

Nominal Stability and Financial Globalization*

Michael B Devereux,[†] Ozge Senay[‡] and Alan Sutherland[§]

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Abstract

Over the past four decades, advanced economies experienced a large growth in gross external portfolio positions. This phenomenon has been described as *Financial Globalization*. Over roughly the same time frame, most of these countries also saw a substantial fall in the level and variability of inflation. Many economists have conjectured that financial globalization contributed to the improved performance in the level and predictability of inflation. In this paper, we explore the causal link running in the opposite direction. We show that a monetary policy rule which reduces inflation variability leads to an increase in the size of gross external positions, both in equity and bond portfolios. This appears to be a robust prediction of open economy macro models with endogenous portfolio choice. It holds across different modeling specifications and parameterizations. We also present preliminary empirical evidence which shows a negative relationship between inflation volatility and the size of gross external positions.

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[†]NBER, CEPR and University of British Columbia. Address: Department of Economics, University of British Columbia, 997-1873 East Mall, Vancouver, B.C. Canada V6T 1Z1. Email: devm@interchange.ubc.ca. Tel: +1 604 822 2542 Fax: +1 604 822 5915.

[‡]University of St Andrews. Address: School of Economics and Finance, University of St Andrews, St Andrews, KY16 9AL, UK. E-mail: os12@st-and.ac.uk Tel: +44 1334 462422 Fax: +44 1334 462444

[§]CEPR and University of St Andrews. Address: School of Economics and Finance, University of St Andrews, St Andrews, KY16 9AL, UK. E-mail: ajs10@st-and.ac.uk Tel: +44 1334 462446 Fax: +44 1334 462444

1 Introduction

Data on external asset positions show that the gross size of country portfolios has increased substantially over the past four decades. Over the same period the volatility of inflation has declined in most countries as monetary authorities have shifted the focus of monetary policy towards inflation stabilization and away from output stabilization. This paper investigates whether these two phenomena are related. The question we address is: has the increased monetary policy focus on nominal stability resulted in greater financial globalization?

We are not the first to explore the link between financial globalization and inflation. But to our knowledge, all the literature has focused on the causation going in the other direction. For instance, many authors have suggested that increasing globalization in goods and financial markets has led to a decline in national inflation rates, either through direct market mechanisms or by influencing the behavior of monetary authorities¹.

We do not dispute the possibility that financial globalization may influence inflation, either directly through trade effects or indirectly through affecting the conduct of monetary policy. But we argue in this paper that there is a very strong theoretical case that the link may also go the other way. We find that monetary policy which reduces the variability of domestic inflation leads to an increase in the diversification of international portfolios, generating higher gross external assets and liabilities. We show that this result is robust across a variety of modeling specifications and parameter assumptions.² In addition, we provide some preliminary empirical evidence for this link.

We provide a theoretical investigation of the impact of monetary policy and nominal stability on the size of external asset positions in a general model in which gross external financial positions are endogenous. The model is a two-country DSGE structure with Calvo-

¹For instance, Rogoff (2004, 2006) suggests that increasing economic openness may steepen the trade-off between inflation and output, and reduce the equilibrium inflation rate chosen by monetary authorities. Chen et al. (2004) find empirical evidence that increasing openness, by reducing non-competitive distortions in domestic markets, reduces the inflation bias in monetary policy. In addition, it has been suggested that there are direct disinflationary forces imparted by international trade (Pain et al. 2006, Borio and Filardo 2007). Alternatively, financial globalization could affect inflation indirectly by imposing a ‘disciplining effect’ on domestic monetary policy. This link is explicitly tested in Tytell and Wei (2004). They find evidence that financial globalization has led to lower inflation rates. Related research by Kose et al. (2007) suggest that there are ‘collateral’ benefits of financial globalization coming from its effect on the quality of domestic economic policy. Stark (2011) also conjectures that financial globalization was a contributing factor in improved monetary policy performance in OECD countries.

²Note that we are not claiming that inflation stabilization is the only (or even the main) cause of financial globalization. We are simply showing that it may be one (possibly) quite important factor.

style wage and price setting where monetary policy in each country is modeled as a Taylor rule. There is international trade in nominal bonds and equities, and following recent literature, we compute equilibrium gross portfolios. The size of these portfolios will depend on the structure and stochastic environment of the model, including the properties of the monetary rule. The benchmark model displays home bias in equity holdings while each country holds a long position in bonds denominated in their own currency. By varying the feedback coefficient on inflation in the Taylor rule it is possible to analyze the relationship between the anti-inflation stance of monetary policy, the variance of inflation and equilibrium portfolio positions.

In the baseline parameterization of the model, as the policy feedback coefficient on inflation is increased, the variance of inflation falls and the absolute size of equilibrium gross positions in both equities and bonds increase. So the model predicts a *negative* relationship between the variance of inflation and the size of equity and bond portfolio positions.

The underlying cause of this negative relationship can be explained in terms of simple expressions which show that the equilibrium gross portfolio position in any asset is proportional to the variability of home income relative to foreign income and inversely related to the variability of relative asset returns. Lower variability of relative asset returns compared to the variability of relative income implies that gross portfolios have to be larger in order to provide adequate hedging of income shocks. We show that the model implies that, as the feedback coefficient on inflation in the Taylor rule is increased, the variability of relative asset returns decreases compared to the variability of relative income. This leads to an increase in gross asset positions.

We further show that the size of gross positions depends on the correlation between relative asset returns and cross-country income shocks. The more relative asset returns are correlated with income shocks, the larger are equilibrium gross holdings. Our model shows that, when asset markets are incomplete (meaning there are fewer independent assets than there are sources of uncertainty) a reduction in inflation variability increases the correlation between relative asset returns and income shocks. In effect, inflation stabilization moves the equilibrium closer to the complete markets outcome. This tends to raise the size of equilibrium gross holdings.

There are thus two effects which link a reduction in inflation variability to an increase in the size of gross portfolio positions, a *return volatility effect* and a *return-income correlation effect*. The model shows that both effects can contribute to an expansion of gross asset positions, the more that monetary policy is focused on inflation stabilization.

Numerical experiments with our model show that the negative relationship between infla-

tion variability and gross positions appears to be very robust across a wide range of parameter variations and model variants. There is, however, some sensitivity to the precise form of the monetary rule. For instance, if the Taylor rule is based on producer price inflation (PPI) rather than consumer price inflation, gross equity holdings are (mildly) positively related to inflation variability. We argue however that a rule based on consumer price inflation is a better representation of monetary policy practice in the last four decades.

The relationship between gross positions and inflation volatility can be investigated empirically using the Lane and Milesi-Ferretti (2001, 2007) data on gross external portfolio positions. In order to put our theoretical results in context, we first report panel regression estimates for advanced economies for the period 1972-2005 which show a statistically significant negative relationship between inflation variability and the size of gross portfolio positions. This empirical result appears to be quite robust to different specifications of the regression equation and different definitions of the variables. In particular the results are robust for overall gross positions and also the gross positions in bonds and equities separately.

The paper is part of a large literature on the theoretical and empirical underpinnings of international capital flows. On the theory side, Devereux and Sutherland (2010, 2011a) and Tille and Van Wincoop (2010) develop techniques for computing equilibrium portfolios in DSGE models. Applications to the ‘home bias’ puzzle include Coeurdacier *et al* (2010), Engel and Matsumoto (2009), Heathcote and Perri (2007), and Benigno and Nistico (2009). Empirically, Lane and Milesi-Ferretti (2008a, 2008b) and Lane and Shambaugh (2010) have explored the determinants of international portfolio positions. With respect to the relationship between monetary policy rules and international portfolios, Devereux and Sutherland (2008) note that a monetary policy focused on stabilizing producer price inflation can increase nominal bond positions by enhancing the risk sharing properties of nominal bonds. De Paoli *et al* (2010) examine the implication of different types of monetary policy rules for international portfolio positions and welfare. Neither Devereux and Sutherland (2008) nor De Paoli *et al* (2010) focus on the relationship between CPI inflation volatility and gross international portfolio positions in the way that is addressed in this paper.³

³Devereux and Sutherland’s (2008) main focus of analysis is optimal monetary policy in the presence of endogenous portfolio choice. They use a theoretical model which is much less general than the model described below. They do not directly analyze the relationship between inflation stabilization and the size of portfolio positions. They simply note that, in their simple model (where asset trade is restricted to trade in nominal bonds) that the size of gross bond positions increases as inflation is stabilized. The current paper analyses a much more general model and shows that the size of gross positions in both equities and bonds tend to rise as monetary policy focuses on inflation stabilization. We also set out a general framework for understanding this result (which encompasses the effect noted in Devereux and Sutherland, 2008) and tests

There is also a large empirical literature on the determinants of international financial globalization. Okawa and van Wincoop (2010) develop a gravity based model of international financial linkages where bilateral financial holdings are determined by basic principles of portfolio diversification, adjusted for relative informational asymmetries across countries. They show that their model allows for a theory-based estimate of the size of financial frictions. Lane and Milesi-Ferretti (2008a, 2008b) and Faruqee *et al* (2004) use simple models of portfolio diversification to examine the determinants of bilateral cross border equity holdings. None of these papers explore the influence of inflation on international financial holdings, however.

The paper proceeds as follows: Section 2 presents a brief empirical analysis of the relationship between gross asset positions and inflation variability over the period 1970-2007. Section 3 describes our theoretical model. Section 4 derives some useful relationships which aid in the analysis of gross positions within the theoretical model. Section 5 derives some simple analytical results based on a simplified version of the model. Section 6 presents the main numerical analysis of the general model. Section 7 discusses the results and section 8 concludes the paper.

2 Empirical Evidence

In order to put our theoretical model in context we first report some basic panel regression estimates of the relationship between gross positions and inflation variability.

We estimate a panel regression of the following form

$$100 \ln(GP_{i,t}/GDP_{i,t}) = \beta_0 + \beta_i + \beta_1 \sigma_{i,t}(\pi) + \beta_2 Z_{i,t} \quad (1)$$

where $GP_{i,t}$ is a measure of the size of the gross portfolio position of country i in period t and $\sigma_{i,t}(\pi)$ is a measure of inflation variability for country i in period t , Z is a vector of other potential explanatory variables and β_i is a country dummy.

Our main results focus on the total gross position, GP , which we define as

$$GP = \frac{(Total\ External\ Assets + Total\ External\ Liabilities)}{2}$$

We also estimate variants of our basic equation where the dependent variable is the gross position in equity-type assets, and another where the dependent variable is the position in debt-type assets, where again the gross position is defined as the average of the asset and liability position in the relevant type of asset.

the robustness of the result across a wide range of model and parameter variations.

We define $\sigma_{i,t}(\pi)$ to be the standard deviation of the CPI inflation rate of country i for the period $t - k$ to t where inflation is measured as the annual percentage change in the CPI measured at quarterly intervals. In the main results we report below we choose k to be 6 years, so $\sigma_{i,t}(\pi)$ is the standard deviation of annual inflation based on the 24 quarterly observations of the CPI up to and including the final quarter of year t .⁴

Data on gross asset and liability positions is taken from Lane and Milesi-Ferretti (2007) who provide annual data for the period 1970-2007 on gross external positions for 178 countries for various classes of assets. Our measure of the variability of inflation is based on CPI inflation data obtained from the IMF IFS database for the period 1965-2007. The highest frequency available for all countries is quarterly.

Although the focus of our analysis is on the effects of inflation variability on asset holdings, we include a number of other possible explanatory variables in the above regression. These are: financial frictions, trade openness, exchange rate variability, real output variability and a linear time trend. Financial frictions, such as regulatory and legal controls on capital movements, have obvious implications for international portfolio allocation. There have been major changes in capital controls for many countries over the last 40 years so it is clearly necessary to control for such effects in our regression. We use the Chinn-Ito index (Chinn and Ito, 2007) of capital controls as a measure of financial frictions. Openness to trade in goods and services has also increased for many countries over the past 40 years and this again may be an explanation for the parallel growth in financial integration. We control for this by including the average of exports and imports as a percentage of GDP as an explanatory variable in our regression. Exchange rate variability is a major factor determining relative asset returns so changes in exchange rate variability are potentially an important determinant of portfolio holdings. Exchange rate variability in year t is measured as the standard deviation of the annual change of the effective nominal exchange rate over the 6 years up to the end of year t . Output variability is a major source of the risk which motivates the holding of financial assets so output variability is potentially an important determinant of portfolio holdings. Output variability in year t is measured as the standard deviation of the growth rate of real GDP over the 6 years up to year t . Trade and GDP data is obtained from the IMF IFS database, while effective exchange rate data is obtained from the BIS.⁵

⁴We have estimated variants of our equation where k is equal 5 or 7 years and found results very similar to those report below.

⁵The BIS provides monthly data on effective exchange rates for all the countries in our sample. The standard deviation of the exchange rate for year t is calculated as the standard deviation of the annual

Before discussing the estimation results it is useful to consider some general features of the data. The six panels in Figure 1 plot the cross country averages of the data for the G7 countries, while Table 1 shows a cross-country comparison of the data for asset holdings and inflation variability based on individual country averages for each country for two sub-periods (1970-1989 and 1990-2007). Table 1 also shows the same data for other OECD countries. Figure 1 and Table 1 show a strong upward trend in the data for gross positions through the sample period. This upward trend is common to all countries. Figure 1 and Table 1 also show a strong downward trend in inflation volatility through the sample. This is also common to all countries. There are no obvious country outliers in the G7 group of countries in terms of the general behavior of the data, but the UK, because of its position as a major financial center, tends to have a much larger gross positions than other countries in the G7. In terms of the other potential explanatory variables for the G7, Figure 1 shows an upward trend in the Chinn-Ito index and trade integration, a downward trend in output variability and (after 1980) a downward trend in exchange rate variability.

Regression results relating to equation (1) are reported in Table 2.⁶ The estimates reported in this table are based on OLS or IV estimation of (1) corrected for autoregression in the error term.

We begin by focusing on the G7 group of advanced countries. The results for this country grouping are presented in Columns 1 and 2 of Table 2. The estimates reported in Column 1 show that inflation variability has a negative effect (which is significant at the 5% level) on the size of total gross positions. The magnitude of the coefficient on the standard deviation of inflation suggests that inflation variability has quite a large effect on the size of gross positions. A coefficient of -3.2 implies that a fall in the standard deviation of annual inflation by 1 percentage point raises GP/GDP by approximately 3.2%. The average range of the standard deviation of inflation over the sample period is approximately 5 percentage points, while gross portfolio positions for the G7 reached approximately 200% of GDP by the end of our sample period. A coefficient of -3.2 on the standard deviation of inflation suggests that gross positions would have been approximately 170% of GDP had inflation volatility remained at the levels seen in the 1970s.

change of the exchange rate measured at monthly intervals over the 72 months ending in the last month of year t . Quarterly GDP data is only available for a very small group of countries for our estimation period so the standard deviation of GDP is calculated using annual observations of GDP growth. The standard deviation of GDP in year t is calculated as the standard deviation of the annual growth of GDP measured at annual intervals over the 6 years up to year t .

⁶To save space, the estimated coefficients on the country dummies are not reported.

