	C08 ^b
$\frac{sd(c)}{sd(y)}$	0.69	0.49	0.55~0.6
$\frac{sd(inv)}{sd(y)}$	4.46	3.15	2.1~3.4
$cor(c, y)$	0.86	0.76	0.65~0.85
$cor(inv, y)$	0.67	0.9	0.7~0.8
$cor(c, c^*)$	0.23	-0.23~0.65	0.6
$cor(y, y^*)$	0.07	0.3~0.5	0.8

Table 2-2: Second-moments of selected macro variables.

a) Backus et al. (1992), b) Civelli (2008)

Table 2-2 reports ratios of the standard deviations of macroeconomic variables to that of output. Columns 3-4 show the range of reported estimates in the literature.

Given the presence of investment specific technology shocks, the model still predicts a more volatile investment than empirical estimates. It is known that investment adjustment costs are needed to match the ratio of standard deviation of investment

to output. Cross-country correlations of output and consumption are low compared to others' estimation. In this paper, I assume there is no cross-country correlation of shocks. This assumption may lead to the low cross-country correlations of output and consumption. The cross-country correlation of consumption is higher than that of output, which suggests that there is a high degree of consumption risk-sharing in the model even with incomplete asset markets.

The predicted volatility of the change of NFA is smaller than that of output and it is negatively correlated with GDP. This countercyclicality is consistent with the finding of Coeurdacier et al. (2008). Coeurdacier et al. (2008) however find that NFA position changes are mostly driven by movements in asset prices. In this model, the changes of the NFA position are driven by *both* changes in asset prices and quantities of assets traded. The analysis above shows that valuation effects are negatively correlated with volume effects. These effects offset each other leading to a smaller volatility of the NFA position.

In terms of capital flows dynamics, the model generates sizeable fluctuations in equity and bond holdings and trade. Net equity (bond) holding is defined as the difference between equity (bond) positions in gross assets and gross liabilities. Both net equity and bond holdings are more volatile than output, and the correlation between them is negative. I define the net deviation from steady state of equities as $eqpc = \varepsilon q^* (E_{t+1}^F - E^F) - q (E_{t+1}^{*H} - E^{*H}) = \varepsilon q^* E_{t+1}^F - q E_{t+1}^{*H}$ ¹⁶, i.e., the difference between home net deviation of foreign equity and domestic equity by US and foreign investors respectively. I similarly define net bond deviation. Simulation results show that the net deviations of financial assets are very volatile, particularly that of eq-

¹⁶The second equality is derived from the symmetric structure of the steady state portfolio.

uity. The predicted correlation between net responses of bond and equity is negative (-0.37) which indicates a reallocation of wealth between the two types of assets in this model.

	Rel. sd to GDP	CKM ^a	Corr. with GDP	CKM ^a
<i>nx</i>	0.64	0.21~0.91	-0.38	-0.56~0.01
<i>ca</i>	0.64	0.21~0.83	-0.37	-0.74~0.18
Δnfa	0.51	0.88~2.69	-0.45	-0.46~-0.0
<i>rer</i>	0.84	3.1~6.3	0.59	-0.18~0.43

Table 2-3: Predicted second-moments of external balances and the real exchange rate

a) Coeurdacier et al. (2008) estimates of G-7 countries

It is useful to recall the definition of the first difference of the NFA position $\Delta NFA_{t+1} = NFA_{t+1} - NFA_t$. From the budget constraint (eq 2.36), it is simple to show that

$$\Delta NFA_{t+1} = CA_t + \xi_{H,t}$$

where $CA_t = NX_t + (r_{B,t} - 1)NFA_t$ corresponds (approximately) the conventionally measured current account and $\xi_{H,t} = r'_{xt}\alpha_{t-1}$ is the "excess return". Results show that both current accounts and net exports are less volatile than output. They are also negatively correlated with output. The correlation between the trade balance/GDP ratio and the real exchange rate is negative and very small. The predicted ratio of standard deviation of the real exchange rate to that of output is 0.84; the correlation between the real exchange rate and output is 0.59. The model generates a considerable

but still small volatility in the real exchange rate compared to empirical data. The empirical correlation between the real exchange rate and output is close to zero. It is well known that Law of One Price and PPP assumptions do not hold empirically.

It is known that theoretical models may not be able to match with all empirical moments. This model is not an exception. The model generates some empirically comparable results but not all. To match all of empirical moments in a model as complex as this is not an easy task. Altig et al. (2005) and Ireland and Schuh (2007) provide methods that, instead of calibrating models, directly estimate parameters by matching theoretical moments with empirical ones. Moreover, additions of other features such as fiscal policy, demand shock, or wage rigidity into the model may help to capture more empirically observed moments.

2.6 Conclusions

In this paper, I incorporate endogenous international portfolio choices in a symmetric two country NOEM model with capital accumulation, price stickiness and incomplete asset markets. This paper applies new approximation methods to study the dynamics of international portfolio choices in a general equilibrium framework. For the benchmark calibration, the model can account for the observed home bias in equity in the current US portfolio. Around this steady state portfolio, I calculate the impulse responses of asset holdings and trading to different types of domestic shocks in the model. I find that the model can generate sizeable volatility of the net foreign asset position, its asset and liability components, and each type of asset holdings and trades. Valuation effects and volume effects are quite large but offsetting each other, which leads to smaller volatility in the NFA position in this model. More

importantly, the model provides new evidence of monetary policy impacts on the portfolio dynamics under a sticky price environment and incomplete asset markets. I find that monetary policy has important effects on the dynamics of portfolio holdings and generate sizeable valuation effects (due to effects on asset prices of bonds and equities).

The impulse responses and volatility of portfolio dynamics predicted in this model can be tested empirically by applying the structural VAR framework to the available US data. Altig et al. (2005) develop a SVAR estimation procedure that considers the same three types of shock considered in this paper. Bems et al. (2007) extend that framework to include government spending shocks. A simple SVAR estimation generates counterfactual impulses of net foreign asset positions to a domestic expansionary monetary policy shock. Further extensions and modification of this model as well as empirical studies are required to resolve this unusual finding¹⁷. Altig et al. (2005) and Ireland and Schuh (2007) also suggest that one can empirically estimate this type of model using econometric methods to minimize differences between empirical and theoretical moments.

Furthermore, this framework can also be extended and used to study other issues of international finance and open macroeconomics literature such as consumption risk sharing and welfare with embedded endogenous portfolio choices, which is not available in the earlier papers. The Devereux and Sutherland (2007, 2008) method is very flexible and easily applicable to adapt additional features and/or types of shocks. Features that can be included are nominal wage rigidity, investment adjustment costs and additional sources of innovations. In this model, I only assume three types of

¹⁷See Bui (2009) for more detailed discussion of the empirical estimation and results.

shocks that are often used in the literature; but there are also others, for example, preference and fiscal policy shocks. Additionally, we can introduce non-zero supply bonds to make bond portfolios more realistic.

APPENDIX

2.A Budget constraint derivation

The home budget constraint in nominal term is:

$$\begin{aligned} P_t C_t + Q_t E_{t+1}^H + S_t Q_t^* E_{t+1}^F + \frac{B_{t+1}^H}{R_t} + \frac{S_t B_{t+1}^F}{R_t^*} \\ = W_t L_t + E_t^H (Q_t + D_t) + S_t E_t^F (Q_t^* + D_t^*) + B_t + S_t B_t^F \end{aligned}$$

where E_{t+1}^i is the percentage of home (foreign) equities held by home agents and B_{t+1}^i is the holding of nominal bonds issued by the home (and foreign) country brought from period t into period $t+1$. Q_t (Q_t^*) represents the nominal home (foreign) equity price and D_t (D_t^*) is the nominal dividend paid by home (foreign) firms. The nominal variables are denominated in their respective currency. S_t is the nominal exchange rate.

Divide both sides by P_t , the real budget constraint is written as:

$$\begin{aligned} C_t + \frac{Q_t E_{t+1}^H}{P_t} + \frac{\varepsilon_t Q_t^* E_{t+1}^F}{P_t^*} + \frac{B_{t+1}^H}{R_t P_t} + \frac{\varepsilon_t B_{t+1}^F}{R_t^* P_t^*} \\ = w_t L_t + \frac{(Q_t + D_t) E_t^H}{P_t} + \frac{\varepsilon_t (Q_t^* + D_t^*) E_t^F}{P_t^*} + \frac{B_t^H}{P_t} + \frac{\varepsilon_t B_t^F}{P_t^*} \end{aligned}$$

Now define the home agent's real holdings of financial assets:

$$\begin{aligned}\alpha_{E,t} &= \frac{Q_t E_{t+1}^H}{P_t} & \alpha_{E^*,t} &= \frac{\varepsilon_t Q_t^*}{P_t^*} E_{t+1}^F \\ \alpha_{B,t} &= \frac{1}{R_t} \frac{B_{t+1}^H}{P_t} & \alpha_{B^*,t} &= \frac{1}{R_t^*} \frac{\varepsilon_t B_{t+1}^F}{P_t^*}\end{aligned}$$

and the real returns on these assets are:

$$\begin{aligned}r_{E,t} &= \frac{(Q_t + D_t)/P_t}{Q_{t-1}/P_{t-1}} & r_{E^*,t} &= \frac{\varepsilon_t(Q_t^* + D_t^*)/P_t^*}{\varepsilon_{t-1}Q_{t-1}^*/P_{t-1}^*} \\ r_{B,t} &= R_{t-1} \frac{P_{t-1}}{P_t} & r_{B^*,t} &= R_{t-1}^* \frac{\varepsilon_t}{\varepsilon_{t-1}} \frac{P_{t-1}^*}{P_t^*}\end{aligned}$$

All real variables are defined in units of home consumption and $\varepsilon_t = \frac{S_t P_t^*}{P_t}$ is the real exchange rate.

Then the home budget constraint in real terms can be written as:

$$C_t + \alpha_{E,t} + \alpha_{E^*,t} + \alpha_{B,t} + \alpha_{B^*,t} = w_t L_t + r_{E,t} \alpha_{E,t-1} + r_{E^*,t} \alpha_{E^*,t-1} + r_{B,t} \alpha_{B,t-1} + r_{B^*,t} \alpha_{B^*,t-1}$$

Use the definitions of real wealth $\Omega_t = \sum \alpha_{k,t-1}$ and the vector of excess real returns:

$$r'_{x,t} = [(r_{E,t} - r_{B,t}) \quad (r_{E^*,t} - r_{B,t}) \quad (r_{B^*,t} - r_{B,t})]$$

The budget constraint appears as equation (2.6) in the text.

Similarly, I can derive the foreign budget constraint in terms of home goods as

in (2.28).

Total shares issued are normalized to be 1. Thus, market clearing conditions for equities are:

$$E_t^H + E_t^{H*} = 1$$

$$E_t^F + E_t^{F*} = 1$$

For bonds, I assume that nominal bonds are in net-zero supply such that:

$$B_t^H + B_t^{H*} = 0$$

$$B_t^F + B_t^{F*} = 0$$

It is easy to show that these asset market clearing conditions imply ones in the text defined in terms of $\alpha_{k,t}$.

$$\alpha_{E,t} + \alpha_{E,t}^* = q_t$$

$$\alpha_{E^*,t} + \alpha_{E^*,t}^* = \varepsilon_t q_t^*$$

and

$$\alpha_{B,t} + \alpha_{B,t}^* = 0$$

$$\alpha_{B^*,t} + \alpha_{B^*,t}^* = 0$$

Let define the Net Foreign Asset position and Net Export as follows:

$$NFA_{t+1} \equiv \alpha_{E^*,t} - \alpha_{E,t}^* + \alpha_{B,t} + \alpha_{B^*,t}$$

$$NX_t \equiv w_t L_t + d_t - C_t$$

where

$$w_t L_t + d_t = p_t^H Y_{H,t} - \frac{P_t^I}{P_t} I_t - \frac{\psi_P}{2} (\pi_t^H - 1)^2 p_t^H Y_{H,t}$$

Combining these definitions with the asset market clearing conditions for α 's, I can re-write the home budget constraint as

$$NFA_{t+1} = NX_t + r_{B,t} * NFA_t + \xi_{H,t}$$

where

$$\xi_{H,t} = \alpha_{E^*,t}(r_{E,t} - r_{B,t}) - \alpha_{E,t}^*(r_{E,t} - r_{B,t}) + \alpha_{B^*,t}(r_{B^*,t} - r_{B,t})$$

2.B Data description and VAR identification

This appendix describes the data sources and the identification scheme used in the estimated VAR reported in the Section 2.5.1.

Data

Data used are quarterly and seasonally adjusted at annual rate for the US. The relative investment price index is constructed from related series of the National Income and Payment Accounts table. It is constructed as the ratio of the investment price index over the GDP deflator. The GDP deflator is calculated from dividing the nominal real GDP by the real GDP. The labor productivity is the per-capita GDP per hour worked. The GDP per hour worked and population over 16 series are available from the Fed St. Louis FRED database. Inflation is the growth rate of GDP deflator. Hours worked are available from the Bureau of Labor Statistics database and are normalized by population over 16. The federal fund rate is the quarterly average of monthly effective fed fund rates of corresponding months.

The definition of the net foreign asset position used in this estimation is different from what is usually used in the literature. The NFA position is calculated as the difference between the gross holdings of US private investors of foreign assets and foreigners' private holdings of US assets. This makes extensive use of the availability of data from the Flows of Funds Accounts (Table F.107). US private investors' assets consist of foreign equities, foreign bonds, and foreign direct investment (series coded FL263169175, FL263163003, FL263164003, FL263192005). Foreign private investors' assets consist of open market purchases, Federal and municipal bonds, and US equities plus direct investment (series coded FL263061123, FL263061723, FL263062003,

263063005, FL263064105, FL263062001). The Flows of Funds Accounts provide quarterly data of these series. The NFA position is normalized by annualized nominal GDP.

Identification scheme

The estimated VAR is defined as:

$$Y_t = B(L)Y_{t-1} + u_t \quad Eu_t u_t' = \Sigma$$

where:

$$B(L) \equiv B_1 + B_2L + \dots + B_qL^{q-1}$$

$$Y_t = \begin{bmatrix} \Delta \log p_t^I \\ \Delta \log z_t \\ Infl_t \\ hours_t \\ ffr_t \\ NFA_t/GDP_t \end{bmatrix} .$$

To identify the shocks to technology, I follow the strategy used by Fisher (2003) and Altig et al. (2005) to identify neutral and capital embodied shocks to technology. I assume that innovations to technology (both neutral and embodied) are the only shocks which affect the level of labor productivity in the long run. In addition, I assume that embodied technology shocks are the only shocks that affect the relative price of investment goods in the long run. The fundamental economic shocks ε_t are

related to the one-step-ahead forecast error u_t according to the relationship:

$$u_t = C\varepsilon_t \quad \text{and} \quad CC' = \Sigma$$

where the first two elements in ε_t are the embodied and neutral technology shocks, respectively. The technology shocks are identified using the long-run restrictions as follows:

$$P \equiv [I - B(1)]^{-1}C = \begin{bmatrix} p_{11} & 0 & 0 \\ p_{21} & p_{22} & 0 \\ P_{31} & P_{32} & P_{33} \\ 4 \times 1 & 4 \times 1 & 4 \times 4 \end{bmatrix}$$

where $B(\cdot)$'s are coefficients of lag polynomial of the estimated VAR.

Monetary policy shock is identified using the recursive approach of Christiano et al. (1999). Specifically, I assume that policy makers set the interest rate so that it contemporaneously responds to the relative price of investment goods, the labor productivity and other macroeconomic variables included in X_t . The monetary policy shocks, on the other hand, do not have contemporaneous effects on those variables. Under these assumptions and the ordering of variables, I can obtain the estimates of 1st, 2nd and 5th columns of matrix C, which are required to compute the structural responses of Y_t to the neutral technology, embodied technology, and the monetary policy shocks¹⁸.

