Mussa Puzzle Redux*

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UNDER CONSTRUCTION

Abstract

The Mussa (1986) puzzle — a sharp and simultaneous increase in the volatility of both nominal and real exchange rates after the end of the Bretton Woods System of pegged exchange rates in early 1970s — is commonly viewed as a central piece of evidence in favor of monetary non-neutrality. Indeed, a change in the monetary regime has caused a dramatic change in the equilibrium behavior of a real variable — the real exchange rate. The Mussa fact is further interpreted as direct evidence in favor of models with *nominal rigidities* in price setting (sticky prices). We show that this last conclusion is not supported by the data, as there was no simultaneous change in the properties of the other macro variables — neither nominal like inflation, nor real like consumption, output or net exports. We show that the extended set of Mussa facts equally falsifies both flexible-price RBC models and sticky-price New Keynesian models. We present a resolution to this broader puzzle based on a model of segmented financial market — a particular type of financial friction by which the bulk of the *nominal* exchange rate risk is held by a small group of financial intermediaries and not shared smoothly throughout the economy. We argue that rather than discriminating between models with sticky versus flexible prices, and monetary versus productivity shocks, the Mussa puzzle provides sharp evidence in favor of models with monetary non-neutrality arising due to *financial market segmentation.* Sticky prices are neither necessary, nor sufficient for the qualitative success of the model.

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1 Introduction

The Mussa (1986) puzzle is the fact that the end of the Bretton Woods System and the change in the monetary policy regime in the early 1970s away from pegged towards floating exchange rates had naturally increased the volatility of the nominal exchange rates (by an order of magnitude), but had also instantaneously increased the volatility of the *real* exchange rate almost by the same proportion (see Figure 1). This fact is commonly viewed by economists as a central piece of evidence in favor of monetary non-neutrality, since a change in the monetary regime has caused a dramatic change in the equilibrium behavior of a real variable — the real exchange rate.[1] Indeed, in models with complete monetary neutrality, the property of the real exchange rate should not be affected by the change in the monetary rule, absent other contemporaneous changes.[2] However, the Mussa fact is further interpreted as the direct evidence in favor of models with *nominal rigidities* in price setting (sticky prices). We show that this last conclusion is not supported by the data and provide an alternative explanation to the puzzle.