Table 1: Summary of data for G7 and OECD countries

	Gross portfolio		StDev	
	% of GDP		of Inflation	
	70-89	90-07	70-89	90-07
Canada	50	91	2.02	1.06
France	36	149	2.33	0.58
Germany	35	112	1.51	0.95
Italy	27	83	3.93	0.86
Japan	20	59	3.21	0.93
UK	117	277	3.92	1.44
USA	24	69	2.38	0.83
Australia	25	81	2.66	1.78
Austria	47	134	1.65	0.78
Belgium	100	293	2.37	0.73
Denmark	46	140	2.64	0.65
Finland	31	131	3.15	1.18
Greece	24	68	6.44	2.47
Ireland	86	551	4.25	1.12
Netherlands	79	259	1.87	0.84
Norway	43	109	2.44	1.13
Portugal		126	5.72	1.75
Spain	23	93	3.41	0.96
Sweden	31	147	2.23	1.83
Switzerland	139	375	2.16	1.09

Table 2: Panel regression results

	(1)	(2)	(3)	(4)	(5)	(6)
	G7	G7	OECD	OECD	OECD	OECD
	Total	Total	Total	Total	Debt	Equities
	portfolio	portfolio	portfolio	portfolio		
Constant	-237.8** (8.31)	-196.9** (6.95)	-230.9** (17.26)	-209.2** (15.16)	-228.8** (12.8)	-433.3** (19.5)
StDev	-3.19**		-2.60**			
Inflation	(3.50)		(3.98)			
StDev		-11.43**		-9.69**	-4.90*	-18.00**
Inflation (IV)		(3.58)		(3.83)	(1.80)	(4.99)
Chinn-Ito	1.92	-1.73	3.36**	3.06**	3.63**	2.08
Index	(1.02)	(0.74)	(2.44)	(2.16)	(2.38)	(1.04)
StDev	1.16**	0.91*	1.06**	1.22**	1.43**	0.81**
Exch rate	(2.22)	(1.68)	(2.53)	(2.85)	(3.16)	(1.35)
StDev	0.47	-2.87**	1.08	-0.09	1.06	-2.27
GDP growth	(0.32)	(2.00)	(1.17)	(0.10)	(1.13)	(1.58)
Trade	1.98** (5.28)	1.70** (4.55)	1.42** (8.10)	1.36** (7.64)	1.15** (6.07)	1.55** (6.11)
Trend	5.93** (7.99)	5.86** (8.90)	6.34** (16.08)	6.30** (18.22)	5.28** (11.37)	10.26** (18.05)
AR coeff	0.91	0.90	0.88	0.85	0.89	0.87
R ²	0.99	0.99	0.99	0.99	0.99	0.99
F-stat	1845.7	1756.3	2053.1	1956.3	1542.7	1856.2
DW-stat	1.73	1.60	1.75	1.66	1.63	1.79

** indicates significant at 5% level, * indicates significant at 10% level

t-stats in brackets

The other coefficient estimates in Column 1 suggest that financial openness and the variability of GDP do not have a statistically significant effect on gross positions for the G7 countries but exchange rate variability and trade integration both have a positive and significant effect. The time trend is also significant.⁷

Of course, while the results in Column 1 suggest that there is statistical relationship between inflation volatility and the size of gross positions, they do not tell us the direction of causation. One simple way to disentangle causation is to use a measure of central bank independence as an instrument for inflation volatility.⁸ This approach can be justified on the basis that increased central bank independence is an exogenous policy driven process which has reduced inflation volatility over the sample period. Column 2 of Table 2 reports the results for a variant of the model where we use the Cukierman *et al* (1992) index of central bank independence as an instrument.⁹ The estimated coefficient on inflation variability continues to be negative and significant (and is much larger than the coefficient reported in Column 1). This suggests that there are grounds for supposing that the causation runs from central bank independence, to lower inflation variability and thus to higher gross asset positions.

In terms of other explanatory variables, the estimated coefficients in column 2 are little changed compared to column 1, except that the variability of GDP is now significant.

Columns 3 to 6 in Table 2 report results for a wider set of OECD economies.¹⁰ Column 3 is a direct estimate of equation (1) for this wider set of countries, while column 4 uses central bank independence as an instrument for inflation variability. These two columns show that extending the analysis to this wider group of countries yields very similar results to those reported for the G7. The coefficient on inflation variability continues to be significant and negative and has a similar absolute size to those reported for the G7.

Columns 5 and 6 report results for debt assets and equity assets respectively for the group of OECD countries. Compared to Column 4 (which shows the results for total gross positions), the general pattern of results in these two columns is similar, but the coefficient

⁷The magnitude of the coefficients in Column 1, together with the evolution of the explanatory variables observed in the G7 data over the sample period, suggest that the growth in trade integration in the G7 had a positive effect on gross positions which is slightly larger than the effect of inflation variability while the time trend is the dominant factor accounting for the change in gross positions since the early 1970s. The other explanatory variables contribute only a very small amount to the overall observed growth in gross positions.

⁸We are grateful to an anonymous referee for this suggestion.

⁹The Cukierman *et al* (1992) dataset has been up-dated and extended by Crowe and Meade (2007).

¹⁰The full list of 20 countries is given in Table 1. This set of countries comprise the membership of the OECD at the start of our sample period.

is larger and somewhat more significant in the case of equities (Column 6) and smaller and less significant in the case of debt assets (Column 5).

The results reported in Table 2 are not intended to be a comprehensive empirical investigation of the determinants of gross positions. Nonetheless, they do appear to confirm that inflation variability is a potentially important factor in the expansion of gross positions over the past four decades.¹¹ The decline in inflation variability over the past 40 years appears to have had a significant positive effect on gross positions which is independent of changes in other potential explanatory variables such as the decline in financial frictions, the increase in trade integration, fluctuations in exchange rate variability and the decline in output variability. The effect of inflation variability appears to be robust across a range of empirical specifications and a range of countries. In the following sections we describe a two-country general equilibrium model and show that the model's predictions are consistent with the above empirical findings, at least in terms of its qualitative properties for the relationship between inflation variability and gross asset positions.

3 A Model of Monetary Policy and Gross Portfolio Positions

We analyze a model of two countries with multiple types of shocks. The model shares many of the same basic features of the closed economy models developed by Christiano *et al* (2005) and Smets and Wouters (2003). Households in each country consume a basket of non-traded final goods and home and foreign produced traded final goods. Final goods are produced by monopolistically competitive firms which use intermediate goods as their only input. Final goods prices are subject to Calvo-style contracts. Intermediate goods are produced by perfectly competitive firms using labor and real capital as inputs. Intermediate goods prices are perfectly flexible. Capital stocks are subject to adjustment costs. Households supply homogeneous labor to monopolistically competitive labor unions. The labor unions supply

¹¹The significance and magnitude of the time trend in all the model variants shown in Table 2 clearly suggests that there are other explanatory variables which are missing from our regressions. An obvious candidate for a missing variables would be some measure of communications technology and transactions costs. The Chinn-Ito index captures the changes in regulatory frameworks over the sample period, but developments in communications technology and increased competition in the provision of financial services are likely to have had a major impact on international financial trade which is independent of regulatory changes. A more comprehensive empirical investigation of gross positions would have to include some measure of these factors.

differentiated labor to firms in the intermediate goods sector. The wages charged by labor unions are subject to Calvo-style contracts. All profits from firms in the intermediate and final goods sectors and surpluses from labor unions are paid to households.

We allow trade in equities and bonds. Home and foreign equities represent claims on aggregate firm profits of each country, and home and foreign nominal bonds are denominated in the currency of each country. This roughly gives us a breakdown of gross asset and liability positions corresponding to the Lane and Milesi-Ferretti database.¹²

The following sections describe the home country in detail. The foreign country is identical. An asterisk indicates a foreign variable or a price in foreign currency.

3.1 Households

Household z in the home country maximizes a utility function of the form

$$U_t = E_t \sum_{i=0}^{\infty} \beta^i \left\{ \frac{C_{t+i}^{1-\rho}(z)}{1-\rho} - \Delta_{t+i} \frac{H_{t+i}^{1+\phi}(z)}{1+\phi} \right\} \quad (2)$$

where $\rho > 0$, $\phi > 0$, $C(z)$ is the consumption of household z and C is aggregate consumption, $H(z)$ is labor supply, β is the discount factor and Δ_t is a stochastic preference shock which affects labor supply. We assume $\Delta_t = \bar{\Delta} \exp(\hat{\Delta}_t)$ where $\hat{\Delta}_t = \psi_{\Delta} \hat{\Delta}_{t-1} + \varepsilon_{\Delta,t}$, where, $0 < \psi_{\Delta} < 1$ and $\varepsilon_{\Delta,t}$ is a zero-mean normally distributed i.i.d. shock with $Var[\varepsilon_{\Delta}] = \sigma_{\Delta}^2$.

C as a consumption aggregator defined across traded and non-traded goods, given by

$$C_t = \left[\eta^{\frac{1}{\varkappa}} C_{N,t}^{\frac{\varkappa-1}{\varkappa}} + (1-\eta)^{\frac{1}{\varkappa}} C_{T,t}^{\frac{\varkappa-1}{\varkappa}} \right]^{\frac{\varkappa}{\varkappa-1}} \quad (3)$$

where $0 \leq \eta \leq 1$ and $\varkappa > 0$ is the elasticity of substitution between traded and non-traded goods. C_N is an aggregator defined across all individual non-traded goods and C_T is an aggregator defined across home and foreign goods, given by:

$$C_{T,t} = \left[\gamma^{\frac{1}{\theta}} C_{H,t}^{\frac{\theta-1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{F,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \quad (4)$$

where C_H and C_F are aggregators over individual home and foreign produced goods. The elasticity of substitution across individual goods within all sectors is $\lambda_t > 1$. The parameter θ

¹²We restrict attention to nominal bonds in each currency. While the inclusion of inflation linked bonds in the menu of assets would certainly raise a number of interesting theoretical issues, from an empirical point of view such bonds still form a relatively small share of portfolio holdings in the relevant data period. For instance, the UK and US governments are to date the two biggest issuers of index-linked debt. The UK started issuing index-linked bonds in 1981 and the outstanding stock is still less than 25% of UK GDP, while the US government started issuing index-linked bonds in 1997 and the outstanding stock is less than 5% of US GDP. These amounts are very small in relation to the total size of international gross asset positions.

in (4) is the elasticity of substitution between home and foreign traded goods. The parameter γ measures the importance of consumption of the home good in preferences over traded goods. For $\gamma > 1/2$, we have ‘home bias’ in preferences. Given this specification, the aggregate CPI for home households is therefore

$$P_t = \left[\eta P_{N,t}^{(1-\varepsilon)} + (1-\eta) P_{T,t}^{(1-\varepsilon)} \right]^{\frac{1}{1-\varepsilon}} \quad (5)$$

where P_N and P_T are the aggregate price indices for traded and non-traded goods where P_T is given by

$$P_{T,t} = \left[\gamma P_{H,H,t}^{1-\theta} + (1-\gamma) P_{F,H,t}^{1-\theta} \right]^{\frac{1}{1-\theta}} \quad (6)$$

where $P_{H,H}$ is the aggregate price index of home traded goods for home consumers and $P_{F,H}$ is the aggregate price index of foreign traded goods for home consumers. The corresponding prices for foreign consumers are $P_{H,F}$ and $P_{F,F}$.

The flow budget constraint of the home country household is

$$P_t C_t + P_t F_t = w_t H_t + P_t \Pi_t + P_t \Theta_t - P_t T_{D,t} + P_t \sum_{k=1}^N \alpha_{k,t-1} r_{kt} \quad (7)$$

where F_t denotes home country net external assets in terms of the home consumption basket, w_t is the home nominal wage, Π_t represents real profits of all home firms, (defined further below), Θ_t is the surplus of labor unions (again defined below) and $T_{D,t}$ is lump-sum taxes imposed on households. The final term represents the total return on the home country portfolio where $\alpha_{k,t-1}$ represents the real *external* holdings of asset k (defined in terms of home country consumption, purchased at the end of period $t-1$ for holding into period t) and $r_{k,t}$ represents the gross real return on asset k . We allow for trade in up to $N = 4$ assets; home and foreign equity, as well as home and foreign nominal bonds.¹³

Nominal bonds are assumed to be perpetuities, so for instance, home nominal bonds represent a claim on a unit of home currency in each period into the infinite future. The real price of the home bond is denoted $Z_{B,t}$. The gross real rate of return on a home bond is thus $r_{Bt+1} = (1/P_{t+1} + Z_{B,t+1})/Z_{B,t}$. For the foreign nominal bond, the real return on foreign bonds, in terms of home consumption, is $r_{B^*t+1} = (Q_{t+1}/Q_t)(1/P_{t+1}^* + Z_{B,t+1}^*)/Z_{B,t}^*$, where $Q_t = SP_t^*/P_t$ is the real exchange rate of the home economy.

Home equities represent a claim on home aggregate profits of all firms in the home traded, non-traded, final and intermediate sectors. The real payoff to a unit of the home equity purchased in period t is defined to be $\Pi_{t+1} + Z_{E,t+1}$, where $Z_{E,t+1}$ is the real price of home

¹³Note that F_t is defined as $F_t = \sum_{k=1}^N \alpha_{k,t}$.

equity and Π_{t+1} is real aggregate profits. Thus the gross real rate of return on the home equity is $r_{E,t+1} = (\Pi_{t+1} + Z_{E,t+1})/Z_{E,t}$.

Without loss of generality, we let the foreign nominal bond act as the N th asset, so that $r_{N,t+1} = r_{B^*t+1}$.

Optimal portfolio choices imply

$$E_t C_{t+1}^{-\rho} (r_{k,t+1} - r_{N,t+1}) = 0, \quad k = 1..N - 1. \quad (8)$$

The portfolio selection equation for the foreign agent must take account of the fact that real exchange rate changes alter the optimal relationship between marginal utility and excess returns, so that

$$E_t C_{t+1}^{*\rho} \frac{(r_{k,t+1} - r_{N,t+1})}{Q_{t+1}} = 0, \quad k = 1..N - 1. \quad (9)$$

3.2 Government

Total government expenditure is assumed to be exogenous and subject to stochastic shocks. In particular we assume that $G_t = \bar{G} \exp(\hat{G}_t)$ where $\hat{G}_t = \psi_G \hat{G}_{t-1} + \varepsilon_{G,t}$, where, $0 < \psi_G < 1$ and $\varepsilon_{G,t}$ is a zero-mean normally distributed i.i.d. shock with $Var[\varepsilon_G] = \sigma_G^2$. G is assumed to be allocated between non-traded and home traded goods in fixed proportions η and $1 - \eta$. The allocation of government expenditure across individual goods within each sector is governed by an aggregators similar to that of consumers.

All government spending is financed via lump sum taxes on households, T_D , and firms, T_C . The budget constraint is $P_{G,t} G_t = P_t T_{D,t} + P_t T_{C,t}$ where it is assumed that $P_t T_D = (1 - \tau) P_{G,t} G$ and $P_t T_C = \tau P_{G,t} G$ where τ is a fixed parameter which determines the share of profit taxes in the overall tax take. $P_{G,t}$ is the price index of government purchased goods and is given by $P_{G,t} = \eta P_{N,t} + (1 - \eta) P_{H,H,t}$.

3.3 The Labor Market

Labor unions are introduced as a convenient modeling device to allow for nominal wage stickiness.

Labor unions hire homogeneous labor from households in a perfectly competitive primary labor market at wage rate w_t . They act as monopolistic competitors in a secondary labor market where they sell differentiated labor to intermediate goods firms. Labor union z charges $w_t(z)$ in the secondary market and faces demand for its variety of labor as follows

$$L_t(z) = L_t \left(\frac{w_t(z)}{W_t} \right)^{-\xi}$$

where L_t is aggregate demand for labor and W_t is the aggregate wage in the secondary labor market and ξ is the elasticity of substitution between labor varieties.

The choice of $w_t(z)$ is subject to Calvo-style sticky-wage contracts with partial backward indexation. In each period $w_t(z)$ can be optimally reset with probability $1 - \varsigma$ or partially indexed to past aggregate wage inflation with probability ς where the degree of indexation is given by ϖ (where $0 \leq \varpi \leq 1$).