¹⁸See Altig et al. (2005) and their Technical Appendix for more details.

Total changes - TFP shock

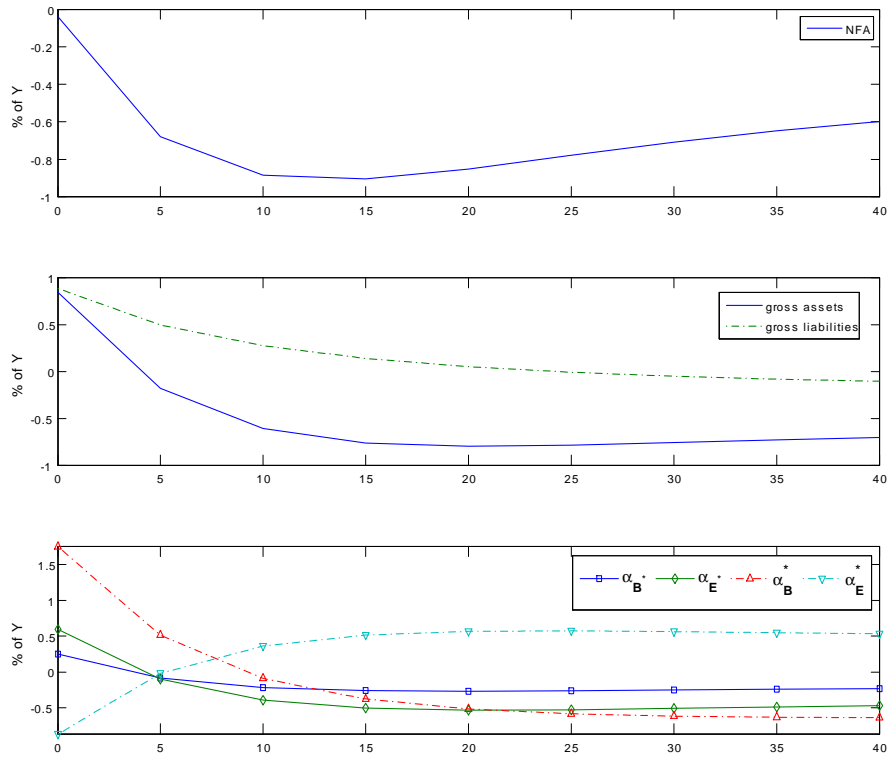


Figure 2-2: Impulse responses of external positions - Home TFP shock

Total changes - Investment specific shock

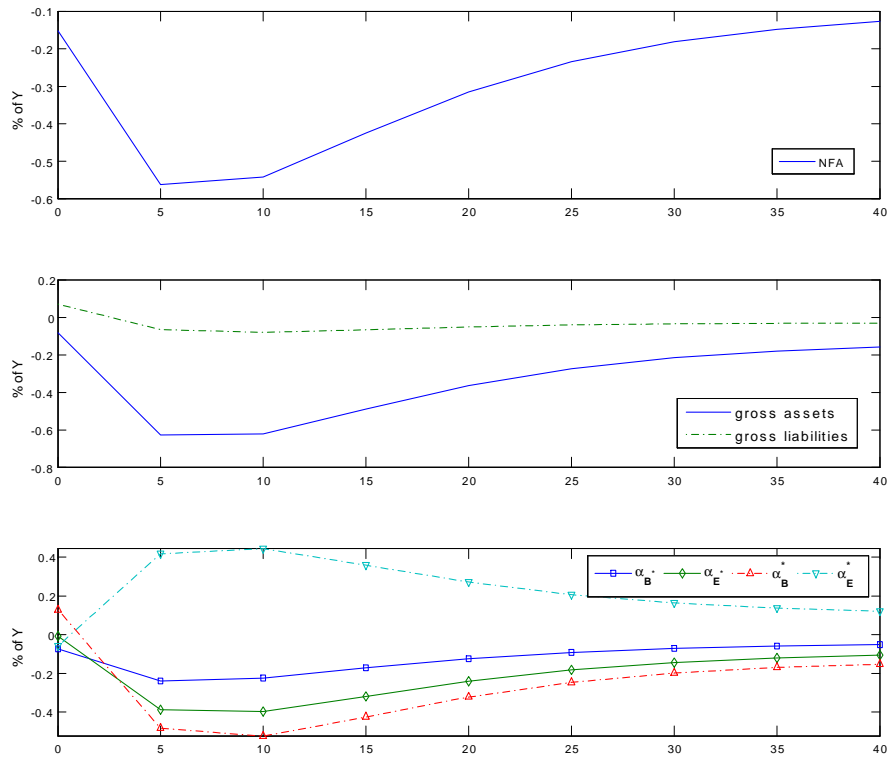


Figure 2-3: Impulse responses of external positions - Home investment specific shock

Total changes - Monetary policy shock

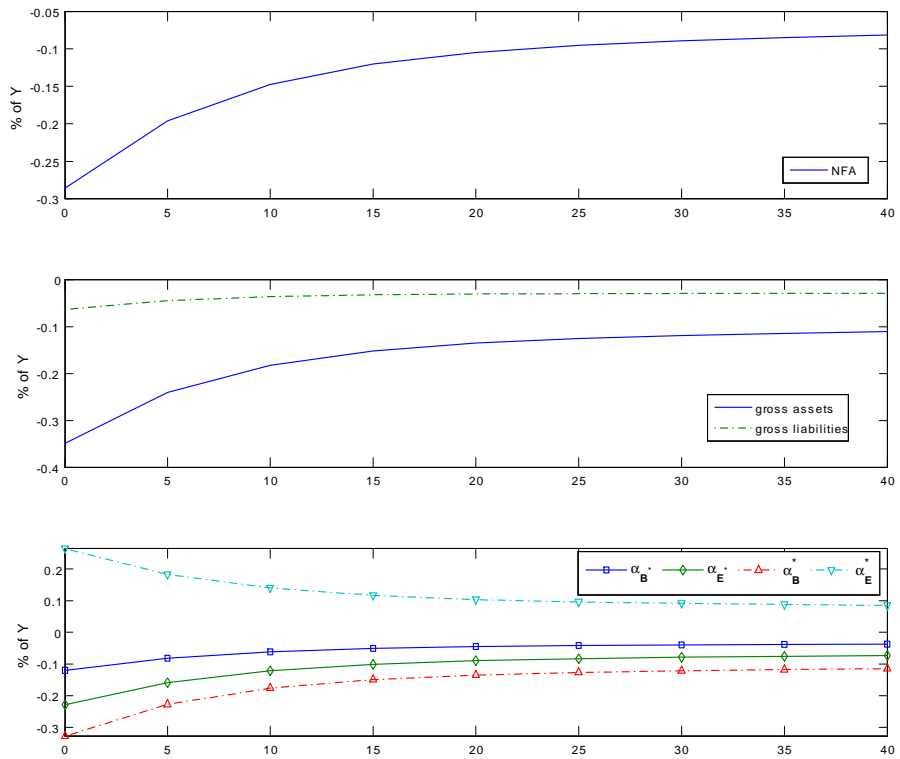


Figure 2-4: Impulse responses of external positions - Home monetary policy shock

Empirical impulse reponses - NFA/GDP ratio

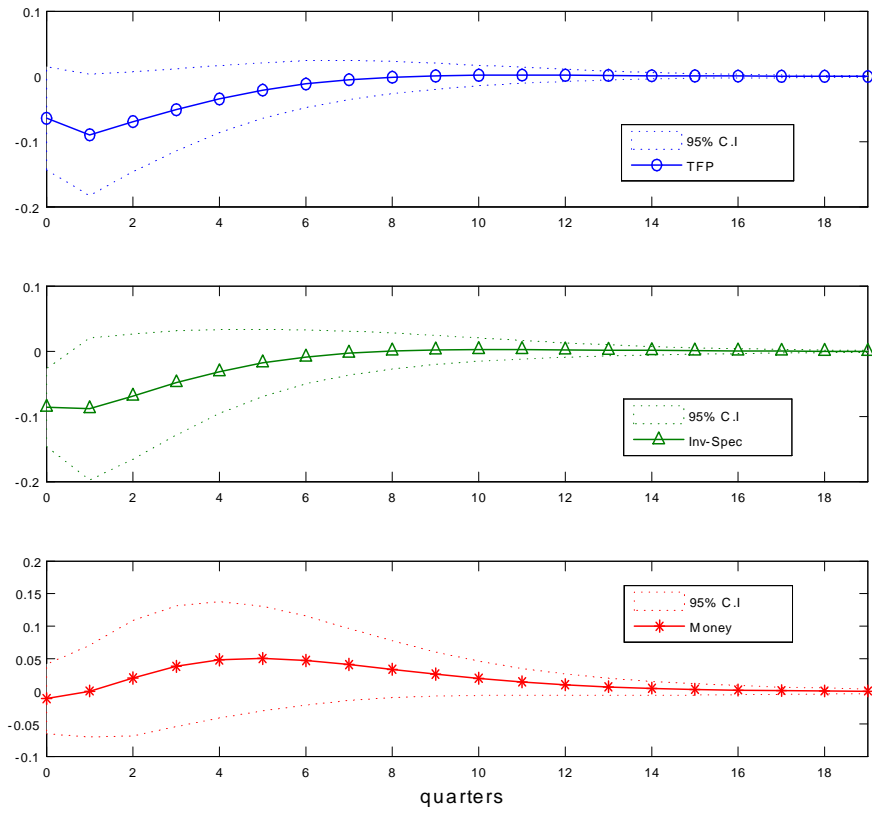


Figure 2-5: Empirical structural responses - US Net Foreign Assets Position

Volume effects - TFP shock

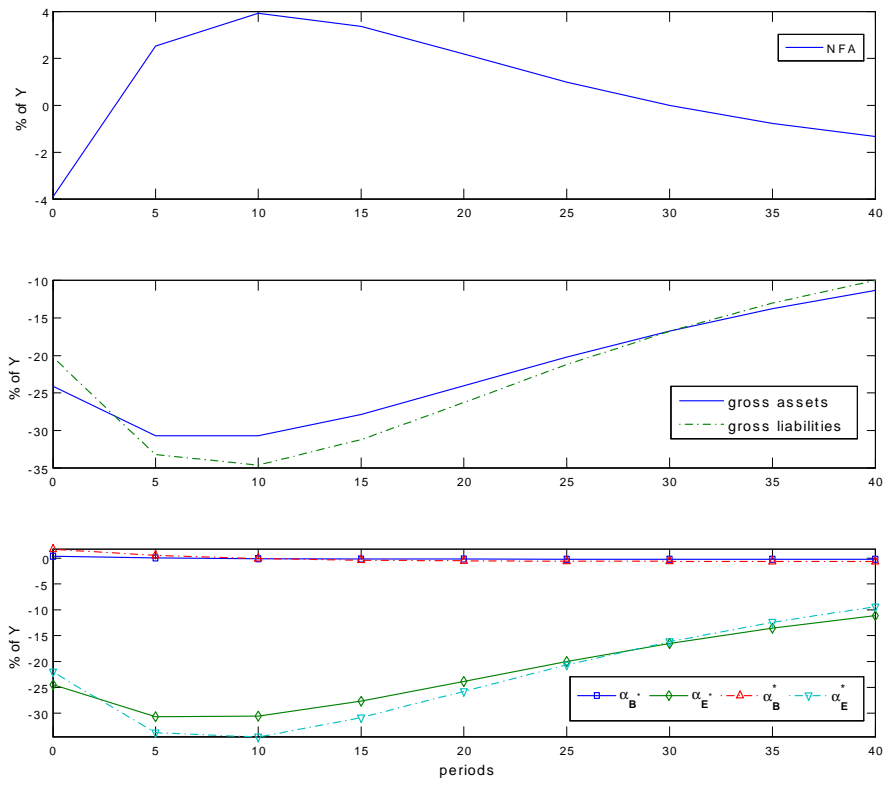


Figure 2-6: Volume effects - Home TFP shock

Valuation effects - TFP shock

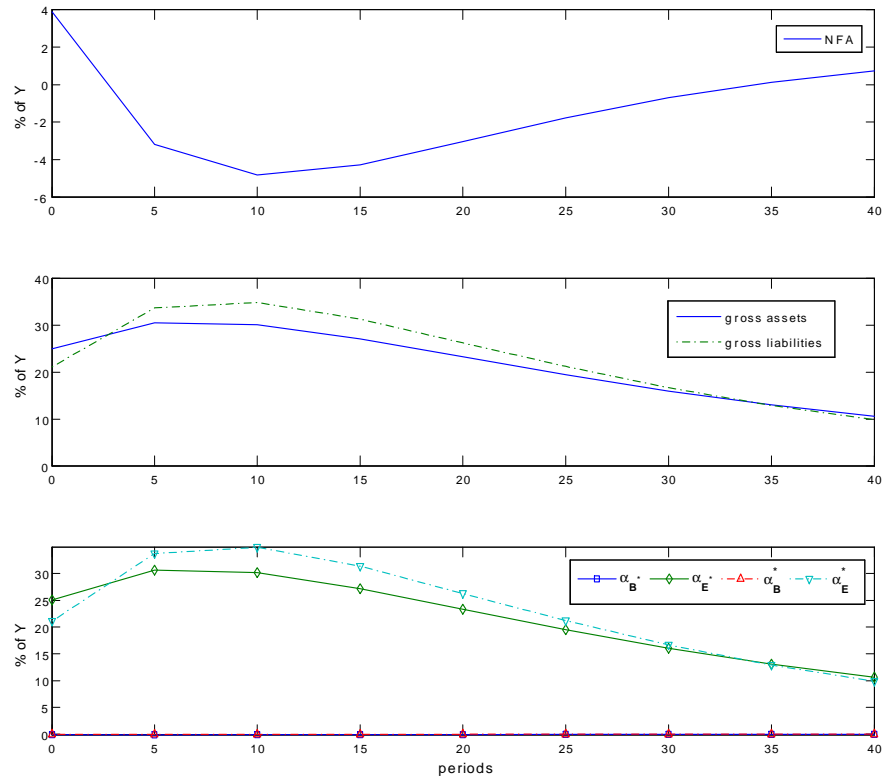


Figure 2-7: Valuation effects - Home TFP shock

Volume effects - Inv-specific shock

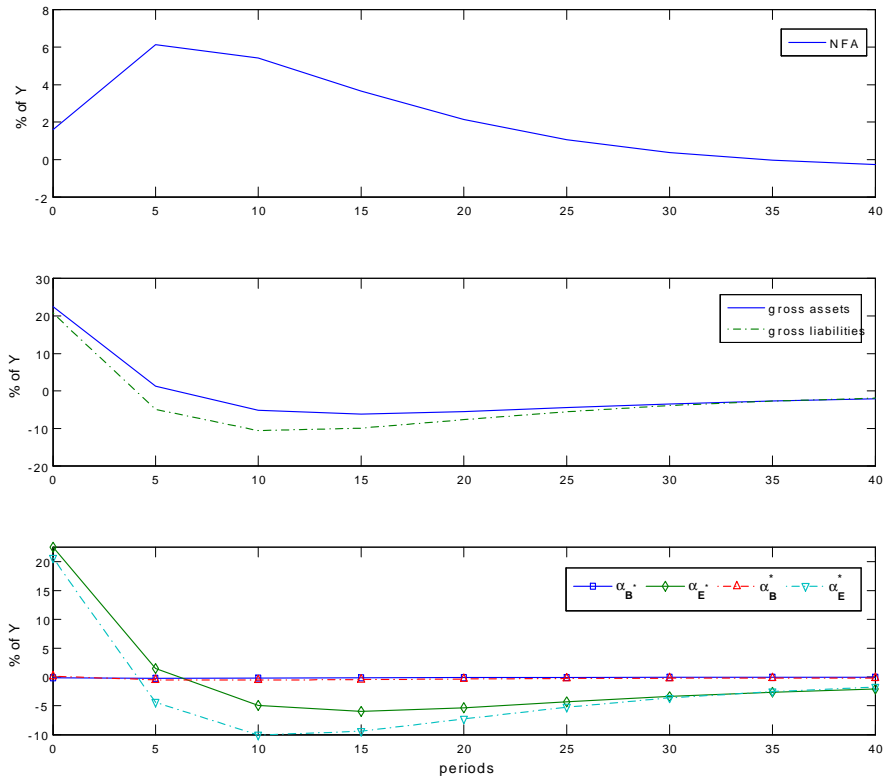


Figure 2-8: Volume effects - Home Investment-specific shock

Valuation effects - Inv-specific shock

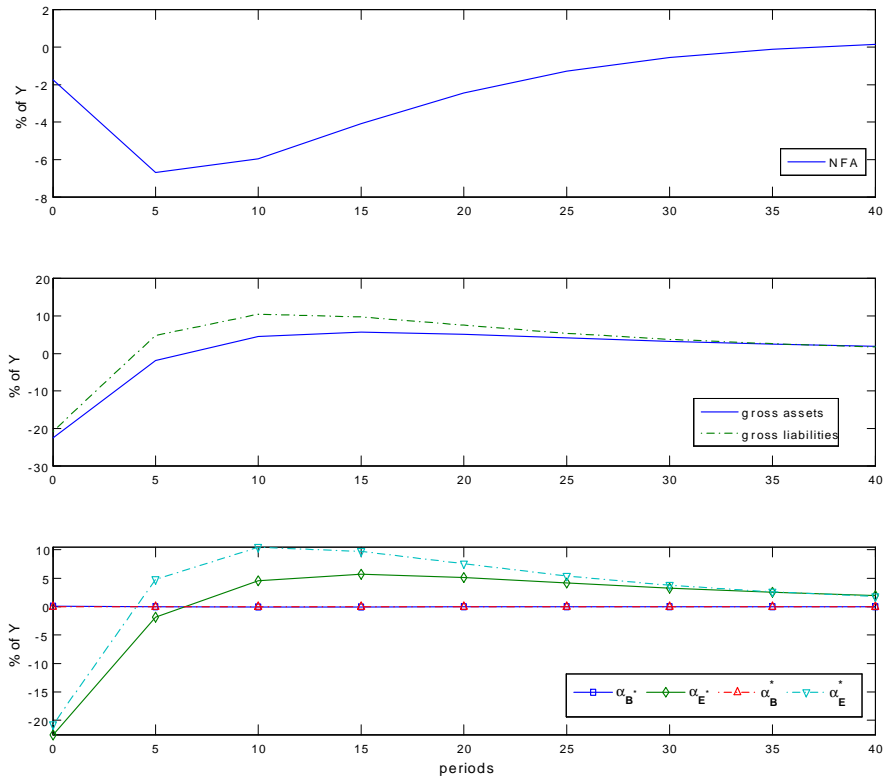


Figure 2-9: Valuation effects - Home Investment-specific shock

Volume effects - Monetary Policy shock

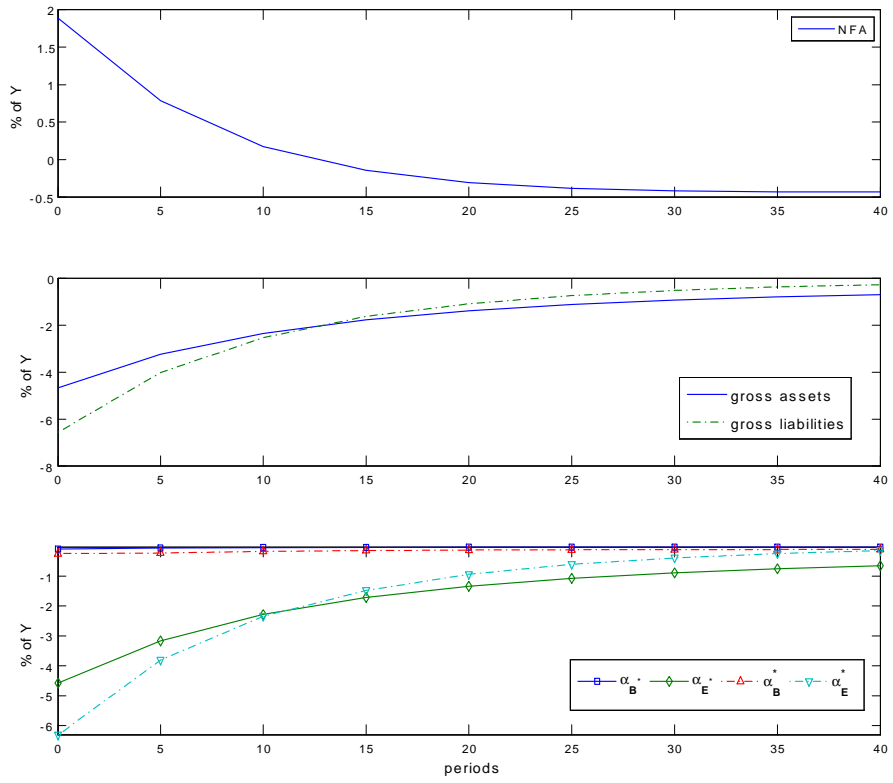


Figure 2-10: Volume effects - Home Monetary policy shock

Valuation effects - Monetary Policy shock

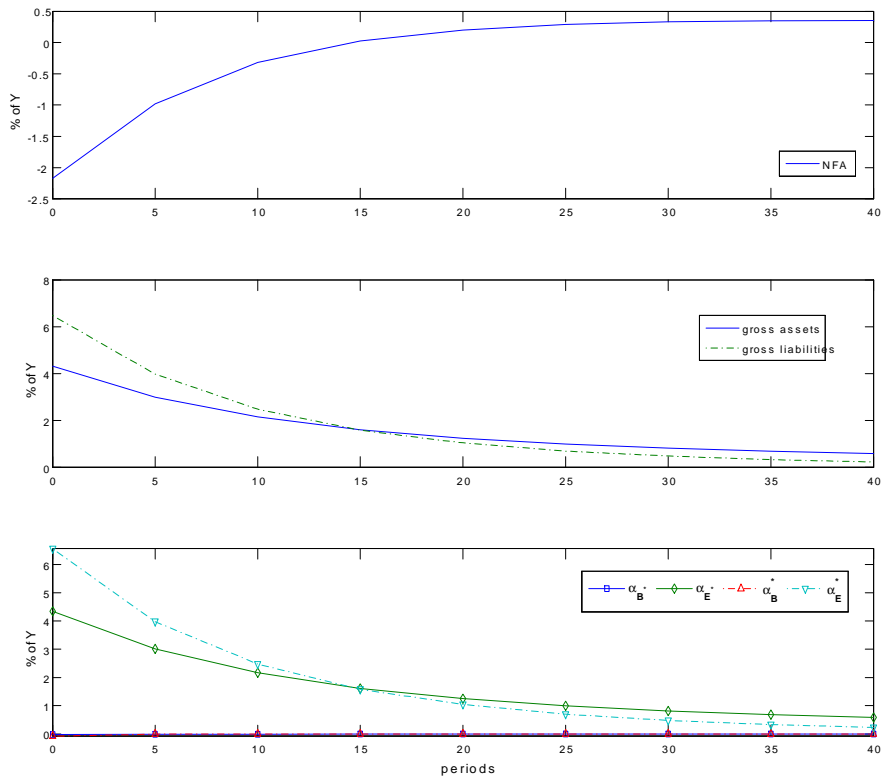


Figure 2-11: Valuation effects - Home Monetary policy shock

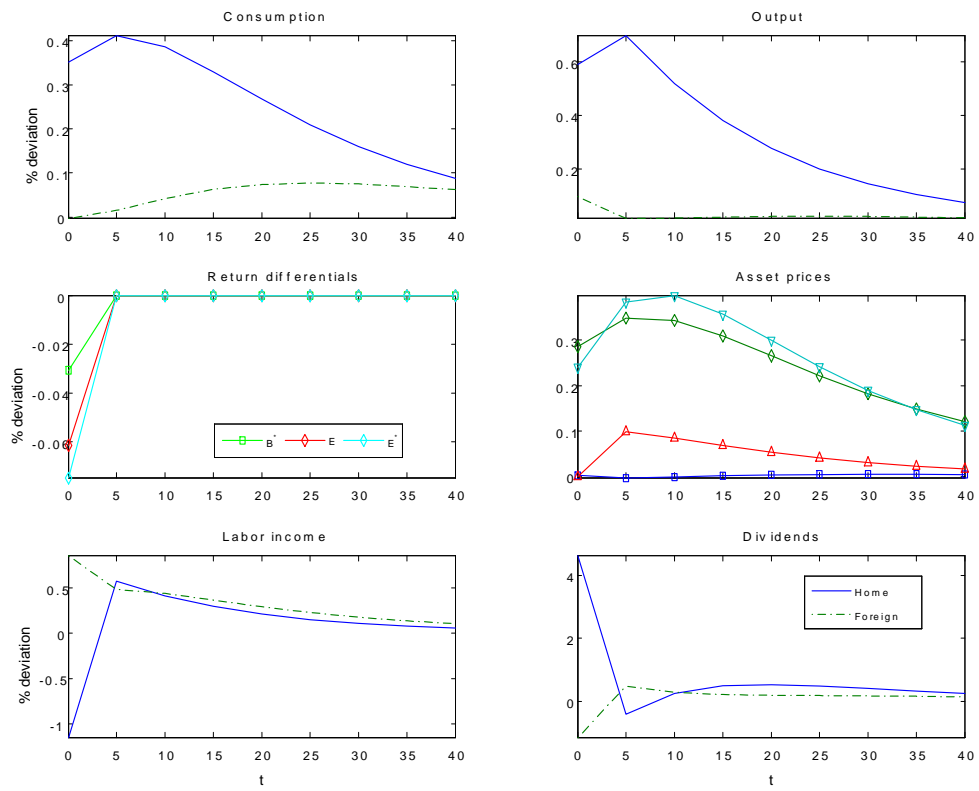


Figure 2-12: IRFs of selected variables to Home TFP shock

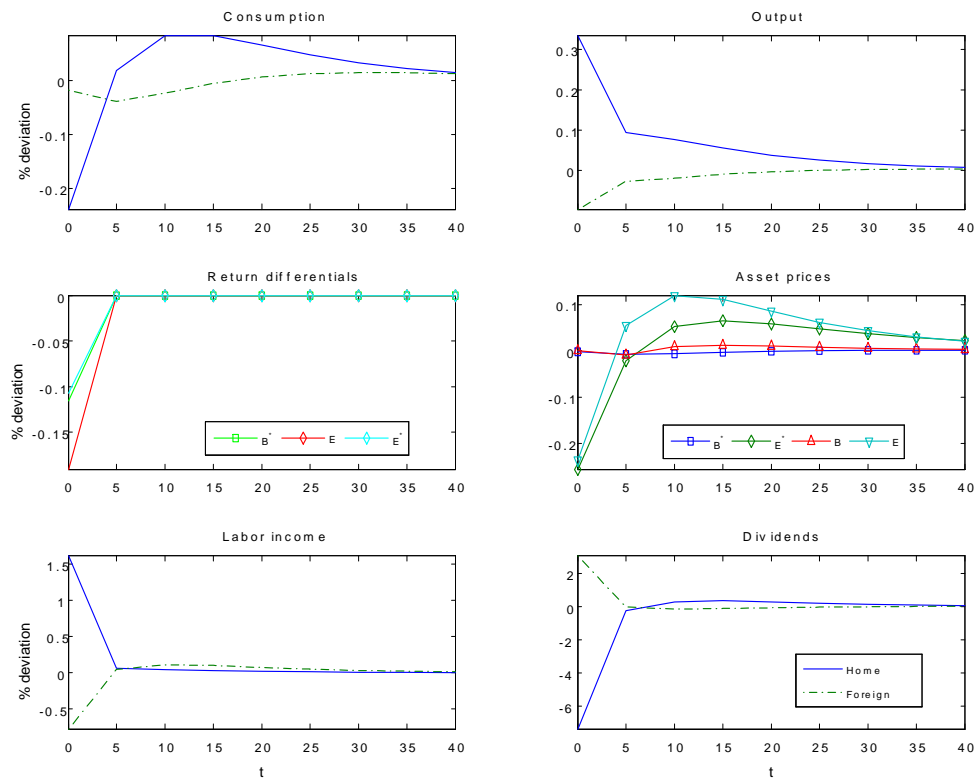


Figure 2-13: IRFs of selected variables to Home Embodied technology

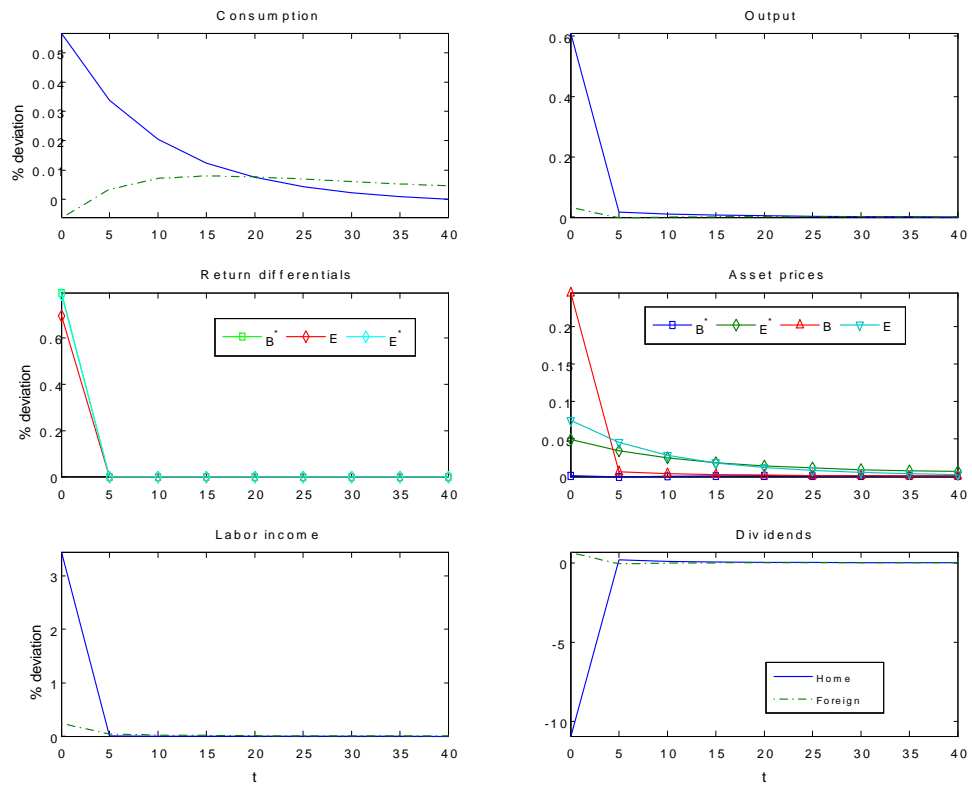


Figure 2-14: IRFs of selected variables to Home Monetary policy shock

Real Exchange Rate

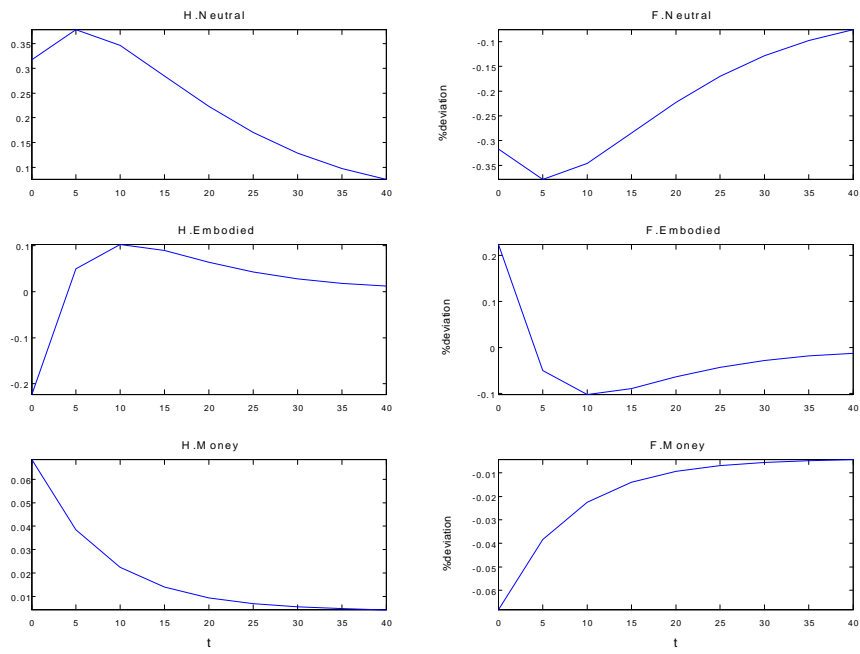


Figure 2-15: Real Exchange Rate

Net Exports

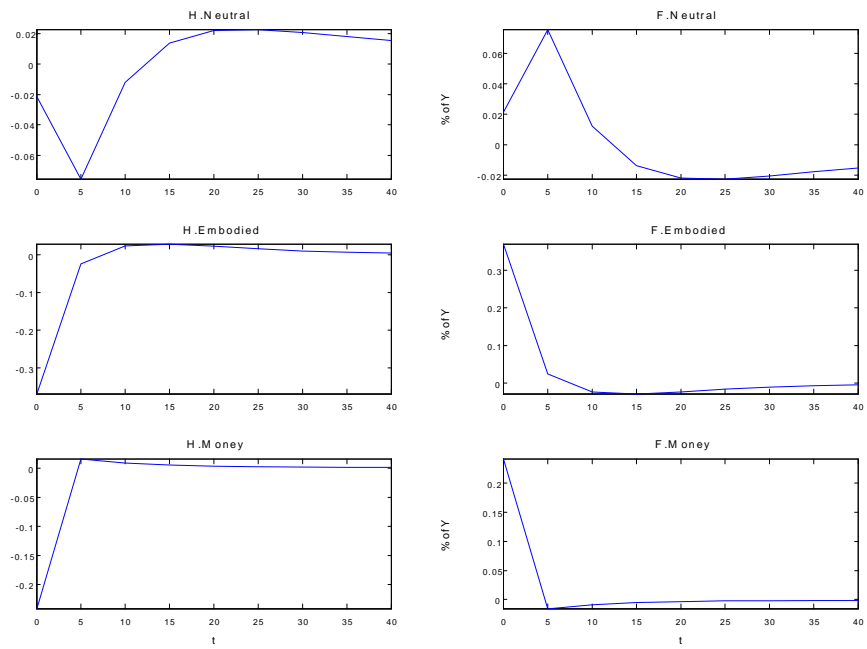


Figure 2-16: Net Exports

Chapter 3

International Portfolio Dynamics: Evidence from US markets

3.1 Introduction

Since the 1980s the US net foreign asset (NFA) position has persistently declined. From a net creditor in the early 1980s, the US has become a net debtor. The difference between the accumulated US gross external liabilities and gross external assets reaches almost (negative) 26% of its annual GDP at the end of year 2007¹. Moreover, the volatility of the NFA position has also increased significantly during this period. Figure 3-1 shows the changes of the US NFA position (expressed in percentages of nominal GDP) between 1960:Q1 and 2007:Q4.

To the best of my knowledge, this is the first paper to investigate the role of

¹Source: The Flow of Funds Accounts. Throughout this paper, I use financial data from the Flow of Funds Accounts, unless note otherwise. The result can be different from numbers calculated using the National Income and Payment Accounts (NIPA) due to different data sources and estimation methods. See Section 3.2.2 and Appendix 3.A for detailed description.

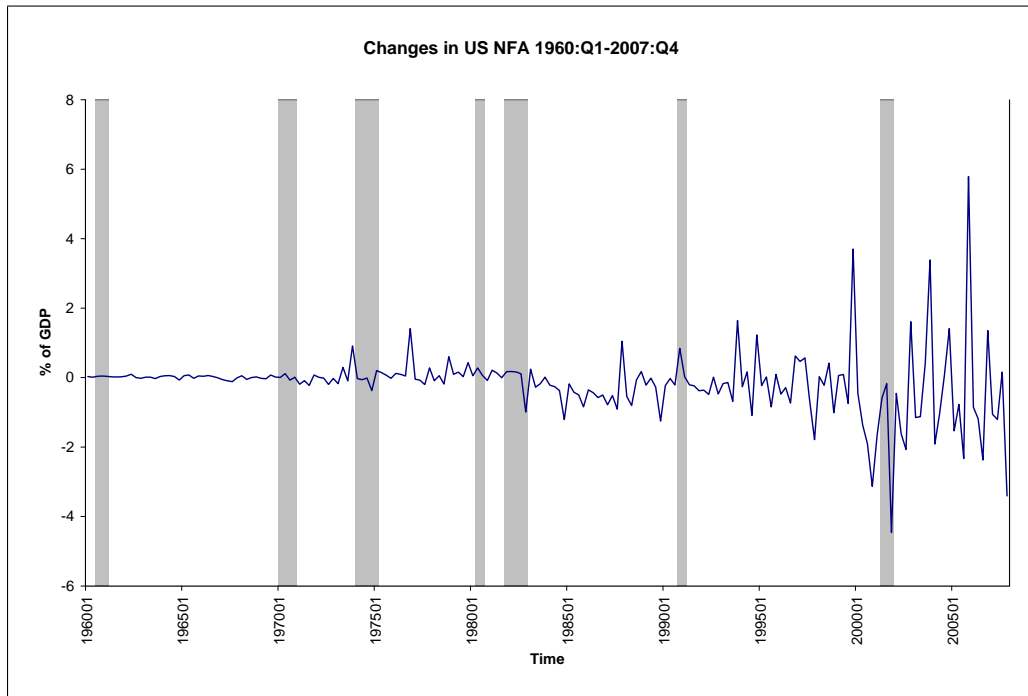


Figure 3-1: Changes in the US NFA position 1960:Q1 to 2007:Q4

structural economic shocks on the asset portfolio dynamics in the literature. In this paper, I focus on the role of domestic US factors as sources explaining the dynamics of the NFA position and asset portfolios. For that purpose, I estimate Vector Auto Regressions (VARs) using the US data. I extensively make use of financial assets data from the Flow of Funds Accounts. Data are available for the period from 1960:Q1 to 2007:Q4 but I choose the benchmark period for VAR estimation to be 1982:Q2 to 2007:Q4. There is a consensus in the macroeconomic literature that US monetary policy regime significantly changed since the beginning of the Volcker-Greenspan era. In addition, Fisher (2003, 2006) finds empirical evidence of a structural break in the US investment efficiency data series around this period. It is also believed that the international financial markets liberalization started around the same time. Nonetheless,

the early period of 1960:Q1 to 1982:Q1 and the full sample are also considered.

Following recent developments in the literature, I partially identify the VAR system and calculate impulse responses of variables in the VAR to three structural shocks: investment specific (embodied capital technology), TFP (neutral technology), and monetary policy shocks. Besides studying their effects on the US NFA position, I also investigate the role of these shocks on driving the international portfolio dynamics based on evidence from the US financial markets. I consider four financial asset variables representing the cross-country gross holdings of bonds and equities by US and foreign private investors respectively. Using these four variables, I define another variable that represents the net asset position between US private holdings of foreign bonds and equities and the foreign private holdings of US bonds and equities. This narrower definition of private sector net foreign asset holding is often studied in theoretical models as is the NFA position.

The important caveat to this US focused approach is that ignoring the international comovement between the US and foreign shocks and their transmission may bias the results. Bems, Dedola and Smets (2007) empirically study the US trade balance and argue that the direction of this bias is not clear. However, there are other important reasons to consider US factors only.

Standard deviations of US net asset acquisitions (US\$mil)				
	1977-1979	1980-1989	1990-1999	2000-2008
Europe	829	2,570	11,104	18,604
Asia	612	2,410	6,648	15,212
Latin America	72	533	6,872	4,902
Canada	233	468	1,783	3,124
Africa	64	63	245	732
Other	48	347	831	1,782

Table 3-1: Standard deviations of net acquisitions of bonds and equities by the US with respect to major trading regions (in US\$ millions).

Source: The US Department of the Treasury TIC database. Author's calculation.

First, the cumulative US net balances of financial asset acquisitions have been consistently negative with respect to each major trading region in the last several decades. As illustrated in Table 3-1, the standard deviations of these (quarterly) balances have also increased dramatically over time. This suggests that there must have been a common source, which could have come from the US markets. Second, the identification of structural disturbances requires restrictions on the estimated coefficients of a multivariable VAR. By focusing only on US factors, I can reduce the size of the VARs as well as minimize the number of assumptions needed to identify the economic shocks. In addition, Altig, Christiano, Eichenbaum and Linde (2005) find that these three shocks can account for a large fraction of business cycle fluctuations in the US. Finally, Bui (2009) finds that these three structural shocks theoretically play important roles in determining international portfolio dynamics. It is therefore important and interesting to find empirical evidence from the available US data.