Labor union z chooses $w_t(z)$ to maximize

$$E_t \sum_{i=0}^{\infty} \Omega_{t+i} \left[L_{t+i}(z) \frac{w_t(z)}{P_{t+i}} - L_{t+i}(z) \frac{w_{t+i}}{P_{t+i}} \right]$$

where Ω_t is the stochastic discount factor of home households. The aggregate surplus of labor unions (which is paid to households) is given by $\Theta_t = L_t (W_t - w_t) / P_t$.

3.4 Firms

Within each country there is a traded and non-traded sector and within each of these sectors firms are divided between final and intermediate sectors. Intermediate goods firms use labor and fixed capital. Labor is fully mobile between sectors but capital is immobile. The structure of the intermediate sector is similar in the traded and non-traded sectors so the equations shown below apply to both traded and non-traded sectors. Variables for the traded and non-traded sectors are indicated with subscripts T and N .

There is a unit mass of firms in each of the non-traded and traded sectors at both the final and intermediate levels.

3.4.1 Final goods

Each firm in the final goods sector of sector j produces a single differentiated product. Sticky prices are modeled in the form of Calvo-style contracts with a probability of re-setting price given by $1 - \kappa$ and partial backward indexation with the degree of indexation given by ω (where $0 \leq \omega \leq 1$). We consider both producer currency pricing (PCP) and local currency pricing (LCP).

If firms use the discount factor Ω_t to evaluate future profits, then, in the PCP case, firm z in the traded sector chooses its prices for home and foreign buyers, $p_{H,H,t}(z)$ and $p_{H,F,t}(z)$, in home currency to maximize

$$E_t \sum_{i=0}^{\infty} \Omega_{t+i} \kappa^i \left\{ y_{H,H,t+i}(z) \frac{[p_{H,H,t}(z) - q_{T,t+i}]}{P_{t+i}} + y_{H,F,t+i}(z) \frac{[p_{H,F,t}(z) - q_{T,t+i}]}{P_{t+i}} \right\} \quad (10)$$

where $y_{H,H}(z)$ is the demand for home traded good z from home buyers and $y_{H,F}(z)$ is the demand for home good z from foreign buyers and q_T is the price of the intermediate good in the traded goods sector.

In the LCP case firm z chooses $p_{H,H,t}(z)$ in home currency and $p_{H,F,t}^*(z)$ in foreign currency to maximize (10) where $p_{H,F,t}(z)$ is replaced by $p_{H,F,t}^*(z)S_{t+i}$ where S is the price of the foreign currency in terms of the home currency.

In the non-traded sector firm z chooses $p_{N,t}(z)$ to maximize

$$E_t \sum_{i=0}^{\infty} \Omega_{t+i} k^i y_{N,t+i}(z) \frac{[p_{N,t}(z) - q_{N,t+i}]}{P_{t+i}} \quad (11)$$

where $y_N(z)$ is the demand for non-traded good z and q_N is the price of the intermediate good in the non-traded goods sector.

Monopoly power in the final goods sector implies that final goods prices are subject to a mark-up given by $v_t = \lambda_t/(\lambda_t - 1)$. The mark-up is assumed to be subject to stochastic shocks such that $v_t = \bar{v} \exp(\hat{v}_t)$ where $\hat{v}_t = \psi_v \hat{v}_{t-1} + \varepsilon_{v,t}$, where, $0 < \psi_v < 1$ and $\varepsilon_{v,t}$ is a zero-mean normally distributed i.i.d. shock with $Var[\varepsilon_v] = \sigma_v^2$.

3.4.2 Intermediate goods

The representative firm in the intermediate goods sector j (where $j = N, T$) combines labor, L_j , and capital, K_j , to produce output Y_j using a standard Cobb-Douglas technology, $Y_{j,t} = A_{j,t}(z_{j,t}K_{j,t-1})^{1-\mu}L_{j,t}^\mu$, where $0 \leq z_{j,t} \leq 1$ is capacity utilization, L is an index defined across all individual varieties of labor supplied by labor unions and $A_{j,t} = \exp(\hat{a}_{j,t})$ is a common stochastic productivity shock across all intermediate goods firms in sector j . Productivity shocks follow a joint process of the form

$$\begin{bmatrix} \hat{a}_{T,t} \\ \hat{a}_{T,t}^* \\ \hat{a}_{N,t} \\ \hat{a}_{N,t}^* \end{bmatrix} = A \begin{bmatrix} \hat{a}_{T,t-1} \\ \hat{a}_{T,t-1}^* \\ \hat{a}_{N,t-1} \\ \hat{a}_{N,t-1}^* \end{bmatrix} + \varepsilon_{a,t} \quad (12)$$

where $\varepsilon_{a,t}$ is a vector of zero-mean normally distributed i.i.d. shocks with variance-covariance matrix Σ_a .

The capital accumulation equation in sector j is

$$K_{j,t+1} = I_{j,t} + (1 - \varrho)K_{j,t}$$

where $0 \leq \varrho \leq 1$ is the rate of depreciation. Capital is subject to adjustment costs given by

$$\frac{\varphi(\iota_t I_{j,t} - \bar{I}_j)^2}{2\bar{I}_j}$$

where $\varphi > 0$ and \bar{I}_j is the steady state level of investment in sector j . ι_t is a stochastic shock to investment costs which is common to both traded and non-traded sectors, where $\iota_t = \exp(\hat{\iota}_t)$ and $\hat{\iota}_t = \psi_\iota \hat{\iota}_{t-1} + \varepsilon_{\iota,t}$, where, $0 < \psi_\iota < 1$ and $\varepsilon_{\iota,t}$, is a zero-mean normally distributed i.i.d. shock with $Var[\varepsilon_\iota] = \sigma_\iota^2$. Capital has the same composition as consumption (see equations (3) and (4)) so the price of investment goods is given by (5).

Firms are assumed to incur costs of unused capacity which are given by the following

$$\frac{F(z_{j,t+i} - 1)^2}{2}$$

where $F \geq 0$.¹⁴

The representative firm in sector j chooses $L_{j,t}$, $I_{j,t}$ and $K_{j,t}$ to maximize the real discounted value of dividends, given by

$$E_t \sum_{i=0}^{\infty} \Omega_{t+i} \Upsilon_{t+i} \left[\frac{q_{j,t+i} Y_{j,t+i}}{P_{t+i}} - \frac{W_{t+i}}{P_{t+i}} L_{j,t+i} - I_{j,t+i} - \frac{\varphi(\iota_{t+i} I_{j,t+i} - \bar{I}_j)^2}{2\bar{I}_j} - \frac{F(z_{j,t+i} - 1)^2}{2} \right]$$

subject to the production function and capital accumulation equations where q_j is the price of intermediate goods in sector j . Ω_t is the stochastic discount factor of shareholders of the firm. Υ_t is a shock which affects the cost of funds to firms. Smets and Wouters (2003) refer to this as a risk premium shock and suggest that it captures the effects of variations in the external finance premium. We assume that $\Upsilon_t = \exp(\hat{\Upsilon}_t)$ and $\hat{\Upsilon}_t = \psi_\Upsilon \hat{\Upsilon}_{t-1} + \varepsilon_{\Upsilon,t}$, where, $0 < \psi_\Upsilon < 1$.

3.4.3 Aggregate output and employment

Total private sector expenditure is

$$D_t = C_t + I_{N,t} + I_{T,t} + \frac{\varphi(\iota_t I_{N,t} - \bar{I}_N)^2}{2\bar{I}_N} + \frac{\varphi(\iota_t I_{T,t} - \bar{I}_T)^2}{2\bar{I}_T} + \frac{F(z_{j,t+i} - 1)^2}{2} \quad (13)$$

so home purchases of home non-traded and home traded final goods are

$$D_{N,t} = \eta \left(\frac{P_{N,t}}{P_t} \right)^{-\eta} D_t \quad (14)$$

$$D_{H,t} = \gamma(1 - \eta) \left(\frac{P_{T,t}}{P_t} \right)^{-\eta} \left(\frac{P_{H,H,t}}{P_{T,t}} \right)^{-\theta} D_t \quad (15)$$

¹⁴Christiano *et al* (2005) argue that variable capital utilization is important in explaining the apparent degree of price inertia. Variable capital utilization implies that the marginal cost of capital tends to be less variable over the cycle and thus output prices are less variable. Variable capital utilization is also a feature of the Smets and Wouters (2003). If capital utilization is assumed to be fixed (i.e. $z_j = 1$) all the qualitative results reported below are unaffected. The only effect is that the size of gross positions is somewhat less sensitive to the degree of inflation variability.

Using the properties of demand curves, we can define equilibrium in the market for good z in the home country non-traded final goods sector as

$$y_{N,t}(z) = \left(\frac{p_{N,t}(z)}{P_{N,t}} \right)^{-\lambda} [D_{N,t} + \eta G_t]$$

So aggregate demand for the non-traded intermediate good is

$$Y_{N,t} = \int_0^1 y_{N,t}(z) dz = V_{N,t} [D_{N,t} + \eta G_t]$$

where $V_{N,t} = \int_0^1 \left(\frac{p_{N,t}(z)}{P_{N,t}} \right)^{-\lambda} dz$.

Each home country firm in the traded final goods sector faces demand for its good from home consumers and foreign consumers. Again, using the properties of demand curves, we can define equilibrium in the market for good z in the home country traded final goods sector as

$$y_{T,t}(z) = y_{H,H,t}(z) + y_{H,F,t}(z)$$

where

$$y_{H,H,t}(z) = \left(\frac{p_{H,H,t}(z)}{P_{H,H,t}} \right)^{-\lambda} [D_{H,t} + (1 - \eta)G_t] \quad y_{H,F,t}(z) = \left(\frac{p_{H,F,t}^*(z)}{P_{H,F,t}^*} \right)^{-\lambda} D_{H,t}^* \quad (16)$$

where $D_{H,t}^*$ is the foreign country demand for home traded goods (which is defined analogously to (15)). So aggregate demand for the home traded intermediate good is therefore

$$Y_{T,t} = \int_0^1 y_{H,H,t}(z) dz + \int_0^1 y_{H,F,t}(z) dz = V_{H,H,t} [D_{H,t} + (1 - \eta)G_t] + V_{H,F,t} D_{H,t}^*$$

where $V_{H,H,t} = \int_0^1 \left(\frac{p_{H,H,t}(z)}{P_{H,H,t}} \right)^{-\lambda} dz$ and $V_{H,F,t} = \int_0^1 \left(\frac{p_{H,F,t}^*(z)}{P_{H,F,t}^*} \right)^{-\lambda} dz$.

Aggregate GDP for the home economy is given by

$$Y_t = \frac{P_{N,t}}{P_{Y,t}} [D_{N,t} + \eta G_t] + \frac{P_{H,H,t}}{P_{Y,t}} [D_{H,t} + (1 - \eta)G_t] + \frac{S_t P_{H,F,t}^*}{P_{Y,t}} D_{H,t}^*$$

where $P_{Y,t}$ is the GDP deflator, which we define as follows

$$P_{Y,t} = \eta P_{N,t} + (1 - \eta)[(1 - g)\gamma + g]P_{H,H,t} + (1 - \eta)(1 - g)(1 - \gamma)S_t P_{H,F,t}^*$$

where g is the steady-state share of government spending in GDP.

Demand for labor variety z is given by

$$L_t(z) = \left(\frac{w_t(z)}{W_t} \right)^{-\xi} [L_{N,t} + L_{T,t}]$$

Aggregating across all varieties of labor yields the aggregate demand for labor in the primary labor market as follows

$$L_t = V_{L,t}^{-1} \int_0^1 L_t(z) dz = L_{N,t} + L_{T,t}$$

where $V_{L,t} = \int_0^1 \left(\frac{w_t(z)}{W_t} \right)^{-\xi} dz$. Equilibrium in the primary labor market implies $L_t = H_t$.

Total after-tax dividends aggregated across all intermediate and final goods firms in both traded and non-traded sectors are given by

$$\begin{aligned} \Pi_t = & \frac{P_{Y,t}}{P_t} Y_t - \frac{W_t}{P_t} L_t - I_{N,t} - I_{T,t} \\ & - \frac{\varphi(\iota_t I_{N,t} - \bar{I}_N)^2}{2\bar{I}_N} - \frac{\varphi(\iota_t I_{T,t} - \bar{I}_T)^2}{2\bar{I}_T} - \frac{F(z_{N,t+i} - 1)^2}{2} - \frac{F(z_{T,t+i} - 1)^2}{2} - T_{C,t} \end{aligned}$$

Home equities represent claims on Π_t (into the infinite future).

3.5 Monetary Authorities

Monetary authorities follow a policy that targets the path of, i_t , the nominal rate of return on the nominal bonds of their respective currencies. We assume that the target for i_t is governed by a Taylor rule. For the home country, this is described by

$$i_t = \beta^{\frac{1}{\vartheta-1}} i_{t-1}^{\vartheta} \left[\left(\frac{P_t}{P_{t-1}} \right)^{\chi} \left(\frac{Y_t}{\tilde{Y}_t} \right)^{\delta} \exp(\varepsilon_{m,t}) \right]^{1-\vartheta} \quad (17)$$

where $0 < \vartheta < 1$, $\chi > 1$, and $\delta > 0$, and \tilde{Y}_t represents potential output of the home country. $\varepsilon_{m,t}$ is a random monetary policy disturbance which is zero-mean, i.i.d. and normally distributed with $Var[\varepsilon_m] = \sigma_m^2$.

Note that the rule (17) determines the nominal interest rate as a function of the historic CPI inflation rate. We choose the CPI inflation rate because this represents a better description of the actual practice in countries that have been explicitly following inflation targeting policies. More generally, even outside of the explicit inflation targeters, the CPI is by far the most visible and relevant price index for guiding monetary policy. Finally, while our focus is not on optimal policy, in the presence of local currency pricing, it has been established that targeting CPI inflation may be preferable to PPI inflation targeting (Engel, 2011).

We will assume that potential output, \tilde{Y}_t , is constant. This assumption would not be justified if we were modeling the optimal choice of policy rule since shocks to productivity and preferences clearly change the welfare relevant measure of potential output. As our purpose

is to represent actual rather than optimal monetary policymaking, we ignore the impact of shocks on \tilde{Y}_t . In practice policymakers are not able directly to observe shocks affecting potential output and therefore tend to measure potential output using a moving average measure of actual output. This tends not to change much in the short run in response to shocks.

While we argue that rule in the form of (17) which depends on CPI inflation and the output gap measured relative to a fairly static measure of capacity output is a reasonable empirical representation of actual monetary policy, we do consider alternative forms of monetary rule in our numerical analysis of the model.

Rule (17) allows for a degree of partial adjustment in monetary policy, which is determined by the parameter ϑ .

The feedback parameter on inflation, χ , will be a key parameter in the analysis which follows. A higher value of χ implies that monetary policy is more focused on inflation stabilization. In equilibrium this will result in lower variability of inflation. The central issue we will investigate is the relationship between χ and the size of equilibrium gross holdings of equities and bonds.

4 Portfolio Choice

Our main interest is in the characteristics of the portfolio positions, and their relationship to the stance of monetary policy. In this vein, we follow Devereux and Sutherland (2011a) in computing the characteristics of the portfolios using a second order approximation to the portfolio selection equations for the home and foreign country (8) and (9), in conjunction with a first order approximation to the home and foreign budget constraints and the vector of excess returns.

The Devereux and Sutherland (2011a) approach allows us to derive reduced-form solutions for gross portfolio holdings of equities and bonds. In order to interpret these solutions we now derive some useful expressions which show how portfolio holdings are related in equilibrium to the second moments of income and asset returns. These expressions are not reduced-form solutions in the sense that the second moments of income and asset returns themselves depend on portfolio holdings. They do however highlight some of the underlying intuition for the link between inflation variability and gross portfolio positions.