In this paper, I find that each of the three US structural shocks has economically and marginally statistically significant impacts on the US NFA position and international portfolio dynamics. The responses of the two NFA definitions to these shocks offer some interesting observations. While the empirical responses of the conventional measure of NFA to neutral technology and monetary policy shocks are consistent with theoretical predictions, its response to an investment specific shock is not. Robustness check indicates that an appropriate series of investment prices used to identify the structural investment specific shock can correct this unexpected result. More interestingly, the response of the narrower definition NFA^* to monetary policy shocks is counter-intuitive and robust across alternative VAR specifications and sample periods. Estimated impulse response functions show that the NFA^*/GDP ratio increases as a result of an expansionary monetary policy shock. Theoretical wisdom, on the contrary, expects the NFA position worsens. Theoretically, in response to an expansionary monetary policy, domestic output, investment and consumption increase relative to foreign country leading to a deterioration of current account. Domestic country has to borrow abroad to pay for its trade deficits, thus, its NFA position worsens.

Moreover, these three structural shocks can have impacts on cross-country private holdings (and trades) of bonds and equities. Although results are not always statistically significant, they provide informative implications of the structural shocks on the dynamics of international portfolio diversification since the liberalization. Variance decomposition analysis shows that these shocks together can explain up to 29% of the US NFA position fluctuations, and between 10% to 45% of variability in the international portfolio holdings. These shocks account for smaller fractions of fluc-

tuations of asset trades (around 9% to 20%). Interestingly, I also find that the two technology shocks explain a larger fraction of movements in bonds while monetary policy shocks have stronger effects on the volatility of equity holdings. Furthermore, the three shocks account for larger fractions of volatility of US holdings of foreign assets than those of foreign holdings of US assets.

The rest of this paper is organized as follows. The following section describes the identification scheme and specification of the VARs and data sources. Section 3 presents results from the VAR estimation and analyzes the effects of structural shocks on asset portfolio dynamics. Finally, section 4 concludes the paper.

3.2 Structural VAR: Identification and specification

A VAR is a convenient device for studying the first and second moments of data. Generally, a (reduced-form) VAR for a k -dimensional vector of variables, Y_t , is given by:

$$Y_t = B_0 + B_1 Y_{t-1} + \dots + B_q Y_{t-q} + u_t, \quad E[u_t u_t'] = \Sigma$$

Here, q is a nonnegative integer which defines how many lags of endogenous variables are needed in the estimation. In all of the VARs estimated in this paper, I assume the number of lags $q = 4$. The one-step ahead forecast error u_t is assumed to be uncorrelated with all lagged variables date $t - 1$ and earlier. Consistent estimates of the polynomial $B(L)$ can be obtained by using Ordinary Least Squares. Even if we know the matrices B_i 's and u_t , it still would not be possible to compute the dynamic response functions of elements of Y_t to the fundamental shocks in the economy. The

basic reason is that each element of u_t reflects a combined effect of all the fundamental economic shocks. There is no reason to presume that any element of u_t corresponds to a particular economic shock. Identifying assumptions are needed to unravel the structural shocks from the reduced form estimates.

The innovation vector e_t represents the uncorrelated fundamental economic shocks. Suppose that the fundamental disturbances are related to the forecast errors u_t via the relationship:

$$u_t = Ce_t \quad \text{and} \quad CC' = \Sigma$$

The structural form representation of the VAR system is:

$$A_0Y_t = A(L)Y_{t-1} + e_t$$

The parameters of the reduced form are related to those of the structural form by:

$$C = A_0^{-1}, \quad B(L) = A_0^{-1}A(L)$$

The identification of the VAR structural shocks is essentially to identify elements of matrix C .

3.2.1 Identification and estimation procedure

There are two common identification approaches used in the structural VAR literature: the long-run restriction and the recursive (short-run) structure. Although, both approaches are subject to various criticisms, they provide very useful techniques

for economists to empirically investigate data and answer many questions in the international macroeconomic literature.

The long-run approach is often used to identify technology shocks. It was first introduced by Blanchard and Quah (1989), and has been used extensively to examine effects of technology shocks on the business cycle properties of macroeconomic variables. It puts restrictions on the coefficients of the long-run moving average coefficient matrix. This approach is appealing to economists because the long-run restrictions are often derived from the steady state properties of a theoretical model. This method is used extensively in the literature to estimate the effects of labor productivity and investment-specific technology shocks on various macroeconomic variables. For example, Galí (1999, 2004), Galí and Rabanal (2004), Christiano, Eichenbaum and Vigfusson (2004) analyze the structural responses of macroeconomic variables to labor productivity shocks. Greenwood, Hercowitz and Krusell (1997) find that investment-specific (embodied) technology shocks can account for a major fraction of business cycle fluctuations. Fisher (2003, 2006) jointly identifies embodied and neutral technology shocks. He finds that together these shock can explain a large portion of the US business cycle fluctuations, and most of those effects are contributed by embodied technology shocks. Altig, Christiano, Eichenbaum and Linde (2005) estimate a larger VAR framework and find similar conclusions.

The second approach, the short-run recursive structure, is more often used to identify policy shocks such as monetary and/or fiscal policy innovations. It has been widely used in the literature to study effects of an economic shock to the monetary policy stance conducted by central banks. This approach relies on a key assumption that a monetary policy innovation does not have contemporaneous effects on the

variables in the information set, from which, the central bank decides its targeted policy stance. Technically, the recursive structure directly put restrictions on the (inverse of) matrix C . This approach has been used by Bernanke and Blinder (1992), Bernanke and Mihov (1995), Strongin (1995), Christiano, Eichenbaum and Evans (henceforth, CEE) (1999, 2005), and many others to examine the qualitative and quantitative effects of innovations to a monetary policy stance. In addition, Bems et al. (2007) use the short-run restrictions to identify fiscal and monetary policy shocks together.

These two approaches can be combined to jointly identify technology and monetary policy shocks. Galí (1992) uses a combination of short-run and long-run restrictions to study the fit of the IS-LM model using postwar US data. Altig et al. (2005) combine the two approaches to construct and estimate a dynamic stochastic general equilibrium model which resolves the micro-macro conflict over the duration of nominal rigidity. Bems et al. (2007) also use a combination of identification approaches to study the role of US technology developments and policies on the deterioration of its current account and trade balance during last two decades.

A key criticism of either approach is that it may require too many assumptions to fully identify the VAR system, especially in a large VAR with multiple variables. The main caveat is that many of those assumptions can be “atheoretical”. However, it is possible to draw structural inference from an identified subset of structural shocks, in which we are interested. In other words, a VAR system can be “partially identified”. Keating (1996, 2002) provides theoretical arguments to support structural inferences of partially identified VAR systems using either the short-run or the long-run approach provided that the restricting assumption is satisfied. Furthermore, Altig et al. (2005)

show that a VAR system can also be partially identified by using a combination of long-run and short-run restrictions.

In this paper, I closely follow Altig et al. (2005) to combine the short-run and long-run restrictions to partially identify a VAR system and draw structural impulse responses of the US net foreign asset position and international portfolios to three economic shocks: the neutral technology, the embodied technology and the monetary policy shocks.

$$Y_t = \begin{bmatrix} \Delta \log pinv_t \\ \Delta \log z_t \\ X_{t(4 \times 1)} \\ ffr_t \\ \Delta FA_t / GDP_t \end{bmatrix}_{8 \times 1}$$

Throughout this paper, all VARs include 8 variables. The variables are ordered to comply with the estimation procedure and the identification assumptions. First, the relative price of investment is included in order to identify the embodied technology shock. Second, non-farm business sector labor productivity is used to identify the TFP shock, z_t . Third, the monetary policy stance is captured by the federal funds rate, ffr_t . In addition to the three variables that are necessary to identify the three shocks, X_t includes the growth rate of real private consumption and real private investment (which together form domestic private absorption) and the inflation in the GDP deflator. Additionally, X_t includes the (first difference) non-farm business hours worked. These macroeconomic variables form the information set which is observed by the Fed in deciding the targeted policy rate. The final variable, FA_t , represents

financial assets. In the benchmark specification, this is the NFA position. Alternatively, this variable can be a sub-component of the NFA such as gross external assets, gross external liabilities, or gross holdings of bonds and equities (domestic and foreign). In particular, I focus on four variables: US gross holdings of foreign bonds and equities, and foreign holdings of US bonds and equities. The estimation requires that the financial data series are stationary; hence, they are entered in the first difference and normalized by the US nominal GDP.

To identify the shocks to technology, I follow Fisher (2003, 2006) and Altig et al. (2005) and assume that innovations to technology (both neutral and investment-specific) are the only shocks that affect the levels of technology in the long run. In addition, the investment-specific technology shocks are assumed as the only shocks that affect the relative price of investment in the long run. The two long run restrictions imply that the long run responses of the above system satisfy:

$$R \equiv [I - B(1)]^{-1}C = \begin{bmatrix} r_{p1} & 0 & 0_{1 \times 6} \\ r_{z1} & r_{z2} & 0_{1 \times 6} \\ R_{Z,1} & R_{Z,1} & R_{Z,.} \\ 6 \times 1 & 6 \times 1 & 6 \times 6 \end{bmatrix}$$

where Z denotes the vector including the non-technology variables in the VAR. The 0's reflect the long run restriction.

In order to identify monetary policy shocks, I use the recursive approach of CEE (1999) which assumes that policy makers set the interest rate so that the following rule is satisfied:

$$f r_t = f(\Omega_t) + \omega e_{M,t}$$

where $e_{M,t}$ is the structural monetary policy shock and ω is a positive coefficient. This is interpreted as a reduced form Taylor rule, which is often studied in theoretical papers. The short-run recursive structure assume that f is a linear function; the information set Ω_t contains lagged values of variables in Y_t and the only date t variables in Ω_t are the two technology and macroeconomic variables $\{pinv_t, z_t, X_t\}$. The recursive assumption allows that the 7th column of the matrix C can be recovered from the Choleski factorization of the covariance-variance matrix Σ up to a particular transformation.

Altig et al. (2005) extend the estimation procedure, developed by Sharpiro and Watson (1988) and used by Fisher (2003, 2006), to accommodate the short-run recursive structure to identify monetary policy shocks together with the two technology shocks. According to this procedure, the corresponding 1st, 2nd, and 7th rows of matrix C are identified, hence, there is enough information to calculate structural impulse responses of variables in Y_t to the three fundamental shocks. I use and modify the Matlab package provided by Altig et al. (2005) to estimate VARs in this paper². For more details, see Altig et al. (2005) and the accompanying Technical Appendix.

Macroeconomic data used in this paper are quarterly and seasonally adjusted at annual rates. Data are taken from the appropriate series of the National Income and Product Accounts Section 1, the Federal Reserve Bank at St. Louis FRED@ database and the Bureau of Labor Statistics database. The benchmark period is 1982:Q2-2007:Q4. To fully understand the US net foreign asset position and portfolio dynamics, it is important to focus on the period when the international markets in

²Matlab code is available upon request.

goods, services and financial markets are being liberalized. In addition, it is widely accepted in the literature that there is a change in the conduct of monetary policy associated with the Volcker-Greenspan era. Galí, López-Salido and Vallés (2003) find evidence that the change in monetary policy regime has influenced both the effects of neutral technology shocks and the effects of monetary policy itself on the US economy. Furthermore, Fisher (2006) finds a structural break in the relative price of investment series around 1982. For these reasons, I focus on the period 1982:Q2-2007:Q4 in the analysis.

3.2.2 The Flow of Funds Accounts financial data

For the financial data, I make extensive use of data from the Flow of Funds accounts (FOFA). The FOFA provide data on holdings (and trading flows) of financial assets by different sectors including government and private, for the US and the Rest of the World (ROW). The National Income and Product Accounts (NIPA) show non-financial accounts and the FOFA feature financial accounts; together they provide a comprehensive picture of the macroeconomic-financial linkage. While the concepts in both accounts are the same, differing data sources and estimation methods employed cause the results to differ.

I specifically pay attention to the Table F.107: The Rest of the World. This table provides data as foreigners' financial claims on US residents and liabilities to US residents³. The difference between the foreigners' holdings of financial assets and liabilities is the net US asset held by the ROW, which is exactly the negative of the US net financial asset holding at the end of each quarter. This measure of net

³Detailed description of data series are available in Appendix 3.A. I perform different unit root tests for the financial data series. Results are available upon request.

holding is different from the NIPA measure of the US NFA position due to different estimation methods. The FOFA however feature more detailed financially related data. In this paper, I consider the FOFA measure of net financial asset holding as it is the US NFA position. This broad definition of the NFA position consists of both official (government) and private sector holdings of various types of financial assets.

In order to compare empirical responses of portfolio holdings to theoretical predictions, I denote four variables HBF , HSF , FBH , and FSH , which represent the cross-country private sector holdings of bonds and equities, US and the ROW. The HBF variable includes US private holdings of foreign bonds and commercial papers. HSF consists of foreign corporate equities and US foreign direct investment to the rest of the world. The ROW private holding of US bonds (FBH) includes the US Treasury securities, state and local, municipal bonds and commercial papers while FSH consists of foreign private holdings of US equities and foreign direct investment into US.

By considering only private sector holdings of bonds and equities, I can compare the empirical responses with the predictions of theoretical models which often assume only households hold and trade financial assets. This assumption is not the case in the data with the conventional and broader measure of the NFA position. The FOFA table F.107 contains data on foreign official and private holdings of US bonds and stocks. Figure 3-2 shows the foreign official holdings of US bonds, expressed in percentage of the total foreign holdings of US assets over the 1960:Q1-2007:Q4 period. After a huge surge at the beginning of 1970s, the share of foreign official holdings of US assets has steadily declined until 2001. The recent trend of the increasing foreign official holding is due to the increasing acquisition of the US assets by governments of China, the

Gulf oil-exporters, and other newly industrialized countries. On the other hand, the US federal and local government only hold a small amount of foreign assets in their balance sheet (as shown in the FOFA tables F.105 and F.106).

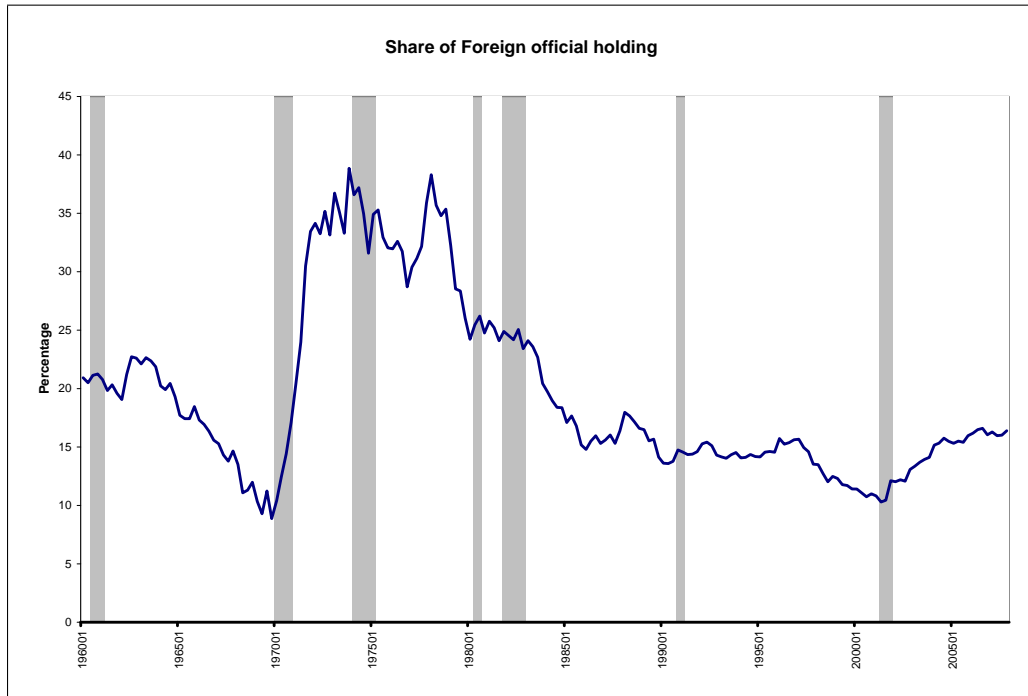


Figure 3-2: Shares of foreign official holdings of US assets (Author's calculation)

Moreover, the menu of available financial assets includes more than just bonds and equities. For instance, bank and government loans, time deposits, trade receivables, and money market and mutual fund shares are included. These types of assets are not explicitly modeled in theoretical frameworks but they have become more relevant in the international financial markets in recent years. Figure 3-3 shows the shares of other assets held by the US and ROW investors respectively. These shares follow different patterns but they are both very volatile during the period between 1960:Q1 and 2007:Q4. The fraction of "other" assets in US gross external assets consistently

declined in the 1960s and hit the trough in the early 1970s before increasing and reaching another peak in the early 1980s. That pattern was repeated between the 1980s and around the end of 2001. It has since decreased to around 20% of total value of US external assets at the end of 2007. On the other hand, the share of other assets in US gross external liabilities moves quite differently. It decreased steadily from the early 1970s and twice reached the bottom around 10% of total US liabilities in the mid 1970s and the early part of 1980s. Since then, foreign holding of US other assets has fluctuated between 20% to 30% of US external liabilities. At the end of 2007, foreign holding of "other" types of US assets is around 25% of US gross external liabilities.

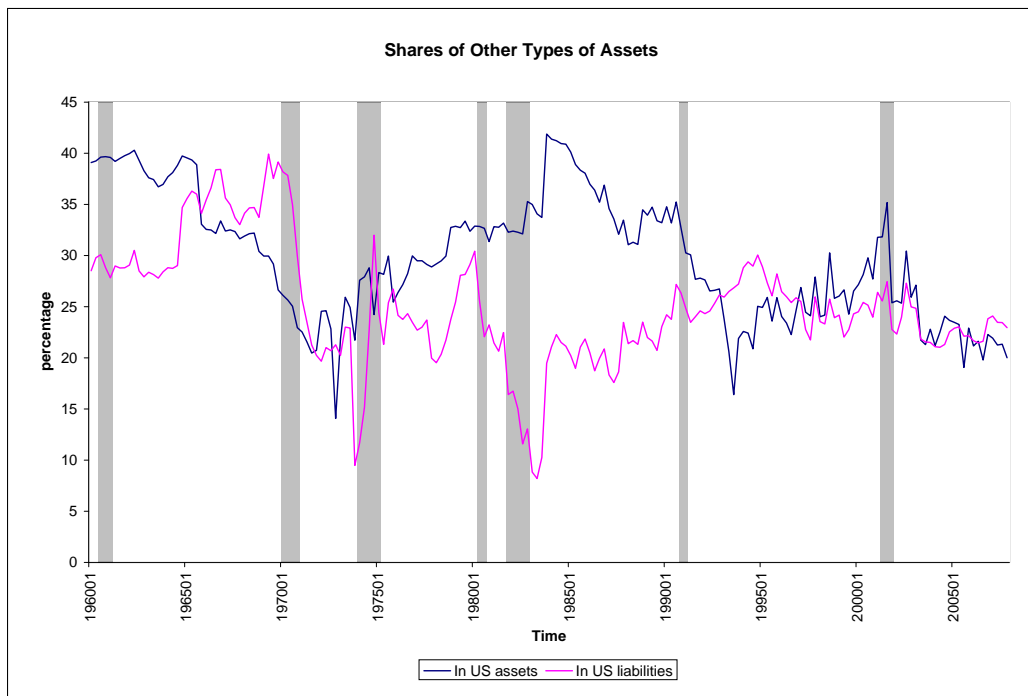


Figure 3-3: Shares of Other assets in US (private holdings of) asset and liabilities

I exclude official holdings and other types of assets discussed above from the

NFA position in order to consider the theoretical models' definition of the net foreign asset position, which includes only equities and bonds. I define a new variable which represents the difference between *US private holdings of foreign bonds and equities* and *foreign private holdings of US bonds and equities ONLY*. This narrower definition of the NFA position is denoted as NFA^* . By definition,

$$NFA_t^* = (HBF_t + HSF_t) - (FBH_t + FSH_t)$$

Each of these financial variables, in turn, is included in the VAR to investigate the effects of US structural shocks on the dynamics of international portfolio holdings during the liberalization period of 1982:Q2-2007:Q4. Furthermore, I also investigate responses of those variables during the earlier period from 1960:Q1 to 1982:Q1. If the market liberalization has any significant effects on the dynamics of international asset holdings, the differences between these responses will show.

3.3 Results

This section discusses the implications of the identified structural shocks on variables included in the 8-variable VAR system. I focus on analyzing their implications on the financial variables in order to investigate the role of the three structural shocks on the NFA position and portfolio dynamics. The impulse response functions and variance decomposition are estimated using the Altig et al. (2005) procedure. The one-standard-deviation confidence bands are calculated using the Monte-Carlo simulation from the estimated coefficients and structural shocks with 100 repetitions.

3.3.1 Macroeconomic variables

Many papers have studied the effects of these shocks on macroeconomic variables such as output, productivity, employment, consumption, investment and others. The following discussion summarizes some of those studies.

Technology shocks

Earlier literature focuses on the effects of neutral technology (or total factor productivity) shocks on employment, output, consumption and investment. For instance, Galí (1999), Basu, Fernald and Kimball (1999), Galí and Rabanal (2004), Christiano et al. (2004). Moreover, Galí, López-Salido and Vallés (2003) find evidence that the Federal Reserve systematically respond to neutral technology shocks. The Fed's responses are varied significantly across different periods. Francis, Owyang and Theodorou (2005) also find a relationship between the volatility of capital investment, the type of monetary rule, and the response to technology shocks in countries of the G-7.