In all the cases we analyze below the home and foreign economies are entirely symmetric. If it is assumed that assets 1 and 2 are respectively home and foreign equities then it follows that $\alpha_1 = -\alpha_2$ in equilibrium. Likewise, if assets 3 and 4 are home and foreign bonds

then in equilibrium it follows that $\alpha_3 = -\alpha_4$. It is useful to define $\alpha_e = -\alpha_1 = \alpha_2$ and $\alpha_b = -\alpha_3 = \alpha_4$. Thus α_e is a measure of the gross external position in equities and α_b is a measure of the gross external position in bonds, where “gross external position” is defined to be the position that one country holds in the assets issued by the other country. It is also useful to define $r_{x,t}^e = r_t^e - r_t^{*e}$ to be the return on home equities relative to the return on foreign equities and $r_{x,t}^b = r_t^b - r_t^{*b}$ to be the return on home bonds relative to the return on foreign bonds.

Following Devereux and Sutherland (2011a) we obtain the condition

$$E_t \left(c_{t+1} - c_{t+1}^* - \frac{1}{\rho} q_{t+1} \right) r_{x,t+1} = 0 \quad (18)$$

where $z = \frac{z - \bar{z}}{\bar{z}}$, except for $r_{x,t}$, which is defined as $r_{x,t} = [r_{x,t}^e, r_{x,t}^b]'$.

Note that using the definitions of F_t , Π_t and Θ_t and the government budget constraint we may write the home country budget constraint as

$$P_t C_t + P_t F_t = P_{Y,t} Y_{C,t} + P_t \sum_{k=1}^N \alpha_{k,t-1} r_{kt}$$

where

$$Y_{C,t} = Y_t - \frac{P_t}{P_{Y,t}} I_{N,t} - \frac{P_t}{P_{Y,t}} I_{T,t} - \frac{P_t}{P_{Y,t}} \frac{\psi(\iota_t I_{N,t} - \bar{I}_N)^2}{2\bar{I}_N} - \frac{P_t}{P_{Y,t}} \frac{\psi(\iota_t I_{T,t} - \bar{I}_T)^2}{2\bar{I}_T} - \frac{P_{G,t}}{P_{Y,t}} G_t$$

is home output net of investment and government expenditure. $Y_{C,t}$ can be thought of as the resources available for household consumption expenditure, i.e. household *disposable income*.

Taking a first order approximation around the initial point where $F = 0$, we obtain

$$\bar{C} c_t + f_t = \bar{C} y_{C,t} + \bar{C} p_{Y,t} - \bar{C} p_t + \beta^{-1} f_{t-1} + \tilde{\alpha}' r_{x,t} \quad (19)$$

where \bar{C} is steady state consumption relative to GDP and f is measured in terms of level deviations from the steady state (of zero), relative to steady state GDP and $\tilde{\alpha} = [\frac{\alpha_e}{\beta Y}, \frac{\alpha_b}{\beta Y}]' = [\tilde{\alpha}_e, \tilde{\alpha}_b]'$ represents the zero order (or steady state) portfolio, relative to steady state GDP.¹⁵

Using the equivalent condition for the foreign country, and leading by one period, we arrive at the condition

$$\bar{C} \left(\Delta c_{t+1} - \frac{1}{\rho} q_{t+1} \right) = \bar{C} \Delta y_{t+1} + \bar{C} \frac{(\rho - 1)}{\rho} q_{t+1} + \beta^{-1} 2f_t - 2f_{t+1} + 2\tilde{\alpha}' r_{x,t+1} \quad (20)$$

¹⁵To simplify notation in this expression (and those which follow) we omit the residual of approximation. Note that, unlike in Devereux and Sutherland (2011a) where shock processes are assumed to have finite support, the shock processes in this model are normally distributed. This implies that the appropriate interpretation of the order of approximation is in terms of “order in probability”.

where $\Delta c = c - c^*$, $\Delta y = y_C - y_C^* - p_Y^* - s + p_Y$. Now iterating forward on (20), using the appropriate transversality constraint, gives

$$\begin{aligned} \bar{C}E_{t+1} \sum_{j=0}^{\infty} \beta^j \left(\Delta c_{t+1+j} - \frac{1}{\rho} q_{t+1+j} \right) &= \bar{C}E_{t+1} \sum_{j=0}^{\infty} \beta^j \left[\Delta y_{t+1+j} + \frac{(\rho-1)}{\rho} q_{t+1+j} \right] \\ &\quad + \beta^{-1} 2f_t + 2\tilde{\alpha}' r_{x,t+1} \end{aligned} \quad (21)$$

From the Euler equations for consumption growth for the home and foreign country we have

$$E_t \Delta c_{t+1} = \Delta c_t + \frac{E_t q_{t+1} - q_t}{\rho} \quad (22)$$

Now, using (21) with (22) we arrive at the expression for real exchange rate adjusted relative consumption in period $t+1$ as

$$\bar{C} \left(\Delta c_{t+1} - \frac{1}{\rho} q_{t+1} \right) = (1-\beta) \left[\Gamma_{y,t+1} + \beta^{-1} 2f_t + 2\tilde{\alpha}' r_{x,t+1} \right] \quad (23)$$

where

$$\Gamma_{y,t+1} = \bar{C}E_{t+1} \sum_{j=0}^{\infty} \beta^j \left(\Delta y_{t+1+j} + \frac{(\rho-1)}{\rho} q_{t+1+j} \right)$$

represents the present value of expected innovations to relative disposable income, plus the present value of expected innovations to the real exchange rate. Note that in the case of $\rho = 1$, the second term drops out, and innovations in current and expected future real exchange rates do not directly affect the value of $\Delta c_{t+1} - \frac{1}{\rho} q_{t+1}$.

Putting (23) together with the orthogonality condition (18), we may compute the expressions characterizing the equilibrium portfolio as

$$\tilde{\alpha} = \frac{1}{2} \Sigma_r^{-1} \text{cov}_t(r_{x,t+1}, \zeta_{y,t+1}) \quad (24)$$

where $\zeta_{y,t+1} = \Gamma_{y,t+1} - E_t \Gamma_{y,t+1}$ and where Σ_r is the co-variance matrix of $r_{x,t+1} - E_t r_{x,t+1}$. Thus, the optimal portfolio position is determined by the way in which innovations in the excess return vector co-vary with innovations in the expected present discounted value of relative income (adjusted by the real exchange rate). Note that expression (24) is not a reduced form because the second moments on the right-hand side depend on $\tilde{\alpha}$.

The Appendix shows that equation (24) is equivalent to the following expressions for equilibrium asset holdings

$$\tilde{\alpha}_e = \frac{1}{2} \text{corr}(\zeta_{y,t}, r_{x,t}^e | r_{x,t}^b) \frac{\text{StDev}(\zeta_{y,t} | r_{x,t}^b)}{\text{StDev}(r_{x,t}^e | r_{x,t}^b)} \quad (25)$$

$$\tilde{\alpha}_b = \frac{1}{2} \text{corr}(\zeta_{y,t}, r_{x,t}^b | r_{x,t}^e) \frac{\text{StDev}(\zeta_{y,t} | r_{x,t}^e)}{\text{StDev}(r_{x,t}^b | r_{x,t}^e)} \quad (26)$$

These expressions show that the size of the gross position in asset i depends on two factors:

- 1 $\text{corr}(\zeta_{y,t}, r_{x,t}^i | r_{x,t}^j)$, the correlation of the return differential of asset i with innovations in the present value of relative disposable income (conditional on the return differential of asset j)
- 2 $\text{StDev}(\zeta_{y,t} | r_{x,t}^j) / \text{StDev}(r_{x,t}^i | r_{x,t}^j)$, the standard deviation of innovations in the present value of relative disposable income (conditional on the return differential of asset j) relative to the standard deviations of returns on asset i (conditional on the return differential of asset j)

Again note that we use the Devereux and Sutherland (2011a) approach to derive solutions for equilibrium portfolios and we use (25) and (26) only as a useful means to analyze the dependence of equilibrium portfolios on monetary policy and inflation variability. The expressions (25) and (26) can not themselves be used to calculate equilibrium portfolios because the second moments on the right-hand side depend on $\tilde{\alpha}$.¹⁶ Note also that these two expressions hold regardless of the completeness of international financial markets. Our model in its most general form contains more sources of shocks than there are independent assets. Full risk sharing is therefore not possible. Equations (25) and (26) can nevertheless be used to analyze equilibrium portfolio holdings.

Expressions (25) and (26) will prove useful in interpreting the impact of inflation variability on portfolio positions. These expressions have a very intuitive explanation. Agents wish to hold a portfolio of assets which hedge against shocks to relative disposable income, ζ_y . The extent to which asset i provides a good hedge against relative disposable income shocks depends on the correlation between the return on asset i and relative disposable income shocks, i.e. $\text{corr}(\zeta_{y,t}, r_{x,t}^i | r_{x,t}^j)$. An asset which is (negatively) correlated with disposable income shocks is a good hedging instrument and so will be held in the equilibrium portfolio with a positive gross position. The stronger the correlation the more of that asset

¹⁶In principle the behavior of both excess returns and relative income depend on portfolio holdings. In any given model it is possible to analyze the degree and nature of this dependence by solving the model for an exogenously fixed portfolio and investigating the effect of variations in that portfolio on asset returns and income differences. In the current model it appears that portfolio holdings have their most significant effect on income differences. For instance, a shift from zero portfolio holdings to optimal equilibrium portfolio holdings appears to reduce the volatility of income differences. This appears to be because the equilibrium portfolio reduces consumption differences (because it improves risk sharing), which tends to reduce fluctuations in relative goods demand across countries. This helps to stabilize output and income. The net result is that the general equilibrium portfolio implies smaller (in absolute size) gross portfolio holdings than would be predicted by (25) and (26) if the moments on the right hand side of these expressions were calculated on the basis of a zero portfolio equilibrium.

will be held. But the amount of the asset that needs to be held to hedge income shocks also depends on the size of fluctuations in disposable income relative to the size of fluctuations in the return on asset i , i.e. $\text{StDev}(\zeta_{y,t}|r_{x,t}^j) / \text{StDev}(r_{x,t}^i|r_{x,t}^j)$. The larger are fluctuations in disposable income relative to fluctuations in the return on asset i the larger must be the gross position in asset i in order to provide the desired degree of hedging.

These two effects, (i.e. *the correlation effect* measured by $\text{corr}(\zeta_{y,t}, r_{x,t}^i|r_{x,t}^j)$, and *the volatility effect* measured by $\text{StDev}(\zeta_{y,t}|r_{x,t}^j) / \text{StDev}(r_{x,t}^i|r_{x,t}^j)$), will prove useful in interpreting the link between inflation variability and the size of gross positions.¹⁷

5 Monetary Policy and Gross Portfolios: A Simple Example

In the quantitative analysis below we show that gross portfolio positions are sensitive to monetary policy, and in particular that a tighter monetary policy rule - associated with a higher value of χ (the feedback coefficient on inflation in the Taylor rule) - leads to an expansion of gross bond and equity positions. Here, we develop a special case to demonstrate the intuition for this result. To do this, we examine a drastically simplified version of the above model.

In this case, rather than Calvo-style price and wage setting, we assume that nominal wages are perfectly flexible and that all final goods prices are re-set period by period with fraction κ of firms setting prices in each period in advance of shocks being realized for that period and fraction $(1 - \kappa)$ setting prices after shocks have been realized. We also assume that there is no non-traded goods sector ($\eta = 0$) and no home bias in preferences over traded goods ($\gamma = 1/2$), no government spending and that utility is linear in work effort, i.e. $\phi = 0$. We further assume that the production function is linear in labor input, i.e. $\mu = 1$ (so real

¹⁷van Wincoop and Warnock (2010) use an expression very simpler to (25) and (26) to analyze the links between home bias in goods markets and home bias in equity holdings. The specific question they address is whether equilibrium equity holdings reflect a desire to hedge real exchange rate fluctuations. Notice that exactly this hedging motive enters (25) and (26) via the definition of $\zeta_{y,t}$. van Wincoop and Warnock show that data on covariances between real exchange rates and excess asset returns do not support the proposition that equity home bias arises because of a desire to hedge real exchange rate risks. Notice however that, while this result casts doubt on the role of real exchange rate hedging in generating equity home bias, it does not necessarily imply that expressions such as (25) and (26) are empirically invalid. Real exchange rate fluctuations are only one of the risks faced by households. Overall portfolio holdings are (in theory) designed to hedge all risks and a full empirical test of (25) and (26) would require data on the covariance between excess returns and an empirical measure of $\zeta_{y,t}$. This is certainly an interesting topic for further research.

capital and investment are zero). We simplify the monetary policy rule by assuming that there is no inertia in interest rate setting, i.e. $\vartheta = 0$. Finally, we assume that there are shocks only to productivity and that these shocks are i.i.d. (i.e. $A = 0$). For transparency, we assume that there are only relative shocks, so that $\hat{a}_T^* = -\hat{a}_T$.¹⁸

With only one source of stochastic shocks, perfect risk sharing can be achieved with just two assets. We therefore consider separately the case where there are two equities (home and foreign) and two nominal bonds (denominated in home and foreign currency).

Using the assumptions just stated, we may derive an expression for the present value of innovations in expected relative home income, $\zeta_{y,t}$, as follows

$$\zeta_{y,t} = \frac{(\chi/\delta)(\theta - 1)(1 - \kappa)}{\chi/\delta + \kappa\theta} 2\hat{a}_{T,t} \quad (27)$$

Thus a shock to home productivity (relative to foreign productivity) raises the expected present value of relative home income, for $\theta > 1$. This expression holds for both the equities-only and bonds-only cases.

5.1 Equities only

Again, using the assumptions specific to this example, we can establish that the excess return on home equity relative to foreign equity is

$$r_{x,t}^e = (1 - \beta) \frac{\kappa(\lambda - 1)\theta + (\chi/\delta)[\theta - 1 + \kappa(\lambda - \theta)]}{\chi/\delta + \kappa\theta} 2\hat{a}_{T,t} \quad (28)$$

Thus a shock to home productivity (relative to foreign productivity) raises the excess relative return on home equity (assuming $\theta > 1$).

Since markets are complete in this example, households can fully insure against shocks by holding a portfolio of home and foreign equities. By definition, the full insurance portfolio has a payoff which perfectly offsets innovations to expected relative home income, $\zeta_{y,t}$. The optimal portfolio must therefore satisfy

$$\tilde{\alpha}_e r_{x,t}^e = -\zeta_{y,t}$$

¹⁸The effect of many of these simplifying assumptions is to shut down most of the dynamic elements of the model and therefore most of the sources of real inertia. This tends to amplify the short run effect of shocks on the endogenous variables of the model and emphasizes the role of monetary policy. The net result is to make portfolio holdings very sensitive to variations in the parameters of the monetary policy rule. The results reported in this section therefore tend to exaggerate the quantitative significance of the link between inflation variability and the size of portfolio holdings. It will become apparent below that, in the general model, once all the dynamic elements of the model are re-introduced, portfolio holdings tend to be less sensitive to the stance of monetary policy.

Using this condition and the expressions for $\zeta_{y,t}$ and $r_{x,t}^e$ given in (27) and (28) the equity portfolio is

$$\tilde{\alpha}_e = \frac{1}{2} \frac{1}{(1-\beta)} \frac{(\chi/\delta)(\theta-1)(1-\kappa)}{\kappa(\lambda-1)\theta + (\chi/\delta)[\theta-1 + \kappa(\lambda-\theta)]} \quad (29)$$

Thus the home country takes a long position in foreign equity, $\tilde{\alpha}_e > 0$ (assuming $\theta > 1$ and $\lambda > \theta$).¹⁹

The key feature of (29) is that gross holdings of equities depend on the parameters of the monetary rule. It is simple to show that (provided $\lambda > \theta$) as the weight on CPI inflation in the monetary rule rises (i.e. as χ rises), the size of the gross equity position rises.