Recent studies consider technological changes specific to new investment goods. Greenwood, Hercowitz and Krusell (2000) quantitatively find that the investment-specific technological change accounts for a large fraction of US postwar business cycle variability. Fisher (2003, 2006) jointly identifies a combination of two technology shocks and finds that they can empirically account for a major fraction of hours and output's variability. The majority of these effects are driven by the investment-specific shocks. De Bock (2007) quantitatively evaluates and suggests a limited role of investment-specific shock in an RBC model with labor market frictions. Bems et al. (2007) find that both shocks lead to a deterioration of the trade balance. Altig et al.

(2005) find that the embodied technology shock leads to marginally significant and smaller increases in output, consumption, investment, and hours worked compared to the effects of the neutral technology disturbance.

Monetary Policy shocks

There is another large volume of empirical literature extensively studies the effects of monetary policy shocks on the fluctuations of the macro variables. Bernanke and Blinder (1992) and Bernanke and Mihov (1995) argue that the federal funds rate is a good indicator of monetary policy actions, thus the interest rate on Federal funds provide a consistent forecast about future movements of real macro variables. CEE (1996, 1999) study the effects of innovations to the US monetary policy stances on different measures of real economic activity and the borrowing and lending activities of different agents in the economy. Moreover, CEE (1999) conclude that the dynamic responses of non-price variables to monetary policy shocks are robust with or without the current and lagged values of commodity prices. CEE (2005) and Altig et al. (2005) observe a hump-shaped pattern in the responses in consumption, investment, output, employment, and capital utilization rate to an expansionary monetary policy shock.

Given the existing empirical results and analyses of the effects of technology and monetary policy shocks on the macroeconomic variables, I do not focus on explaining the responses of the macro variables to the three shocks in this paper. Impulse responses of macro variables to a one-standard deviation to each shock are shown in Appendix 3.B. Those responses are consistent with the findings of other work in the literature. In the following discussions, I focus exclusively on the responses of the

NFA position and the international asset portfolio to the three structural shocks.

3.3.2 International portfolio responses: Evidence from US markets

This subsection presents evidence on the impact of the three structural shocks on the financial variables. I study the impulse responses and variance decomposition of the 6 variables: the two definitions of the NFA position (NFA and NFA^*), and the portfolio holdings: FBH , FSH , HBF , and HSF . The following figures report point estimates of the impulse response functions of the financial variables with a one-standard-deviation confidence band⁴.

Bui (2009) studies the impulse responses of the NFA position and international asset holdings in a dynamic stochastic general equilibrium New Open Economy Macroeconomics framework, which features the same three types of shock. Intuitively, domestic output, investment and consumption increase in response to domestic positive technology or expansionary monetary policy shocks. Domestic imports increases relatively more than its exports, which leads to a deterioration of the trade balance. In order to pay for extra imports, domestic country borrows from abroad, hence, its NFA position declines. The magnitudes of those theoretically calibrated responses are considerably large in that model. The NFA position studied in that model is similar to the narrower measure - NFA^* - defined in this paper.

Figure 3-4 shows the impulse responses of the financial variables to a one-standard-deviation embodied technology shock. Bui (2009) predicts that in response to a positive investment efficiency shock, the NFA position worsens. Empirically, it

⁴Recall that the financial variables are entered in the VAR as the first difference, $\Delta FA_t/GDP_t$. The impulse response functions of *levels* of the NFA position and asset holdings are *accumulated* impulse responses of the *flow* variables. For more details, see Altig et al. (2005) and their Technical Appendix.

shows the contrary. After the realization of a positive investment specific shock, the NFA/GDP ratio increases and peaks at 0.6% after 10 quarters. It stays positive for a long period after that. The ratio of the narrower definition, NFA^*/GDP , remains positive about 8 quarters before decreasing. After 5 years, it declines by almost 0.7%. Results for the four asset holding variables are presented in rows 2-3 of figure 3-4. In response to increased investment efficiency in US, foreign investors tend to hold less US bonds while increase their holding of US equities. On the other hand, US investors tend to decrease their holdings of foreign bonds and equities in the medium- to long-run as results of more efficient investment at home.

Impulse responses to a one-standard-deviation neutral technology (TFP) shock are shown in figure 3-5. As a result of an improved TFP shock, the US NFA/GDP ratio significantly declines upon impact and keeps declining after that. It drops by almost 0.4% after 5 years. On the other hand, the NFA^*/GDP ratio declines by 0.1 percent at the realization of shock, but tends to slightly increase in the long run. The responses of portfolio holdings suggest that US investors will eventually reallocate their wealth from foreign bonds into foreign equities while foreign investors responses are smaller and not stochastically significant. However, those responses may still indicate a trade-off between bonds and equities in response to an increase TFP.

Figure 3-6 shows the impulse responses of the financial variables to an expansionary monetary policy. These results provide some interesting observations. Upon impact, the NFA/GDP ratio declines. This decline is quite statistically significant. It then rises up and peaks at 0.3% about 10 quarters after shocks. Remarkably, the alternative definition NFA^* responds positively to an expansionary monetary policy. This finding is in contrast to theoretical wisdoms, which expect net capital inflows

(i.e., worsening *NFA* position) as a consequence of a domestic monetary expansion. The responses of portfolio holdings show that US (foreign) investors adjust their portfolios by exchanging foreign (US) bonds for foreign (US) equities. The magnitude of adjustments in equities is larger than that of bond holdings.

In short, there is empirical evidence of important roles of the three economic shocks on the international portfolio dynamics. Although not always conclusive, the responses still indicate some significant diversifying activities among US and foreign investors across types of financial assets. Cross-country bond holdings generally decrease in response to the three shocks while equity holdings show different responses depending on types of shocks affected. Moreover, the responses of the two *NFA* definitions to shocks are very counter-intuitive in some cases. Robustness test and more careful consideration of empirical data are required in order to confirm these results.

How much of the fluctuations in the *NFA* position and portfolio holdings over the period 1982:Q2-2007:Q4 can the three structural shocks account for? Table 3-2 gives the contribution of each of three shocks to the forecast variance of the financial asset variables over the horizons. There is evidence which indicates the markedly different impacts of the three shocks on *NFA* and *NFA**. While technology shocks explain more variability of *NFA*, monetary policy shock is more important to *NFA**. Overall, the three shocks account for 28.5% of variability in the *NFA*, which is 1.5 times more than their effects on the *NFA**. Noticeably, technology shocks account for more fluctuations in holdings of bonds while monetary shocks have stronger effects on equity holdings. These shocks together can explain from 10% of foreign holding of US equities variability to 45% of that of US holding of foreign bonds. US factors

have more explanatory power on US holdings of assets than on its foreign liabilities. Furthermore, the three shocks combined account for a relatively larger fraction of bond holding fluctuations compared to that of equity, for both the US and the rest of the world.

Variance Decomposition - Gross asset holdings					
	1	4	8	12	20
<i>Embodied technology shock</i>					
NFA	0.0	8.3	18.4	21.9	18.4
NFA*	0.9	2.0	1.9	1.7	11.0
FBH	0.1	4.5	6.9	10.8	19.9
FSH	1.7	0.8	1.3	1.7	1.4
HBF	0.0	0.1	1.6	6.5	15.9
HSF	2.1	0.8	0.4	0.5	8.9
<i>Neutral technology shock</i>					
NFA	2.6	1.6	3.2	4.3	7.2
NFA*	2.2	1.6	1.6	1.0	0.6
FBH	0.5	1.8	0.9	0.4	0.2
FSH	0.1	1.9	2.6	2.5	1.7
HBF	8.5	20.0	23.2	24.1	29.2
HSF	0.1	2.4	2.9	4.7	6.6
<i>Monetary policy shock</i>					
NFA	2.1	0.8	1.3	2.9	2.9
NFA*	0.0	4.1	8.8	10.9	7.4
FBH	0.0	0.5	0.8	0.7	0.9
FSH	0.9	0.7	1.2	3.5	7.0
HBF	0.0	0.1	0.2	0.3	0.2
HSF	1.3	5.3	9.6	15.5	18.8
<i>All shocks</i>					
NFA	4.7	10.7	22.9	29.1	28.5
NFA*	3.2	7.7	12.4	13.6	19.0
FBH	0.6	6.8	8.6	11.9	21.1
FSH	2.8	3.4	5.0	7.7	10.1
HBF	8.6	20.2	25.1	30.8	45.3
HSF	3.5	8.5	13.0	20.7	34.4

Table 3-2: Variance decomposition - Asset holdings

Figures 3-7 to 3-9 show the responses of quarterly financial asset flows into and out of US (expressed as percentage of the annualized nominal US GDP). There

are some interesting features of these figures. First, there is a negative correlation between the trading flows of bonds and equities in response to the technology and monetary policy shocks. Upon impact, US investors respond to shocks by moving from foreign (US) bonds into foreign (US) equities except in the case of US investors' responses to a US monetary expansion. Those responses are, however, fluctuating very quickly and are not statistically significant. Second, an expansionary monetary policy shock has considerably stronger impact on trades in equities than on those of bonds. Both US and foreign investors increase their cross country holdings of equities in response to a reduction in the US Fed Fund rate. Their responses are quite statistically significant with the magnitude reaching nearly 0.1% of US GDP. Overall, the responses of trading flows are not quite as significant as but more volatile than those of holding levels.

Table 3-3 shows the variance decomposition of the financial variables with respect to each of the three shocks over the business cycle frequencies. The three shocks account for smaller fractions of variability in trading flows of assets than in asset holdings. These shocks together can explain between 14.9% and 18.4% of fluctuations in the changes of the two NFA definitions. Technology shocks have stronger impacts on fluctuations of bond trades while monetary policy shocks seem to affect equities more. This finding is similar to the pattern observed in table 2 for portfolio holdings.

Variance Decomposition - Flows of asset trades					
	1	4	8	12	20
<i>Embodied technology shock</i>					
NFA	0.0	7.9	10.0	9.9	10.6
NFA*	0.9	1.0	1.5	3.4	6.8
FBH	0.1	9.9	11.3	13.2	15.7
FSH	1.7	2.1	3.6	3.6	3.9
HBF	0.0	0.6	2.6	5.2	7.2
HSF	2.1	3.2	4.1	5.2	9.5
<i>Neutral technology shock</i>					
NFA	2.6	3.1	4.7	4.9	4.8
NFA*	2.2	3.8	4.9	4.9	4.7
FBH	0.5	1.3	1.9	2.2	2.1
FSH	0.1	1.3	1.5	1.6	2.2
HBF	8.5	9.5	8.7	9.0	10.9
HSF	0.1	2.2	2.6	3.0	2.9
<i>Monetary policy shock</i>					
NFA	2.1	2.2	2.6	2.7	3.0
NFA*	0.0	3.2	3.2	3.1	3.5
FBH	0.0	0.8	0.8	0.8	1.0
FSH	0.9	0.9	1.2	2.2	2.4
HBF	0.0	0.5	1.1	1.3	1.5
HSF	1.3	3.0	3.6	4.5	4.6
<i>All shocks</i>					
NFA	4.7	13.3	17.4	17.6	18.4
NFA*	3.2	8.0	9.6	11.5	14.9
FBH	0.6	12.0	14.0	16.2	18.8
FSH	2.8	4.3	6.4	7.4	8.6
HBF	8.6	10.6	12.4	15.5	19.6
HSF	3.5	8.4	10.3	12.6	17.0

Table 3-3: Variance decomposition - Trades of assets

3.3.3 Robustness of VAR implications

I consider two alternative periods including the early period of 1960:Q1-1982:Q1 and the full sample 1960:Q1-2007:Q4. In the following figures, I present only responses of the two NFA definitions considered in this paper. The rows correspond to investment-specific, neutral technology, and monetary policy shocks respectively.

Figure 3-10 shows that the responses of two definitions of the NFA position to shocks are similar before the market liberalization. Both definitions of NFA increase in response to investment specific and monetary policy shocks and show similar patterns. This is quite different from results for the benchmark period. The difference can be accounted for by the differences in responses of other assets, particularly in response to monetary policy shocks⁵. It is however difficult to draw direct comparisons because there are structural changes in the macroeconomic environment between the two periods. Moreover, the variance decomposition analysis shows that the three shocks account for much larger fraction of variability in NFA^* but have less explanatory power in NFA in the earlier period. Results for the full sample 1960:Q1-2007:Q4 are shown in figure 3-11. While responses of the two NFA definitions to investment specific shocks changes dramatically, it is surprising that the responses to monetary policy shocks are also counter-intuitive similar to the pattern observed in the two sub-samples.

I also consider two alternative VAR specifications. First, I replace the relative price of (gross) investment by the relative price of equipment. It is important to consider various relative investment price indices in order to check for robust response to investment specific shock. It is known that the aggregate investment price index can behave differently compared with its components, which include housing, durable goods, and equipment. In this paper, I only use the relative price of equipment index reported in the NIPA table 1 to check for robustness of the benchmark results. Second, in response to Christiano et al. (2005) argument about the treatment of hours worked, I use the level of hours worked in the VAR instead of the first difference.

⁵Impulse responses of the Net difference of other types of financial assets to the three structural shocks are reported in the Appendix 3.C.

Figure 3-12 shows responses of the NFA positions to the three shocks. Although, the responses of NFA to embodied capital technology shocks seem to be more consistent with theoretical predictions, we may not be able to conclude that the relative price of equipment is a better measure of investment specific shocks. It shows that the responses of NFA are sensitive to the measure of investment specific shocks. It is the case because there is empirical evidence that the behavior of sub indices of the aggregate investment price index such as residential investment, durable consumption goods and equipment prices are different. In order to conclude effects of embodied technology shock on asset diversification, it is important to use the appropriate data series to identify structural investment specific shocks. Fisher (2003) proposes using a weighted average measure of these subcomponent indices to resolve this issue. The responses of the NFA positions in the alternative VAR using levels of hours worked are reported in figure 3-13. Results are considerably robust to either treatment of hours worked in the VAR estimation.

3.4 Conclusions

This paper employs the structural VAR techniques to empirically investigate the effects of fundamental shocks on the US net foreign asset position and international asset portfolios using available macroeconomic and financial data. The current developments in the VAR literature allow me to partially identify selective economic shocks of interest. The paper exclusively focuses on three US fundamental shocks: investment-specific technology, TFP, and monetary policy. I estimate and reports results of alternative VARs for different financial variables. I consider two different definitions of the net foreign asset position: one is broadly defined and often used in

the empirical literature and the other consists of the difference in *private* holdings of bonds and equities only. The latter is usually studied in the theoretical papers as the true NFA position.

I focus on the 1982:Q2-2007:Q4 period because it is commonly agreed that there is a critical change in the US monetary policy regime, investment efficiency as well as the international financial markets are liberalized during this period. Responses of the two definitions of the *NFA* position to shocks are interesting. Particularly, the responses of *NFA* to investment specific technology shocks and of *NFA** to monetary policy shocks are counter-intuitive and require further empirical studies and explanations. Moreover, I find informative but not always statistically significant responses of international portfolio dynamics to these shocks. The variance decomposition shows that the three structural shocks can explain between 19% to 29% of the NFA position fluctuations and between 10% and 45% of variability of holding of each asset. The three US domestic shocks account for more volatility of US investors' asset holdings than those of foreign investors. These shocks explain smaller fractions of trading flows of financial assets as well as the NFA positions. Robustness check shows that it is important to use an appropriate measure of investment price to identify structural investment specific shocks. This can resolve the counter-intuitive responses of the NFA position to investment specific shock found in the benchmark case.