Further insight into the underlying determinants of gross positions can be gained by considering the expressions for asset positions stated in (25) and (26). For the equities-only case in the current model the following expressions can be derived (assuming $\theta > 1$)

$$\begin{aligned} \text{StDev}(\zeta_{y,t}) &= \frac{(\chi/\delta)(\theta-1)(1-\kappa)}{\chi/\delta + \kappa\theta} 2\sigma_a \\ \text{corr}(\zeta_{y,t}, r_{x,t}^e) &= 1 \\ \text{StDev}(r_{x,t}^e) &= (1-\beta) \frac{\kappa(\lambda-1)\theta + (\chi/\delta)[\theta-1 + \kappa(\lambda-\theta)]}{\chi/\delta + \kappa\theta} 2\sigma_a \end{aligned}$$

where σ_a^2 is the variance of productivity shocks. Note that these expressions are for unconditional moments since there is only one type of asset traded.

These expressions show that χ affects portfolio holdings through its impact on the standard deviation of $\zeta_{y,t}$ and $r_{x,t}^e$. More specifically, it can be shown that, as χ rises, $\text{StDev}(\zeta_{y,t})$ increases and $\text{StDev}(r_{x,t}^e)$ decreases.

The link between inflation variability and the standard deviation of relative income, $\text{StDev}(\zeta_{y,t})$, can be explained as follows. The presence of sticky nominal prices implies that, as monetary authorities adopt a monetary stance which is focused on inflation stabilizing, the volatility of real output increases. This translates into more volatility in relative income, as indicated by the behavior of $\text{StDev}(\zeta_{y,t})$.

The impact of inflation variability on equity returns can also be explained in simple economic terms. Sticky nominal prices imply that profit margins are affected by variability in nominal marginal costs. A reduction in the volatility of CPI inflation tends to reduce the variability of nominal marginal costs and thus tends to stabilize profits and equity returns.

¹⁹Recall that $\tilde{\alpha}_e$ measures the gross external position in equities, where the ‘‘gross external position’’ is defined to be the position that one country holds in the equities issued by the other country. It is reasonable to assume that the elasticity of substitution between goods for sale within a country (λ) is higher than the elasticity of substitution between home and foreign goods (θ).

This, combined with the effect of inflation stabilization on $\text{StDev}(\zeta_{y,t})$ implies that the size of gross equity holdings increase as χ is increased.

This simple example illustrates how *the volatility effect* (which operates via the impact of inflation variability on $\text{StDev}(\zeta_{y,t}) / \text{StDev}(r_{x,t}^e)$) links inflation variability to the size of gross positions. Note that *the correlation effect* (which operates via $\text{corr}(\zeta_{y,t}, r_{x,t}^e)$) does not arise in this example because, in a complete markets case, this correlation is equal to unity regardless of the parameters of the monetary policy rule.

5.2 Bonds only

Now consider the case where financial trade is restricted to home and foreign bonds. Using the assumptions outlined above for this special case the excess return on home bonds relative to foreign bonds is

$$r_{x,t}^b = \frac{\theta(1-\kappa)}{\chi/\delta + \kappa\theta} 2\hat{a}_{T,t} \quad (30)$$

Given the form of the monetary rule (17), a productivity shock leads to a rise in the home nominal interest rate, which causes an appreciation of the home currency, so there is a positive excess return on home bonds relative to foreign bonds.

In the bonds-only case the optimal bond portfolio must satisfy

$$\tilde{\alpha}_b r_{x,t}^b = -\zeta_{yt}$$

so

$$\tilde{\alpha}_b = \frac{1}{2} \frac{(\chi/\delta)(\theta-1)}{\theta} \quad (31)$$

Thus the home country takes a long position in foreign bonds, $\tilde{\alpha}_b > 0$ (assuming $\theta > 1$).²⁰

Again, the key feature of (31) is that gross holdings depend on the parameters of the monetary rule. As the weight on CPI inflation in the monetary rule, χ , rises, the absolute size of the gross bond position rises.

As in the equities-only case, further insight into the underlying determinants of gross positions can be gained by considering the expressions for asset positions stated in (25) and (26). For the bonds-only case the following expression can be derived (assuming $\theta > 1$)

$$\text{StDev}(\zeta_{y,t}) = \frac{(\chi/\delta)(\theta-1)(1-\kappa)}{\chi/\delta + \kappa\theta} 2\sigma_a$$

$$\text{corr}(\zeta_{y,t}, r_{x,t}^b) = 1$$

²⁰Again, recall that $\tilde{\alpha}_b$ measures gross external position in bonds, where the “gross external position” is defined to be the position that one country holds in the bonds issued by the other country.

$$\text{StDev}(r_{x,t}^b) = \frac{\theta(1-\kappa)}{\chi/\delta + \kappa\theta} 2\sigma_a$$

These expressions show that the standard deviation of $\zeta_{y,t}$ increases, and the standard deviation of $r_{x,t}^b$ decreases, as χ increases.

The underlying economic explanation for the link between inflation variability and the variability of relative income is identical to the equities-only case, i.e. the presence of sticky nominal prices implies that, as monetary authorities adopt a monetary stance which is focused on inflation stabilizing, the volatility of real output increases. This translates into more volatility in relative income, as indicated by the behavior of $\text{StDev}(\zeta_{y,t})$.

The link between χ and the variability of relative bond returns is also easily understood. The nominal return on nominal bonds is fixed by assumption.²¹ Unanticipated shocks which affect CPI inflation therefore directly impact on the real return on nominal bonds. A monetary policy stance which stabilizes inflation must by definition stabilize the real return on nominal bonds. This is the effect captured by the above expression for $\text{StDev}(r_{x,t}^b)$.

In the case of bond holdings the variability of relative income increases and the variability of bond returns decreases as χ is increased. Both these effects contribute to the increase in the absolute size of gross bond holdings. This is again an example of *the return volatility effect*. Again note that *the correlation effect* (which operates via $\text{corr}(\zeta_{y,t}, r_{x,t}^b)$) does not arise in this example because, as before, when markets are complete, this correlation is equal to unity regardless of the parameters of the monetary policy rule.

6 Monetary Policy and Gross Portfolios: The General Case

The simple example model discussed above shows that, in the presence of sticky nominal prices, a monetary policy which stabilizes inflation tends to reduce the variability of real asset returns. This implies that gross portfolio positions in equities and bonds increase as inflation is stabilized.

We now turn to the general model (with Calvo price setting, real capital, traded and non-traded goods and a range of shocks) and show that this basic result continues to hold. We show that the underlying intuition for the basic result remains true, i.e. a reduction in inflation volatility tends to reduce the variability of asset returns, which tends to increase

²¹Nominal returns vary from period to period, but at the time portfolio allocations are made the nominal returns on bonds between the current period and the following period are known with certainty.

equilibrium gross positions in equities and bonds. We also demonstrate however, that when markets are incomplete, *the correlation effect* comes into play and can reinforce the negative relationship between inflation variability and the size of gross positions.

The general model is too complex to analyze explicitly so we focus on numerical simulations for plausible parameter values.

6.1 Benchmark parameter values

The benchmark parameter values used in the following analysis are listed in Table 3.

The discount factor, β , is chosen to yield a steady state rate of return of approximately 4%. The rate of depreciation of real capital, ϱ , is set at 0.025 (implying an annual rate of depreciation of 10%) and the value of the capital adjustment cost, φ , is chosen to yield a variance of total investment which is approximately 3 times the variance of GDP (which is consistent with the data for most developed economies). The capacity utilization cost parameter, F , is set at 0.2, which is consistent with the value estimated by Smets and Wouters (2003, 2005, 2007).

The value of θ , the elasticity between home and foreign traded goods, is consistent with the benchmark parameterization of Backus *et al* (1994). The share of non-traded goods in the consumption basket, η , the elasticity of substitution between traded and non-traded goods, \varkappa , and the share of home traded goods in the traded consumption basket, γ , are based on an approximate average of values used in Benigno and Thoenissen (2008), Corsetti *et al* (2008) and Stockman and Tesar (1995). In the case of γ , the value is chosen to imply a steady state share of external trade of approximately 20% (taking account of the assumed home-bias in the composition of government spending).

The values of λ (the elasticity of substitution between individual final goods) and μ (the Cobb-Douglas coefficient on labor in the production function of intermediate goods) are chosen to yield a steady state monopoly markup of 11% and share of capital in output of 0.33. The implied steady state share of dividends in GDP is approximately 0.15.

The Calvo parameters for price and wage setting, κ and ς , are chosen to imply an average period between price or wage changes of 4 quarters. The degree of backward indexation in price and wage setting, ω and ϖ , and the values of ϕ (labor elasticity) and ρ (risk aversion) are consistent with the estimates of Smets and Wouters (2003, 2005, 2007).

The values of the Taylor rule parameters δ and ϑ are broadly consistent with the estimates of, for example, Clarida *et al* (1998, 2000) and Smets and Wouters (2003, 2005, 2007).²²

²²Note that the value of δ is adjusted to take account of the difference between annual and quarterly

The steady state share of government spending in GDP, g , is set at 0.2 and the share of dividend taxes in total taxes, τ , is set at 0.15 (which is approximately the same as the assumed steady state share of dividends in total income).

The co-variance matrix of innovations of productivity shocks, Σ_a , and the degree of persistence in productivity shocks, A , are chosen to be approximately the average of the estimated values reported by Benigno and Thoenissen (2008), Corsetti *et al* (2008) and Stockman and Tesar (1995) (with adjustments made to allow for the difference between annual and quarterly series). The parameters of the other shock processes are approximately based on the estimates of Smets and Wouters (2003, 2005, 2007).

Results are reported for a range of variations around the benchmark parameterization.

6.2 Gross portfolios in the benchmark case

We consider two versions of the benchmark parameterization, one with producer currency pricing (PCP) and one with local currency pricing (LCP). We first consider the PCP case. The effect of varying the coefficient on inflation in the Taylor rule, χ , on equilibrium portfolio holdings of equities and bonds in the PCP case is illustrated in Figure 2. Panels (a) and (b) plot the equilibrium holdings of foreign equities and bonds by the home country for a range of values of χ . These figures show that the external positions in foreign equities and foreign bonds by the home country are positive and rising in χ (except, in the case of equity holdings, at very low values of χ) In other words the size of gross positions increase as monetary policy becomes more focused on inflation stabilization.²³ For reference, panel (i) shows the effect of varying the inflation feedback parameter on the variability of inflation. This figure shows that inflation variability declines as χ is increased.²⁴

measures of the nominal interest rate and rate of inflation.

²³The portfolio positions shown in these plots show external asset holdings relative to GDP. It is apparent that the model is predicting large gross positions in equities. Portfolio positions in equities of this magnitude are not realistic (for most countries) so the model is clearly not a good match for the data in this respect. The model, however, assumes that international asset trade is costless and unhindered by capital controls or other market frictions. Tille and van Wincoop (2010) show that it is straightforward to incorporate small transactions costs into a portfolio choice problem of the type analyzed here. If such costs were introduced into the current model it is likely equilibrium gross portfolios would be reduced to more realistic levels.

²⁴Note that panels (a) and (b) are showing the holdings of foreign equity and bonds by the home country. Bond holdings are positive, implying the home country is long in foreign currency bonds. This is a symmetric equilibrium, so the home country is simultaneously short in home currency bonds. Lane and Shambaugh (2010) show that this pattern of bond holdings corresponds to the pattern observed for many developed countries (i.e. these countries tend to be long in foreign currency bonds and short in own-currency bonds).

Table 3: Benchmark Parameter Values

Discount factor	$\beta = 0.99$
Elasticity of substitution between individual goods	$\lambda = 10$
Elasticity of labor supply	$1/\phi = 0.67$
Risk aversion	$\rho = 1.5$
Average share of home goods in consumption basket	$\gamma = 0.58$
Elasticity of substitution between home and foreign goods	$\theta = 1.5$
Share of labor in production of intermediate goods	$\mu = 0.67$
Taylor rule: coefficient on output	$\delta = 0.1$
Taylor rule: interest rate smoothing	$\vartheta = 0.85$
Share of non-traded goods in consumption basket	$\eta = 0.4$
Elasticity of substitution between traded and non-traded	$\varkappa = 0.45$
Share of government spending in output	$g = 0.2$
Share of profit taxes in total taxes	$\tau = 0.15$
Elasticity of substitution between individual labor varieties	$\xi = 10$
Calvo wage setting and indexation parameters	$\varsigma = 0.75, \varpi = 0.5$
Calvo price setting and indexation parameters	$\kappa = 0.75, \omega = 0.5$
Capital adjustment costs	$\varphi = 0.25$
Depreciation of real capital	$\varrho = 0.025$
Capacity utilization costs	$F = 0.2$
Labor supply shocks	$\psi_{\Delta} = 0.9, \sigma_{\Delta} = 0.025$
Mark-up shocks	$\psi_v = 0.0, \sigma_v = 0.0015$
Investment cost shocks	$\psi_l = 0.9, \sigma_l = 0.001$
Government spending shocks	$\psi_G = 0.9, \sigma_G = 0.003$
Risk premium shocks	$\psi_{\Upsilon} = 0.0, \sigma_{\Upsilon} = 0.006$
Monetary shocks	$\psi_m = 0.0, \sigma_m = 0.0012$
Productivity shocks	
	$A = \begin{bmatrix} 0.9 & 0 & 0.6 & 0 \\ 0 & 0.9 & 0 & 0.6 \\ 0 & 0 & 0.9 & 0 \\ 0 & 0 & 0 & 0.9 \end{bmatrix} \quad \Sigma_a = \begin{bmatrix} 0.009^2 & 0 & 0 & 0 \\ 0 & 0.009^2 & 0 & 0 \\ 0 & 0 & 0.005^2 & 0 \\ 0 & 0 & 0 & 0.005^2 \end{bmatrix}$

Figure 2 shows that the basic result demonstrated in the simple example model holds in the general model for the benchmark set of parameter values.

The portfolio expressions (25) and (26) can again be used to investigate the intuition for the relationship between inflation stabilization and the size of equilibrium asset holdings. Panels (c) to (h) of Figure 2 plot the relevant conditional moments. These figures show that the basic properties of conditional moments are similar to those found in the simple example model. Thus the conditional standard deviations of both bond and equity returns decline as monetary policy becomes more focused on inflation stabilization. The behavior of the conditional standard deviation of relative income is also similar to the simple model. The conditional variability of relative income rises for both equities and bonds as χ increases. Panels (c) to (h) of Figure 2 therefore demonstrate that the underlying explanation for the increase in gross positions is the same as in the simple example model, i.e. as the volatility of inflation is reduced the conditional volatility of asset returns falls relative to the conditional volatility of relative income and so it is necessary for households to hold larger gross positions in equities and bonds in order to achieve the desired degree of risk sharing. This is again an example of *the volatility effect*.

The benchmark configuration of our model has a similar basic structure to (but is much more general than) the model used by Engel and Matsumoto (2009) to analyze equity home bias, so it is useful to consider the implications of the results shown in Figure 2 for equity home bias.²⁵ For the benchmark parameter configuration the total value of home equity is approximately 18 times steady state GDP, so the equity position illustrated in Figure 2, panel (a) is consistent with a degree of equity home bias for most of the range of χ considered.²⁶ But notice that one of the implications of the results illustrated in Figure 2 is that the degree of equity home bias is sensitive to the variability of inflation. More specifically, equity home bias is stronger when inflation is relatively volatile but declines as inflation is stabilized.

But there is a significant minority of developed countries where the opposite pattern of bond holding is observed.