Although the current results are informative about the dynamics of international portfolio diversification, they are not always conclusive. It suggests there are more work to be done with either data or VAR specification and estimation techniques in order to improve the statistical significance of results. In addition, other economic shocks may be investigated together with the three shocks. For instance, Bems et al.

(2007) have incorporated fiscal policy shocks in their study of the US trade balance. Furthermore, this paper focuses on US shocks only. The omission of foreign factors and international comovement may bias the results, hence, future extensions should take into account the effects of foreign factors and their correlations with US shocks.

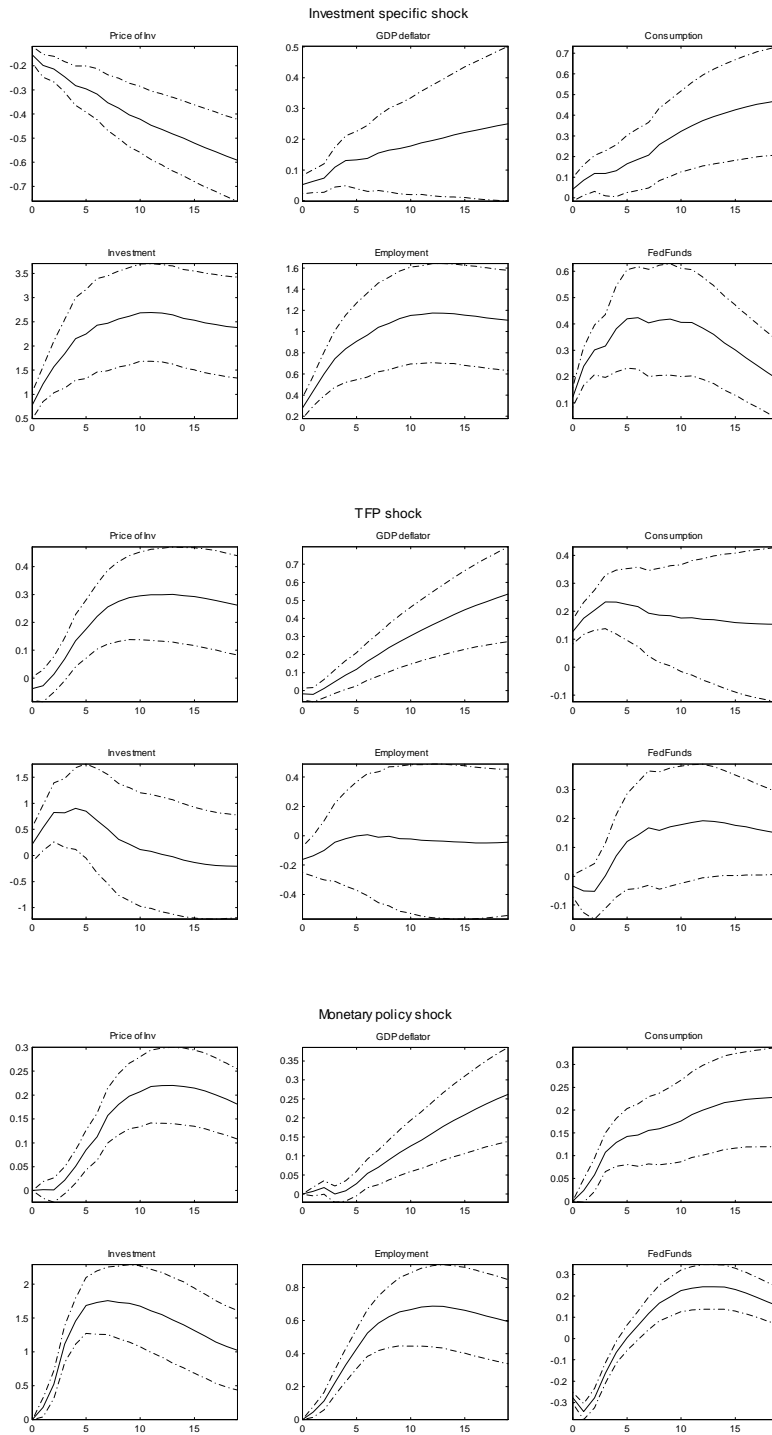
APPENDIX

3.A Data Sources

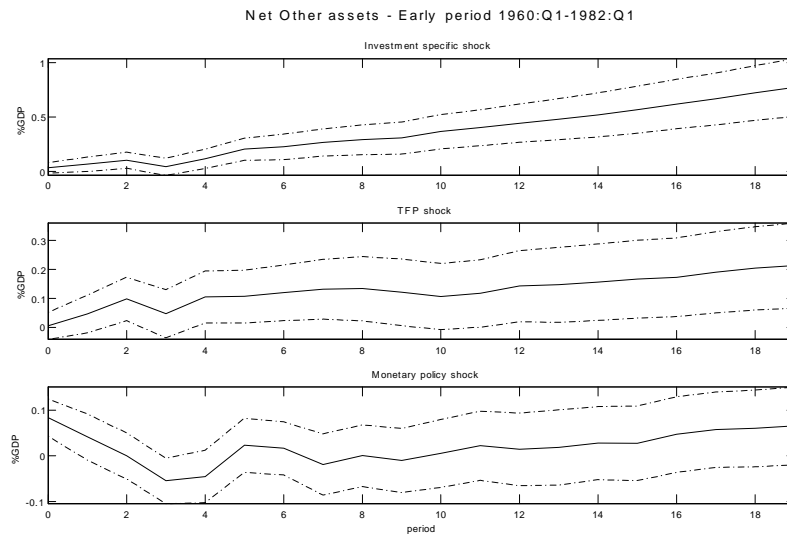
Data used are quarterly and seasonally adjusted at annual rate for the US. The relative investment price index is constructed from related series of the National Income and Payment Accounts section 1. It is constructed as the ratio of the investment price index over the GDP deflator. The GDP deflator is calculated from dividing the nominal real GDP by the real GDP. The labor productivity is the per-capita GDP per hour worked. The GDP per hour worked and population over 16 series are available from the Federal Reserve Bank at St. Louis FRED database. Inflation is the growth rate of GDP deflator. Hours worked are available from the Bureau of Labor Statistics database normalized by population over 16. The Federal fund rate is the quarterly average of monthly effective federal fund rates of corresponding months.

This paper makes extensive use of the Flows of Funds Accounts (Table F.107) data. The empirical *NFA* series is constructed by subtracting US gross external liabilities (FL264090005 plus FL263164003) from gross external assets (FL264190005). US investors' holding of foreign bonds *HBF* is constructed from commercial papers and foreign bonds (FL263169175 and FL263163003). US holding of foreign equities *HSF* includes foreign equities and US foreign direct investments (FL263164003 and FL263192005). Foreign private holding of US bonds *FBH* consists of open market purchases, Treasury, state and local government bonds (FL263061123, FL263061723, FL263062003, and FL263063005) while *FSH* consists of US equities plus direct investment (FL263064105 and FL263062001). The *NFA** is calculated using the formula defined in section 3.2.2 above.

3.B Responses of Macroeconomic Variables

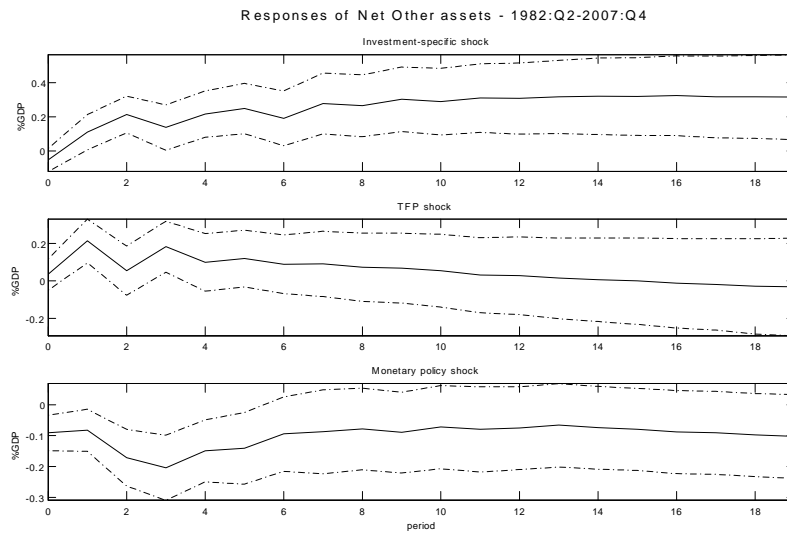


3.C Responses of Net Other Asset types



Responses of Net Other assets - 1960:Q1-1982:Q1

Investment specific, TFP and monetary policy shocks respectively (by rows)



Responses of Net Other assets - 1982:Q2-2007:Q4

Investment specific, TFP and monetary policy shocks respectively (by rows)

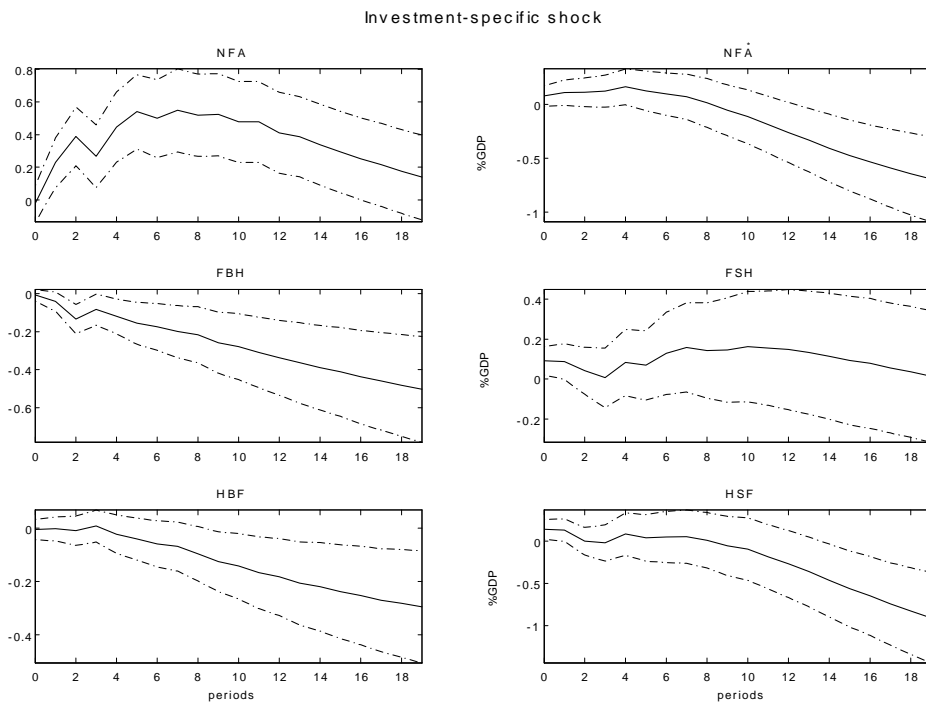


Figure 3-4: Impulse responses to a positive investment specific technology shock - Asset holdings.
 — solid line is point estimate - - dashed line is the 1-standard-deviation band

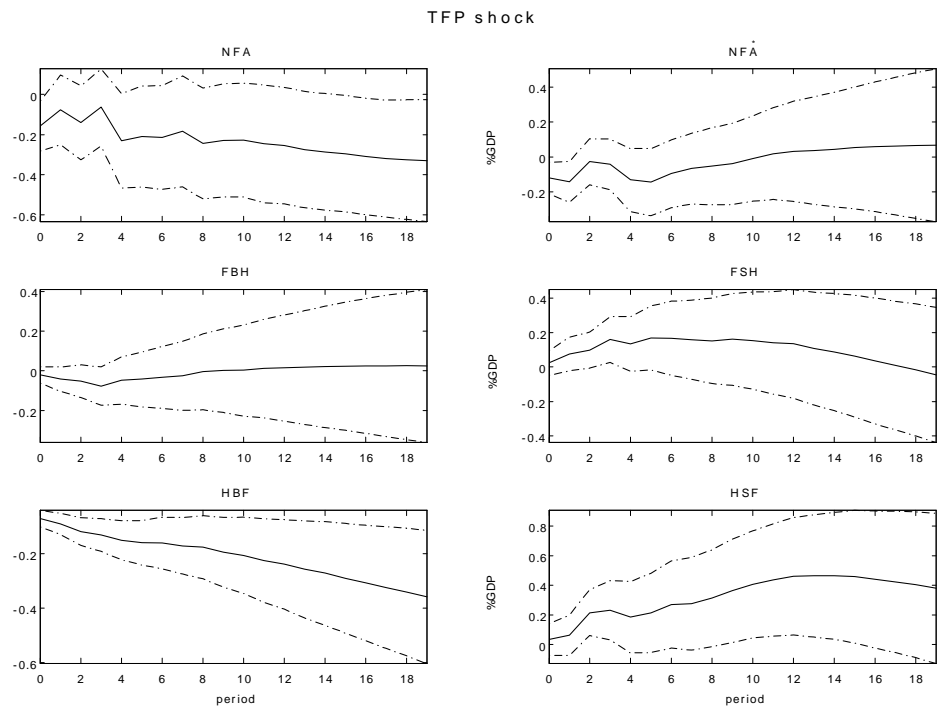


Figure 3-5: Impulse responses to a positive TFP shock - Asset holdings

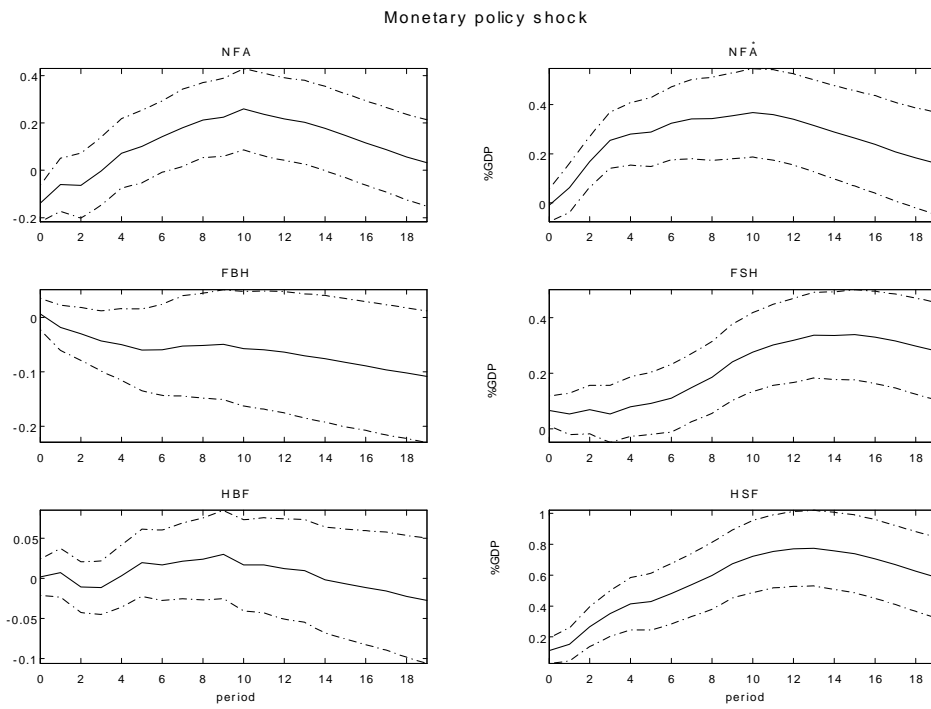


Figure 3-6: Impulse responses to an expansionary monetary policy shock - Asset holdings

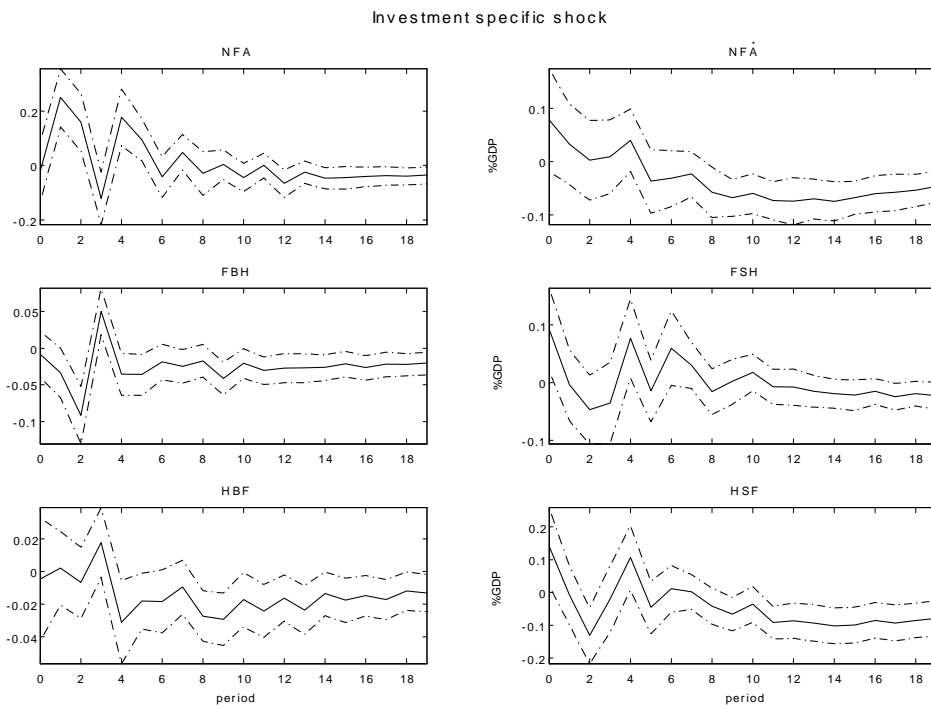


Figure 3-7: Impulse responses to a positive investment specific shock - Asset trades

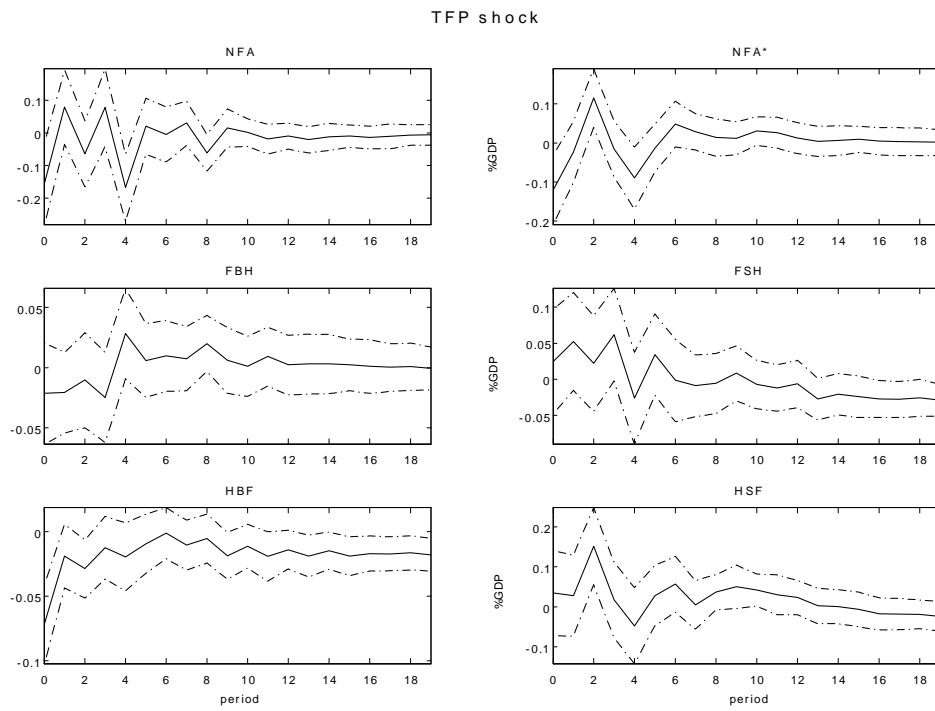


Figure 3-8: Impulse responses to a positive TFP shock - Asset trades

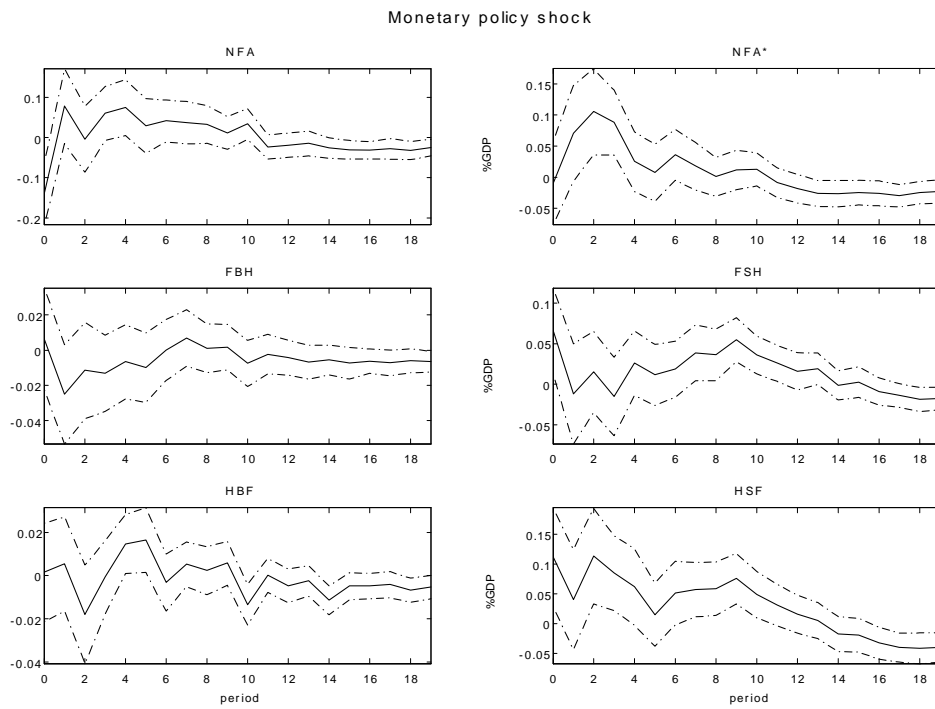


Figure 3-9: Impulse responses to an expansionary monetary policy shocks - Asset trades

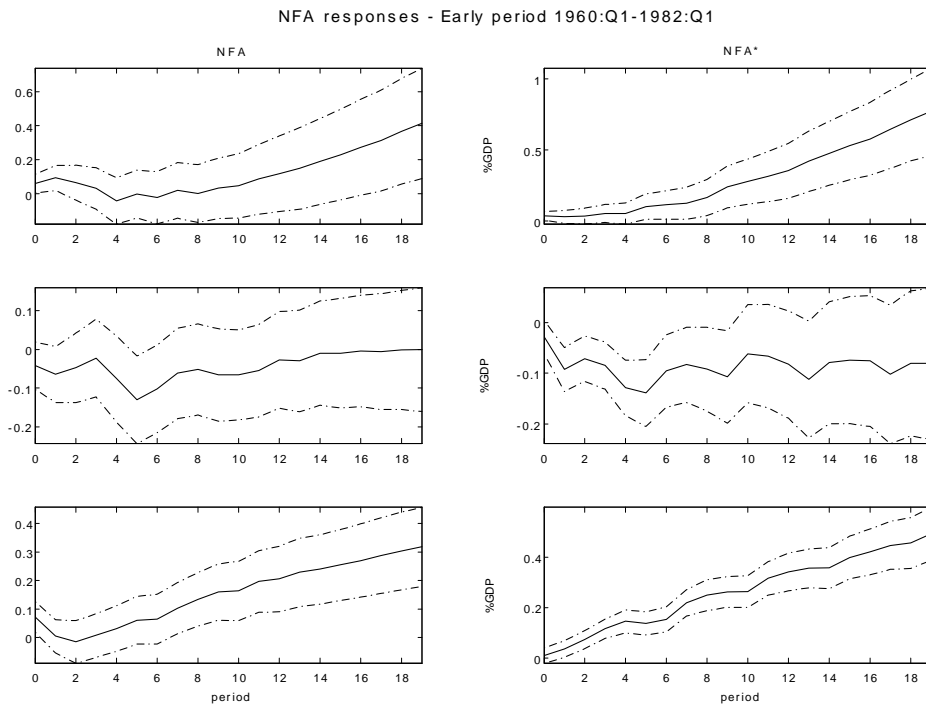


Figure 3-10: Impulse responses of the NFA positions to shocks - Early period 1960:Q1-1982:Q1
Investment specific, TFP and monetary policy shocks respectively (by rows)

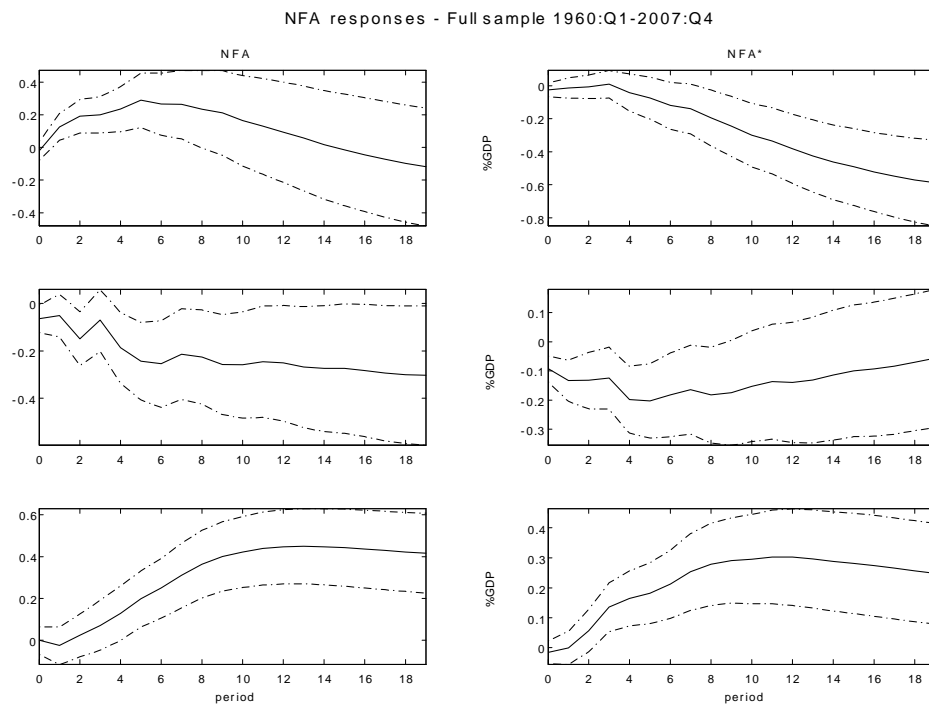


Figure 3-11: Impulse responses of the NFA positions to shocks - Full sample 1960:Q1-2007:Q4
Investment specific, TFP and monetary policy shocks respectively (by rows)

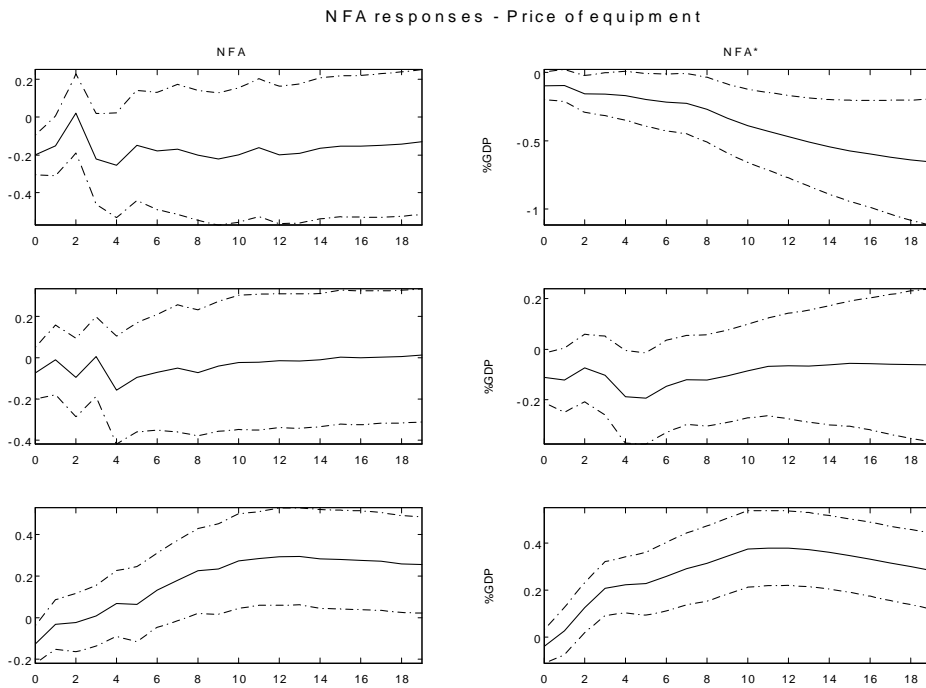


Figure 3-12: Impulse responses of the NFA positions to shocks - Relative price of equipment Investment specific, TFP and monetary policy shocks respectively (by rows)

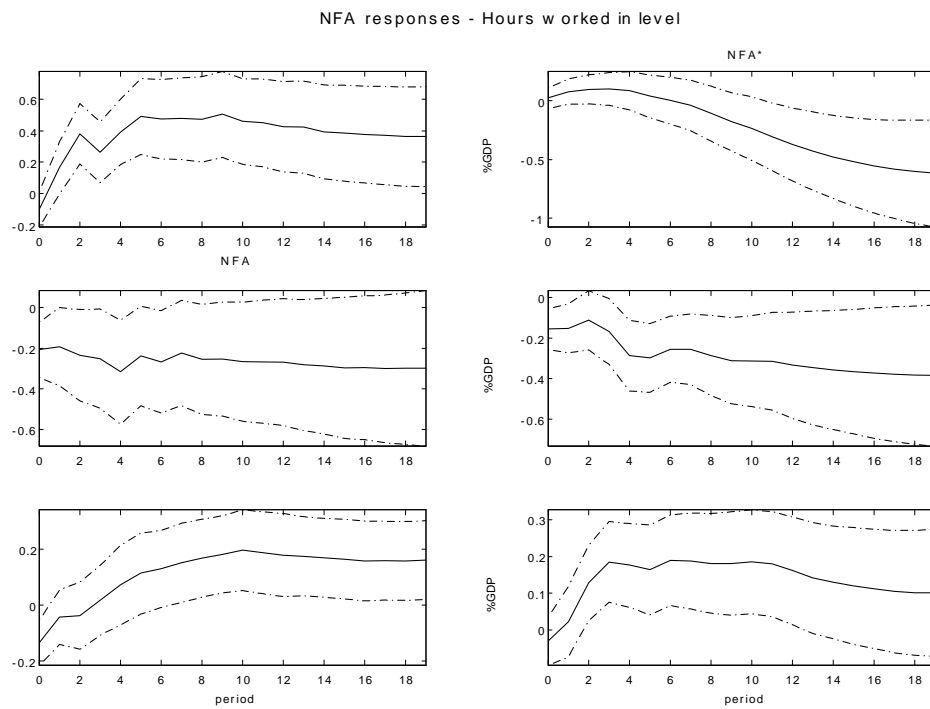


Figure 3-13: Impulse responses of the NFA positions to shocks - Hours worked in levels Investment specific, TFP and monetary policy shocks respectively (by rows)

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