²⁵Our model includes non-traded goods, real capital, wage and price stickiness in the form of Calvo contracts, a Taylor rule for monetary policy and a wider range of shocks compared to the model used by Engel and Matsumoto. The main objective of Engel and Matsumoto (2009) is to show how nominal inertia provides a possible explanation for home equity bias. They do not consider the role of monetary policy or inflation volatility in determining the size of equity portfolios.

²⁶At $\chi = 2$ panel (a) of Figure 1 shows external equity holdings are approximately 7 times steady state GDP so the home country is holdings approximately 61% of home country equity. At $\chi = 6$ equity holdings are approximately 9 times steady state GDP, so the home country holds approximately 50% of home country equity. In each case the foreign country holds the same percentage of foreign equity as the home country holds of home equity..

Figure 3 reports results for the LCP case with benchmark parameter values. The general features of this case are similar to the PCP case. Both equity and bond holdings are positive and increase in χ (again except for equity holdings for very low values of χ). The main difference compared to the PCP case is that equity holdings are somewhat less sensitive, and bond holdings are somewhat more sensitive to the increase in χ . Panels (g) and (h) of Figure 3 show that the underlying explanation for the increase in the size of gross positions is again the fact that increasing χ , and stabilizing inflation, tends to reduce the conditional volatility of relative asset returns. Panels (g) and (h) of Figure 3 show that the conditional volatility of both relative equity and relative bond returns decline as χ increases. For bonds and equities the conditional standard deviations of relative returns declines relative to the conditional standard deviation of income, so again the increase in gross positions is caused by *the volatility effect*.

6.3 The correlation between relative income and asset returns

In their analysis of the welfare effects of monetary policy, Devereux and Sutherland (2008) note that, in a model which is a special case of the benchmark model presented above, the size of the equilibrium gross position in bonds increases as the coefficient on inflation in the Taylor rule is increased. Devereux and Sutherland (2008) do not analyze this result in any detail but they do offer a simple intuition which appears to be different from the reasoning described above in relation to the results in Figure 2 and Figure 3. They suggest that inflation volatility causes extraneous noise in the real return on bonds which partly undermines the efficiency of bonds as a hedge against productivity shocks. They argue that a monetary rule which focuses on inflation stabilization reduces the extraneous noise in bond returns and therefore implies that bonds become a better hedge against productivity shocks. Inflation stabilization therefore encourages an expansion of gross holdings of bonds.

Given the that the model described above contains the model used by Devereux and Sutherland (2008) as a special case, it is important to trace the links between the intuition offered in Devereux and Sutherland (2008) and the intuition emphasized in this paper.²⁷ In

²⁷While Devereux and Sutherland (2008) analyze a model which is a special case of the model of the current paper, they only comment very briefly on the effect of inflation stabilization on the size of gross positions. In fact they only consider this issue very briefly in relation to bond holdings in a special case of their model. They do not decompose portfolio holdings using (25) and (26) and they offer only a brief intuition for the effect of inflation stabilization on the size of gross positions. In contrast, the current paper provides a comprehensive analysis of the links between inflation stabilization and gross positions in both equities and bonds in a much more general model.

fact the links between the two papers can be easily understood in terms of *the volatility effect* and *the correlation effect*. The result emphasized in Devereux and Sutherland (2008) is an example of *the correlation effect*.

Figure 4 illustrates the Devereux and Sutherland (2008) result using a special case of the model of this paper. In this special case there are shocks only to productivity and monetary policy, the coefficient on output in the Taylor rule, δ , is set to zero, productivity in the traded and non-traded sectors is assumed to be perfectly correlated and nominal bonds are assumed to be of one-period maturity (rather than the infinite maturity assumed in the benchmark model). These assumptions make the model of this paper more closely aligned to the model used by Devereux and Sutherland (2008). Figure 4 illustrates the effect of χ on bond holdings in this simplified model when asset trade is restricted to trade in home and foreign currency bonds. Panel (a) of Figure 4 shows that the absolute size of the gross position in bonds is increasing in χ .²⁸ As already explained, Devereux and Sutherland (2008) argue that the underlying explanation for the increase in the (absolute) size of the gross position in bonds is that bonds become a better hedge against productivity shocks as inflation is stabilized. In other words, as χ increases, the correlation between relative income and bond returns tends towards +1 or -1. Panel (b) of Figure 4 shows that in fact the correlation tends towards -1. And (26) shows that, other things being equal, this will cause an increase in the (absolute) size of the gross bond position. The results illustrated in Figure 4 are therefore entirely consistent with the intuition offered by Devereux and Sutherland (2008).²⁹

But notice from Figure 4 that the effect of inflation stabilization that works through the correlation between bond returns and relative income is not the only channel that links inflation stabilization to the gross bond position. Panels (c) and (d) of Figure 4 show that inflation stabilization also reduces the volatility of bond returns relative to the volatility of relative income. This is exactly *the volatility effect* emphasized above in relation to Figures 2 and 3. Equation (26) shows that, just as in the cases illustrated in Figures 2 and 3, a reduction in the standard deviation of bond returns relative to the standard deviation of relative income implies that the gross bond position must increase in order to achieve the desired degree of risk sharing.

²⁸In order to offer a clear illustration of the Devereux and Sutherland (2008) result, Figure 6 shows a much wider range for χ than used in Figures 2 and 3.

²⁹Devereux and Sutherland (2008) further emphasized that, if monetary policy were to stabilize inflation completely, bonds would become a perfect hedge for productivity shocks. In other words perfect risk sharing would be possible. In terms of the case illustrated in Figure 4, this would be the limiting case where χ tends to infinity and there is perfect negative correlation between bond returns and relative income.

Figure 4 shows therefore that *the volatility effect* emphasized above (i.e. the impact of inflation stabilization on the variability of asset returns) reinforces *the correlation effect* described by Devereux and Sutherland (2008) (i.e. the impact of inflation stabilization on the correlation between asset returns and relative income).

Now re-consider the general case illustrated in Figures 2 and 3. Previously we emphasized the link between inflation stabilization and gross asset positions that operates through *the volatility effect* (i.e. the effect of inflation stabilization and the variability of asset returns). However, notice from panels (c) and (d) of Figure 2, that inflation stabilization also affects the correlation between asset returns and relative income. In fact, as χ increases, it can be seen that the correlation between bond returns and relative income increases from zero towards +0.6. In other words, bonds become a better hedging instrument as inflation is stabilized. As can be seen from (26), this reinforces the impact of inflation stabilization on the gross position in bonds. This is *the correlation effect* identified by Devereux and Sutherland (2008). The effect of χ on the correlation between equity returns and income is less clear from the figure but this also tends to increase as χ increases. So the *correlation effect* is also contributing to the increase in the gross position in equities.

Panels (c) and (d) of Figure 3 similarly show the correlation effect in operation in the LCP case. The general pattern is similar to the PCP case.

Note that *the correlation effect* only arises when markets are incomplete. In the simple cases illustrated in Section 5, where there are only productivity shocks and trade in either equities and bonds, markets are complete. This implies that asset returns are perfectly correlated with relative income regardless of the level of χ . In those cases *the correlation effect* is not present. *The volatility effect* nevertheless continues to operate.

6.4 Generalizations

We have experimented with a wide range of parameter variations around the benchmark values. Plausible variations in many of the model's parameters have no significant qualitative or quantitative effect on the relationship between χ and gross asset positions. Rather than catalogue every case, here we report only on those parameter variations where the results differ in a qualitatively significant way from those reported above. We also comment on a number of model variants.

6.4.1 Parameter Variations

Although most macroeconomic evidence suggests that the elasticity of substitution between baskets of traded goods produced in different countries (θ in our model) is close to unity, there is no clear agreement in the literature on whether the empirically relevant value is just above or just below unity. Our benchmark value, $\theta = 1.5$, is consistent with the values used by Backus *et al* (1994) and Benigno and Thoenissen (2008) but Corsetti *et al* choose $\theta = 0.85$. Panels (a) and (b) of Figure 5 show the relationship between gross asset positions and χ when we set $\theta = 0.85$ (in the PCP case). It is apparent the sign of the bond position has switched but the relationship between the absolute size of bond holdings and χ is the same as in the benchmark case, i.e. the absolute size of gross positions increase as inflation is stabilized. The effect of setting $\theta = 0.85$ in the LCP case is very similar and is not illustrated.³⁰

Our benchmark value for the Calvo pricing parameter, $\kappa = 0.75$, is very standard and implies that individual prices are changed on average every 4 quarters. Christiano *et al* (2005) report a benchmark estimate for this parameter of 0.6 while Smets and Wouters (2003, 2005, 2007) report an estimate of 0.9. Experiments show that setting a lower value of κ (consistent with Christiano *et al*, 2005) tends to reduce the sensitivity of gross equity positions and increase the sensitivity of gross bond positions to χ , while a higher value of κ (consistent with Smets and Wouters, 2003, 2005, 2007) switches the sign of gross bond positions (see panel (d) of Figure 5). In the latter case the absolute size of both equity and bond positions continues to be increasing in χ .

The cases illustrated in Figure 5 panels (b) and (d) share the feature that the sign of bond holdings is reversed compared to the benchmark case, but the absolute size of bond holdings continues to be positively related to χ . The basic benchmark result is therefore robust against empirically relevant variations in θ and κ .

Experiments with the parameters of the monetary policy rule, and the variance of monetary policy shocks, show, however, that in some circumstance the positive relationship between the (absolute) size of gross asset positions and χ can break down. Panels (e) to (h) of Figure 5 show two particular cases. In panels (e) and (f) the parameter ϑ , which determines the degree of inertia in interest rate setting, is set at the higher value of 0.95

³⁰As noted earlier, Lane and Shambaugh (2010) show that many developed countries tend to be long in foreign currency bonds and short in own currency bonds (i.e. the opposite sign to the holdings displayed in panel (b) of Figure 5). However, Lane and Shambaugh also find that a significant minority of developed countries are short in foreign currency bonds and long in own currency bonds, which is a pattern consistent with panel (b) of Figure 5.

(the benchmark value is 0.85). In this case the relationship between equity holdings and χ is non-monotonic, first falling and then rising, while bond holdings are negative and falling in absolute value as χ rises. Clarida *et al* (1998, 2000) estimates of ϑ range between approximately 0.7 and 0.9 while Smets and Wouters (2003) estimate a value closer to 0.95. However, Smets and Wouters (2005, 2008) find ϑ to be in the range 0.8 to 0.9. $\vartheta = 0.95$ is therefore at the extreme upper end of the range of estimates from Clarida *et al* and Smets and Wouters.

Panels (g) and (h) of Figure 5 show the case where the standard deviation of monetary shocks is set at the higher value of 0.0024 (the benchmark value is 0.0012). In this case the relationship between bond holdings and χ is negatively sloped, while equity holdings continue to be positively related to χ . Smets and Wouters's (2003) estimate of the standard deviation of monetary shocks to be 0.001, while in Smets and Wouters (2005, 2008) their estimates of the standard deviation are between 0.001 and 0.0024, but most of their estimates fall in the range 0.001 to 0.0013. A standard deviation of 0.0024 is therefore at the extreme upper end of the range of estimated values.

Apart from the two cases illustrated in Figure 5 panels (e) to (h), the benchmark results appear to be robust against empirically relevant variations in all other parameters of the model.

6.4.2 Model Variants

We now discuss the implications of a number of modifications to the structure of the benchmark model.

First consider the following alternative form of household utility function

$$U_t = E_t \sum_{i=0}^{\infty} \beta^i \left\{ \epsilon_{t+i} \frac{[C_{t+i}(z) - hC_{t+i-1}]^{1-\rho}}{1-\rho} - \Delta_{t+i} \frac{H_{t+i}^{1+\phi}(z)}{1+\phi} \right\} \quad (32)$$

where hC_t represents the stock of (external) habits and ϵ is a shock to consumption preferences where $\epsilon_t = \bar{\epsilon} \exp(\hat{\epsilon}_t)$, $\hat{\epsilon}_t = \psi_\epsilon \hat{\epsilon}_{t-1} + \varepsilon_{\epsilon,t}$, $0 < \psi_\epsilon < 1$ and $\varepsilon_{\epsilon,t}$ is a zero-mean normally distributed i.i.d. shock with $Var[\varepsilon_\epsilon] = \sigma_\epsilon^2$.

Numerical experiments show that the relationship between asset holdings and χ is unaffected by the value of the habit parameter, h . The benchmark results are therefore robust to the introduction of consumption habits. Shocks to consumption preference do however tend to reduce the sensitivity of equity holdings to χ . Panels (a) and (b) of Figure 6 show the case where $\psi_\epsilon = 0.9$ and $\sigma_\epsilon = 0.003$ (which is in the middle of the range of estimates of Smets and Wouters, 2003, 2005, 2007). The relationship between bond holdings and χ

is largely unaffected by the introduction of consumption preference shocks, while the relationship between equity holdings and χ is somewhat flatter than the benchmark case (and is downward sloping for small values of χ).

A second variant of the benchmark model is one where international traded bonds are short maturity (rather than the infinite maturity assumed in the benchmark model). Panels (c) and (d) of Figure 6 show the relationship between asset holdings and χ in this case. The figure show that bond holdings are negative in this case, but the absolute size of bond holdings is increasing in χ , while the holdings of equities are somewhat less sensitive to χ than in the benchmark case (and is slightly downward sloping for higher values of χ).

The final two variants of the benchmark model considered involve changes to the monetary policy rule. In the first the inflation term in the rule is assumed to depend on producer price inflation (rather than consumer price inflation). In the second the output gap term in the rule is assumed to be measured relative to the flexible price level of output (rather than an exogenously fixed measure of capacity output). Both these modifications to the policy rule move the rule closer to the form that has been shown to be optimal in basic models of monetary policy. It is important to note, however, that stabilizing producer price inflation (PPI) is only optimal in quite restrictive cases and there is no reason to suppose that PPI targeting is any closer to the optimal policy in the benchmark model than is CPI inflation targeting.³¹ Likewise, stabilizing output around the flexible price output level is only welfare maximizing in restrictive circumstances and there is no reason to suppose that the flexible price output level is the welfare relevant target level of output in the benchmark model of this paper. Furthermore, the monetary rule assumed in the benchmark model is adopted because it is regarded as a good empirical representation of actual monetary policy over the last few decades. The fact that it may not be a correct theoretical specification of optimal policy is not a relevant consideration for the purposes of this paper. Nevertheless it is useful to consider the implications of alternative forms of policy rule for the relationship between gross asset holdings and χ . These are illustrated in panels (e) to (j) of Figure 6.

Panels (e) and (f) of Figure 6 show the case where the inflation term in the policy rule depends on producer price inflation (as measured by the rate of change of the GDP deflator). It is apparent that equity holdings are negatively related to the value of χ in this case, while bond holdings continue to be positive and positively related to χ . Panels (g) and (h) show the

³¹An alternative argument for considering PPI targeting is that it more closely represents targeting of ‘core inflation’. However, the correspondence between the two concepts is not perfect because the producer prices index (in this model) includes the price of goods produced for export, while ‘core inflation’ is typically a measure of price inflation for domestic consumers.

case where the output gap term in the policy rule depends on output measured relative to the flexible price output level. In this case equity holdings are quite insensitive to the value of χ while bond holdings are negative, with the absolute size of bond holdings positively related to χ . Finally panels (i) and (j) show the case which combines the previous two, i.e. the inflation term in the policy rule depends on producer price inflation and the output term depends on the output measured relative the flexible price equilibrium. In this case equity holdings are positively related to χ while the relationship between χ and bond holdings is non-monotonic, first rising then falling for higher values of χ . Panels (e) to (j) of Figure 6 show that some aspects of the benchmark results carry over to these alternative specifications of the policy rule, but some also break down. However, as previously emphasized, these alternative forms of the policy rule are of interest only because they have been identified as closer to the optimum form of rule in simple models. Arguably, they are neither the empirically relevant form of rule, nor are they necessarily the optimal form of rule in the model of this paper.

We conclude that many of the general properties illustrated for the benchmark model and the benchmark parameter set are robust across a wide range of parameter and model variations.

7 Discussion

Our model suggests that a more aggressive monetary policy which reduces the variability of inflation in almost all cases leads to an increase in the absolute size of gross external asset and liability positions. As we mentioned in the introduction, previous researchers have argued that the causation may go in the other direction. Econometric evidence such as Tytell and Wei (2004) finds that measures of financial globalization have significantly negative coefficient estimates in cross country inflation (level) equations. By contrast, our empirical evidence finds that inflation *variability* is significant in panel regressions of financial globalization. Sorting out the full set of causal links between the level of inflation, the variability of inflation, and financial globalization is beyond the scope of this paper. Both inflation and international portfolio positions are endogenous and affected by all aspects of the macroeconomy, and it is difficult to obtain robust instruments for both variables.³² Moreover, our theory by no means precludes the possibility that there may be additional forces leading from international

³²Our use of central bank independence as an instrument for inflation volatility in our regressions reported in Section 2 provides some evidence of causation running from inflation variability to financial globalization. But a full empirical investigation of causation would obviously require robust instruments for all the endogenous variables in the relationship.

financial globalization to inflation either directly or indirectly through endogenous monetary policy. Our main point is that evidence suggesting that increased capital market openness has been associated with reductions in average inflation rates does not necessarily establish the direction of causation, since we have shown that there are strong theoretical reasons to think that there may also be a link between inflation stability and the size of gross external financial positions.

The effect of inflation variability on gross external assets depends on the correlation and variability channels defined above. Are these channels empirically relevant? There is evidence of an increase in the co-movement of major world stock markets since the mid 1990s (see e.g. Kizys and Pierdzioch, 2009). This should be associated with a fall in the variability of *relative* equity returns and is consistent with the volatility effect we describe in relation to equity holdings. The second component of the volatility effect is determined by the conditional variance of relative income across countries. One way to measure this would be to look at business cycle co-movement across countries. Here, the results of the literature are quite ambiguous. Heathcote and Perri (2002) and Stock and Watson (2003) find that business cycle co-movement among the major economies fell in the 1990's relative to earlier periods. In principal, this should lead to an increase in the conditional variance of relative income across countries. However, using a wider sample of countries, Kose *et al* (2003) find that correlations tended to increase over time during the 1960-99 period. There is clearly scope for a more detailed empirical investigation of the variability and correlation effects in terms of data on relative asset returns and relative income differences. We leave this topic for future research.

The model used in this paper can be extended in a number of obvious directions which may have important implications for the size of gross positions and the relationship between gross positions and monetary policy. A particularly important issue which we have not explored in any detail in this paper is the role of financial frictions. The model includes a 'risk premium shock' of the form proposed by Smets and Wouters (2003). This captures some of the effects of frictions which drive a wedge between the costs of internal and external finance, but it fails to capture the endogenous nature of the financial accelerator. The model also does not capture any of the frictions that exist in international financial markets, such as transactions costs, informational asymmetries or limits on pledgeability than may give rise to collateral constraints and wedges between international borrowing and lending rates. While there is now quite an extensive literature which analyzes a range of financial frictions in the context of closed-economy models, there are relatively few contributions to the current literature which model the international aspects of these frictions. Devereux and Sutherland

(2011b) for instance analyze a model of international portfolio allocation where collateral constraints exist at the international level. The model is, however, very simple and the form of the collateral constraint considered is only one of a number of possible representations of financial frictions. At the current stage of development of this literature it is difficult to predict (with any degree of accuracy) how financial frictions may affect the relationship between inflation variability and the size of gross positions. Again, we leave this topic for future research.

8 Conclusions

This paper investigates the relationship between inflation variability and the size of external asset positions. Panel regression results based on Lane and Milesi-Ferretti's data on gross portfolios show a fairly robust negative relationship between inflation variability and the size of gross positions. Using a general two-country dynamic general equilibrium model, we solve for gross positions and show that the model predicts a relationship between inflation variability and the size of gross positions which has the same general features as the data. Our solutions show that the link between inflation variability and the size of gross positions can be explained by a combination of a return *volatility effect* and a return-income *correlation effect*. A reduction in inflation variability tends to reduce the variability of returns for both bonds and equities. It is therefore necessary to hold larger positions in bonds and equities in order to achieve the desired level of risk sharing. Lower inflation variability also reduces the amount of extraneous noise in bond and equity positions and thus increases the correlation between asset returns and relative income. This increases the hedging efficiency of both bonds and equities and therefore increases equilibrium gross positions in bonds and equities.

The paper thus shows that there are strong theoretical reasons to think that there may be a link between inflation stability and the size of gross external financial positions, this suggests that evidence that capital market openness has been associated with reductions in average inflation rates does not necessarily establish the direction of causation.

Appendix

The unconditional one-period ahead covariance matrix of the vector $[r_x^e \ r_x^b \ \zeta_y]'$ can be written as follows

$$\begin{bmatrix} \sigma_e^2 & \sigma_{e,b} & \sigma_{e,\zeta} \\ \sigma_{e,b} & \sigma_b^2 & \sigma_{b,\zeta} \\ \sigma_{e,\zeta} & \sigma_{b,\zeta} & \sigma_\zeta^2 \end{bmatrix}$$

Equation (24) implies

$$\tilde{\alpha} = \frac{1}{2} \Sigma_r^{-1} \text{cov}_t(r_{x,t+1}, \zeta_{y,t+1}) = \frac{1}{2} \begin{bmatrix} \sigma_e^2 & \sigma_{e,b} \\ \sigma_{e,b} & \sigma_b^2 \end{bmatrix}^{-1} \begin{bmatrix} \sigma_{e,\zeta} \\ \sigma_{b,\zeta} \end{bmatrix} \quad (33)$$

So

$$\tilde{\alpha}_e = \frac{1}{2} \frac{\sigma_{e,\zeta} \sigma_b^2 - \sigma_{e,b} \sigma_{b,\zeta}}{\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2} \quad (34)$$

$$\tilde{\alpha}_b = \frac{1}{2} \frac{\sigma_{b,\zeta} \sigma_e^2 - \sigma_{e,b} \sigma_{e,\zeta}}{\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2} \quad (35)$$

Following Eaton (2007) Section 3.4 it is possible to show that the covariance matrix of the vector $[r_x^e \ \zeta_y]'$ conditional on r_x^b is given by

$$\begin{bmatrix} \sigma_e^2 & \sigma_{e,\zeta} \\ \sigma_{e,\zeta} & \sigma_\zeta^2 \end{bmatrix} - \frac{1}{\sigma_b^2} \begin{bmatrix} \sigma_{e,b} \\ \sigma_{b,\zeta} \end{bmatrix} \begin{bmatrix} \sigma_{e,b} & \sigma_{b,\zeta} \end{bmatrix} = \begin{bmatrix} \frac{\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2}{\sigma_b^2} & \frac{\sigma_{e,\zeta} \sigma_b^2 - \sigma_{e,b} \sigma_{b,\zeta}}{\sigma_b^2} \\ \frac{\sigma_{e,\zeta} \sigma_b^2 - \sigma_{e,b} \sigma_{b,\zeta}}{\sigma_b^2} & \frac{\sigma_\zeta^2 \sigma_b^2 - \sigma_{b,\zeta}^2}{\sigma_b^2} \end{bmatrix}$$

from which it follows that

$$\begin{aligned} \text{corr}(\zeta_{y,t}, r_{x,t}^e | r_{x,t}^b) &= \frac{\sigma_{e,\zeta} \sigma_b^2 - \sigma_{e,b} \sigma_{b,\zeta}}{(\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2)^{1/2} (\sigma_\zeta^2 \sigma_b^2 - \sigma_{b,\zeta}^2)^{1/2}} \\ \text{StDev}(\zeta_{y,t} | r_{x,t}^b) &= \frac{(\sigma_\zeta^2 \sigma_b^2 - \sigma_{b,\zeta}^2)^{1/2}}{\sigma_b} \\ \text{StDev}(r_{x,t}^e | r_{x,t}^b) &= \frac{(\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2)^{1/2}}{\sigma_b} \end{aligned}$$

Substituting these expressions into (25) and simplifying yields (34).

Likewise the covariance matrix of the vector $[r_x^b \ \zeta_y]'$ conditional on r_x^e is given by

$$\begin{bmatrix} \sigma_b^2 & \sigma_{b,\zeta} \\ \sigma_{b,\zeta} & \sigma_\zeta^2 \end{bmatrix} - \frac{1}{\sigma_e^2} \begin{bmatrix} \sigma_{e,b} \\ \sigma_{e,\zeta} \end{bmatrix} \begin{bmatrix} \sigma_{e,b} & \sigma_{e,\zeta} \end{bmatrix} = \begin{bmatrix} \frac{\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2}{\sigma_e^2} & \frac{\sigma_{e,\zeta} \sigma_b^2 - \sigma_{e,b} \sigma_{e,\zeta}}{\sigma_e^2} \\ \frac{\sigma_{e,\zeta} \sigma_b^2 - \sigma_{e,b} \sigma_{e,\zeta}}{\sigma_e^2} & \frac{\sigma_\zeta^2 \sigma_b^2 - \sigma_{b,\zeta}^2}{\sigma_e^2} \end{bmatrix}$$

from which it follows that

$$\begin{aligned} \text{corr}(\zeta_{y,t}, r_{x,t}^b | r_{x,t}^e) &= \frac{\sigma_{e,\zeta} \sigma_b^2 - \sigma_{e,b} \sigma_{e,\zeta}}{(\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2)^{1/2} (\sigma_\zeta^2 \sigma_b^2 - \sigma_{b,\zeta}^2)^{1/2}} \\ \text{StDev}(\zeta_{y,t} | r_{x,t}^e) &= \frac{(\sigma_\zeta^2 \sigma_b^2 - \sigma_{b,\zeta}^2)^{1/2}}{\sigma_e} \\ \text{StDev}(r_{x,t}^b | r_{x,t}^e) &= \frac{(\sigma_e^2 \sigma_b^2 - \sigma_{e,b}^2)^{1/2}}{\sigma_e} \end{aligned}$$

Substituting these expressions into (26) and simplifying yields (35).

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Figure 1: Average of G7 data

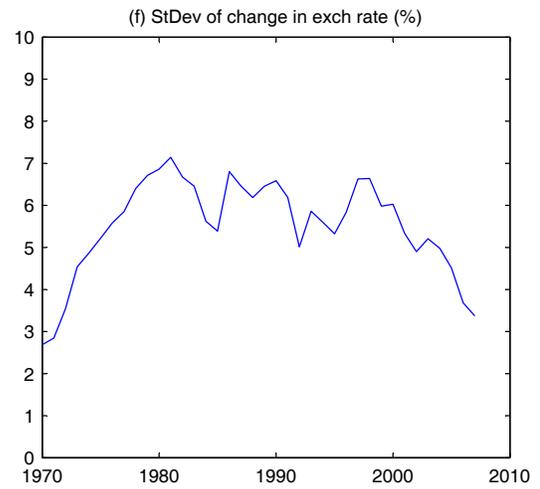
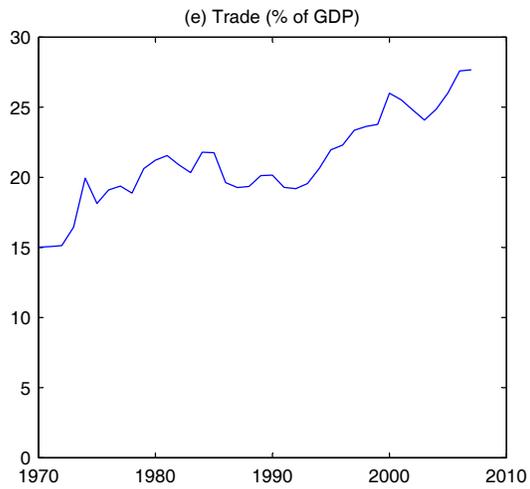
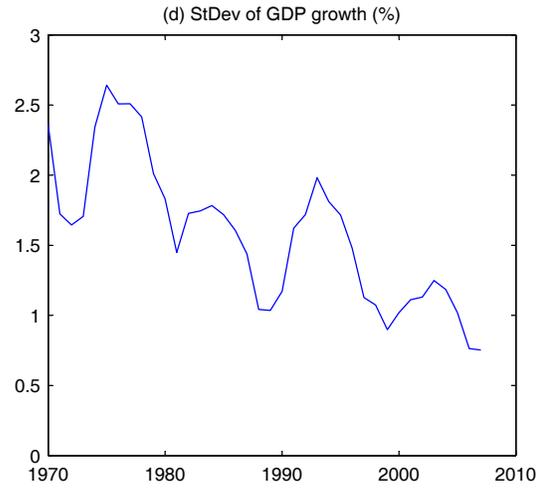
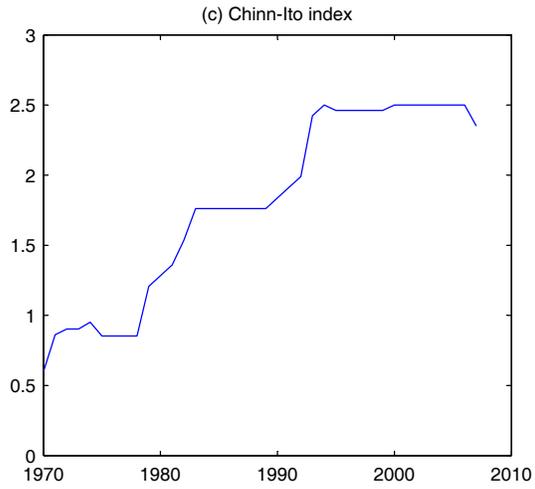
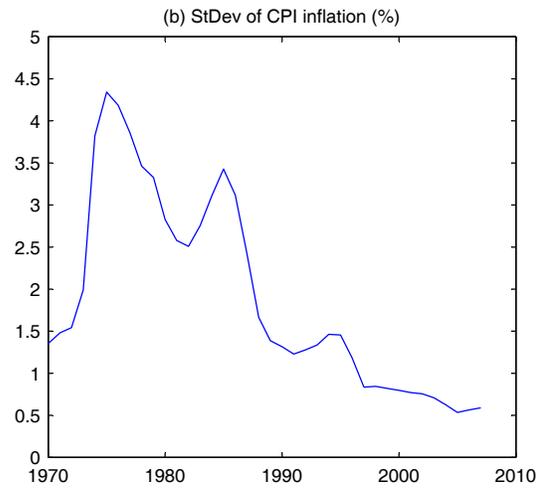
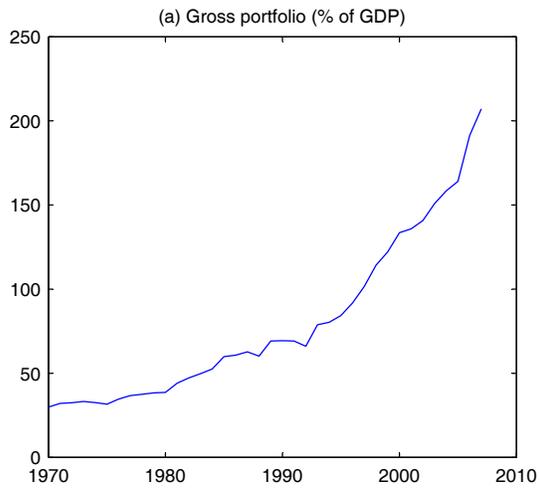


Figure 2: Inflation stabilization and gross portfolio holdings.
 Benchmark parameter values and producer currency pricing

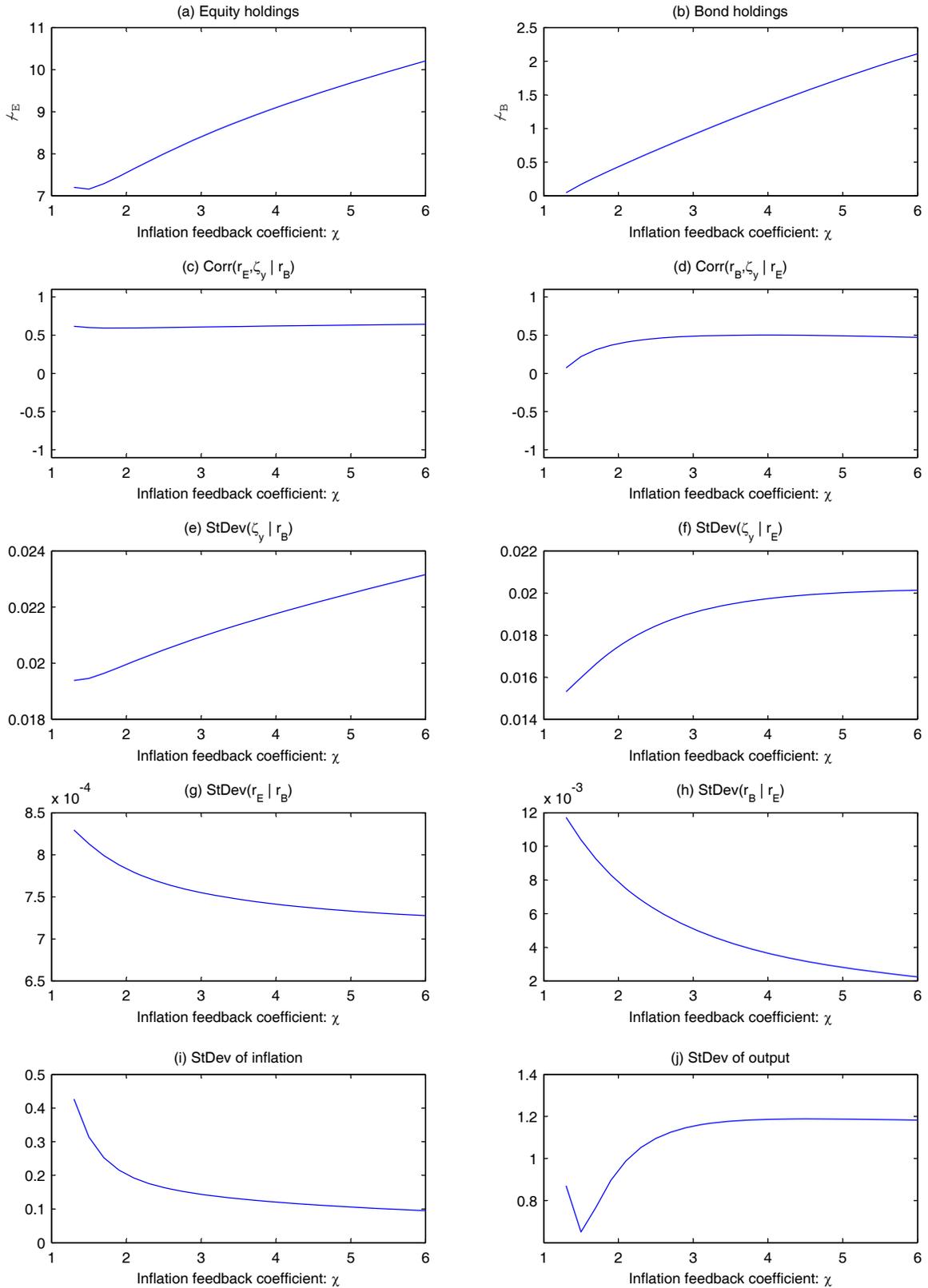


Figure 3: Inflation stabilization and gross portfolio holdings.
 Benchmark parameter values and local currency pricing

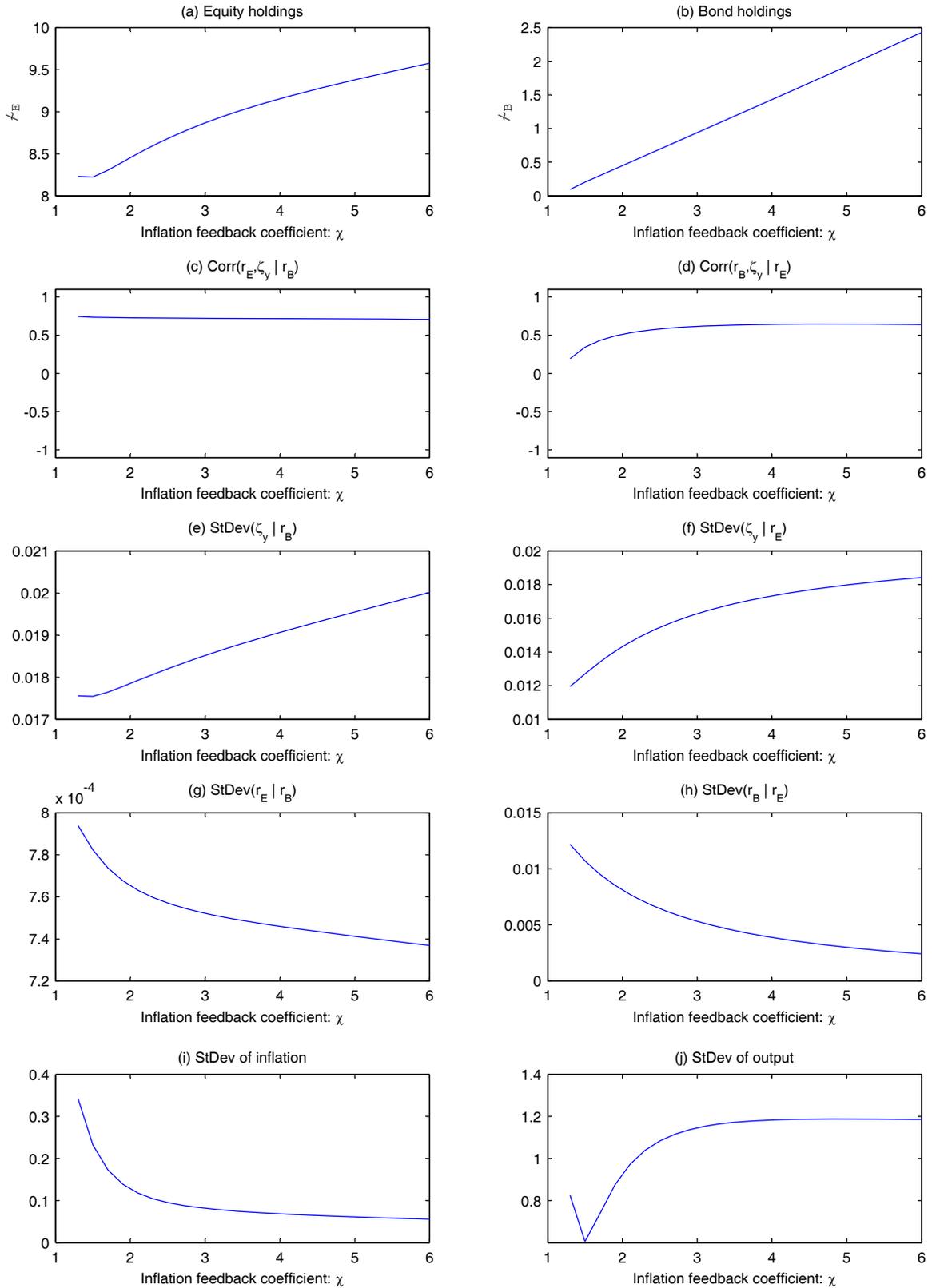


Figure 4: Inflation stabilization and gross bond holdings:
the correlation effect (cf. Devereux and Sutherland, 2008)

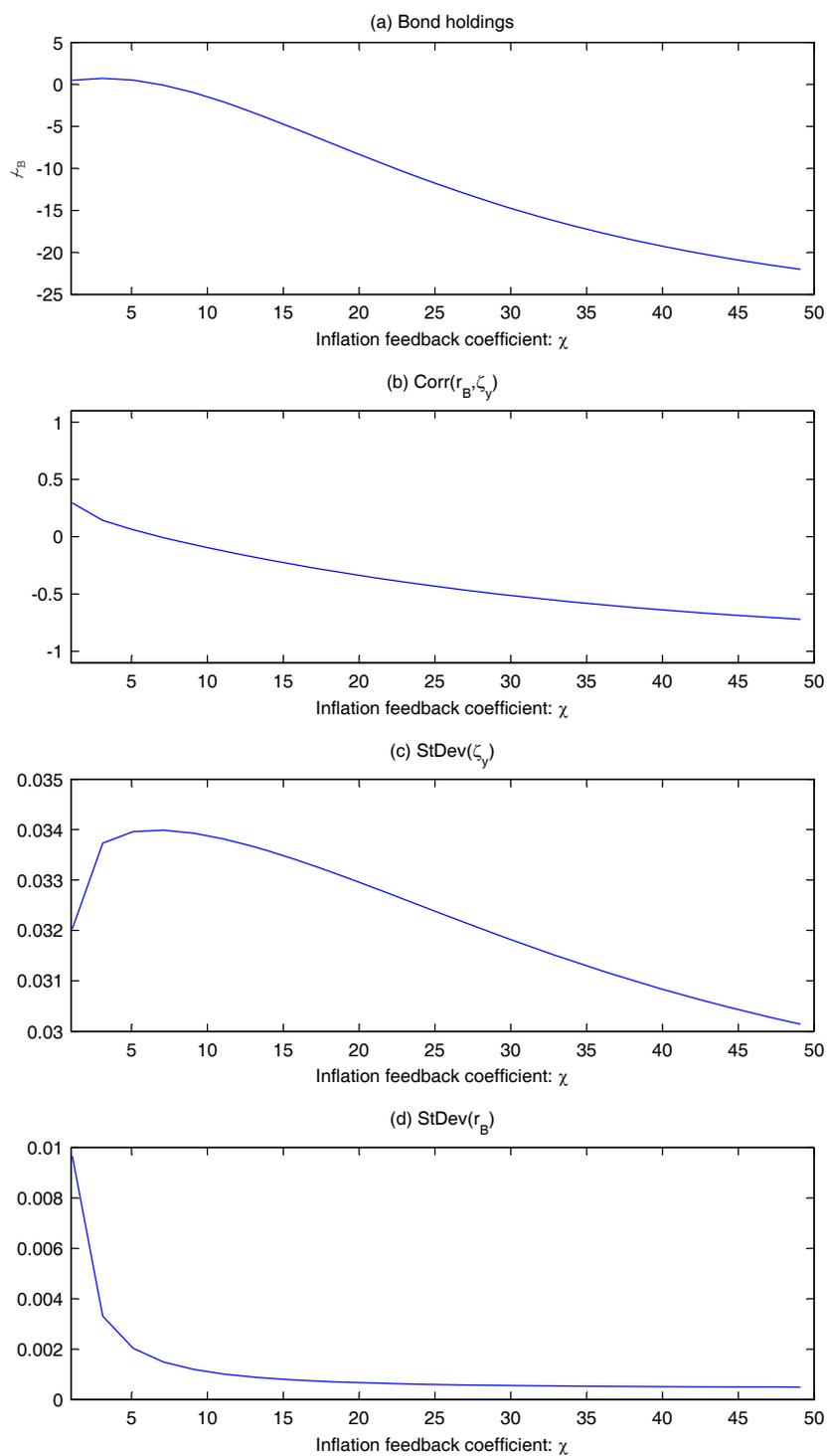


Figure 5: Parameter variations.

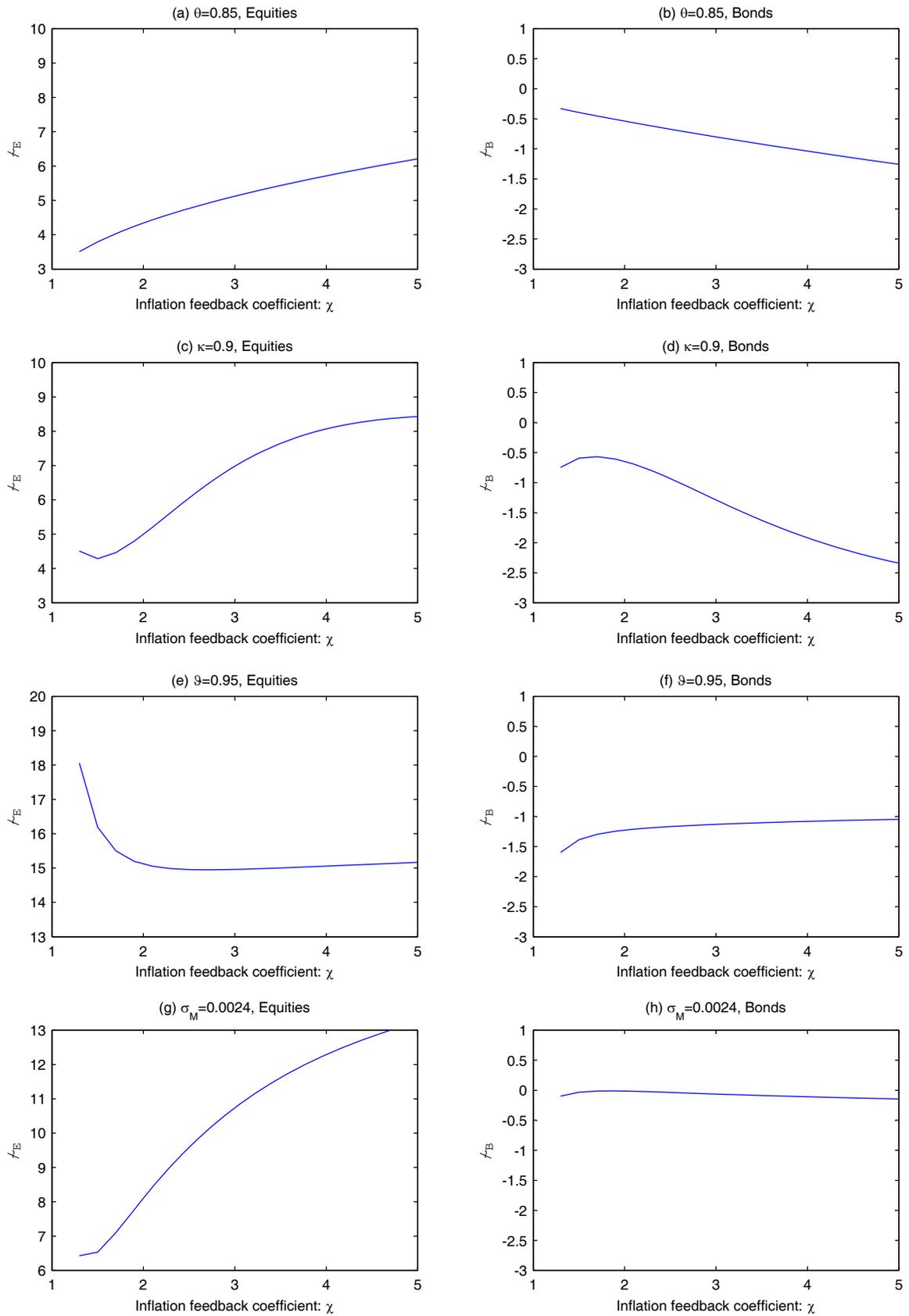


Figure 6: Model variants.