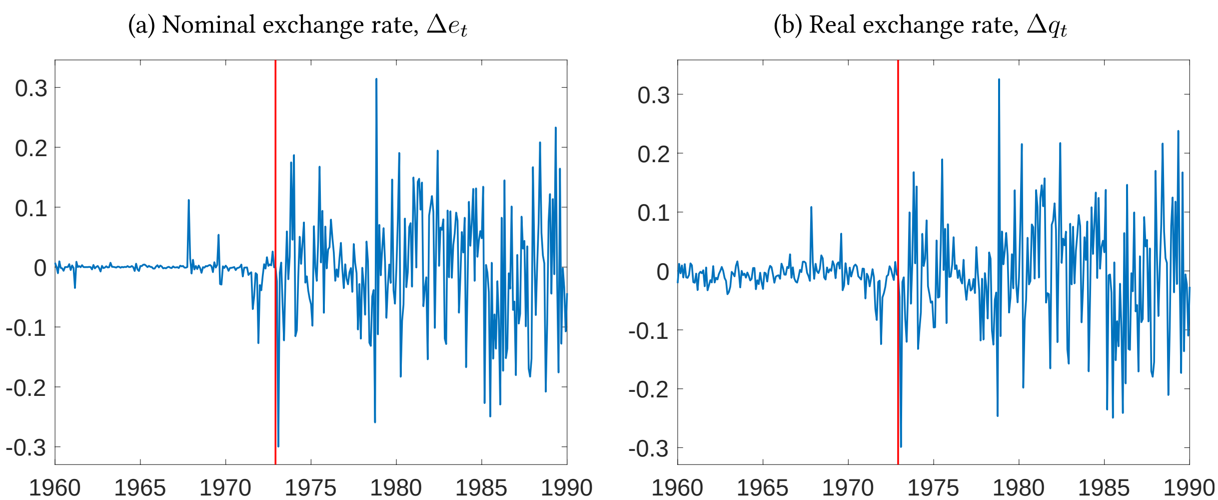


Figure 1: Nominal and real exchange rates, log changes

Note: US vs the rest of the world (defined as G7 countries except Canada plus Spain), monthly data from IFM IFS database. See Appendix Figure A1 for the comparison of volatilities and the correlation of the two exchange rate series over time.

We start by documenting empirically that while there was a change in the properties of the real exchange rate, there was no change in the properties of other macro variables — neither nominal like inflation, nor real like consumption, output or net exports (see Figure 2, which exhibits no evident structural break). One could interpret this as an extreme form of *neutrality*, where a major shift in the monetary regime, which increased the volatility of the nominal exchange rate by an order of magnitude,

[1]When Nakamura and Steinsson (2018, pp.69–70) surveyed "prominent macroeconomists [on what is the most convincing evidence for monetary nonneutrality], the three most common answers have been: the evidence presented in Friedman and Schwartz (1963) regarding the role of monetary policy in the severity of the Great Depression; the Volcker disinflation of the early 1980s and accompanying twin recession; and the sharp break in the volatility of the US real exchange rate accompanying the breakdown of the Bretton Woods System of fixed exchange rates in 1973."

[2]The argument here relies on the timing and the sharp discontinuity in the behavior of the exchange rates (see Figure 1), absent other immediate major changes in the environment.

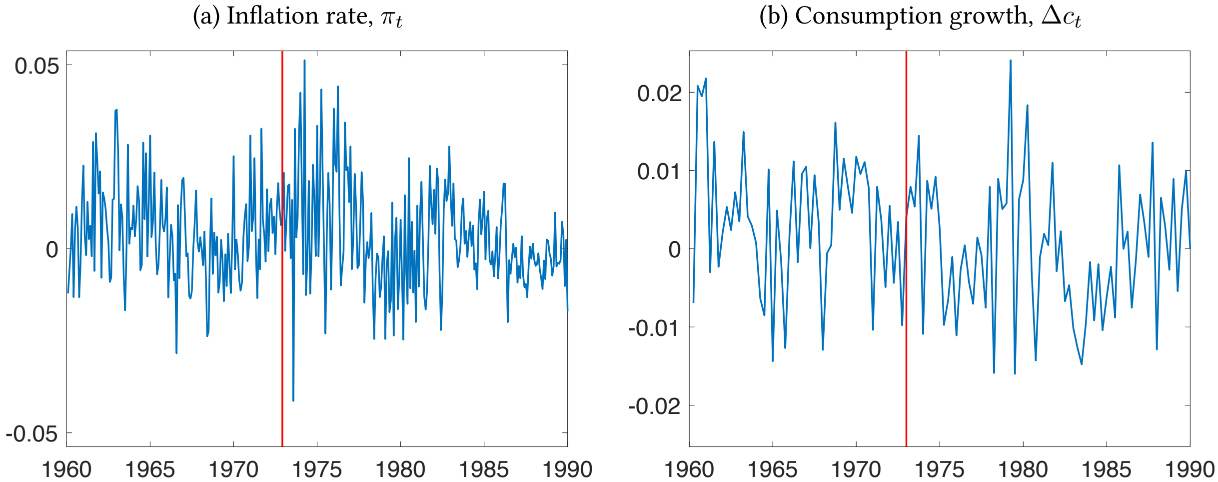


Figure 2: Inflation and consumption growth

Note: average inflation rates (monthly) and consumption growth rates (quarterly) for G7 countries except Canada plus Spain.

fails to affect the equilibrium properties of any macro variables, apart from the real exchange rate. In fact, this is a considerably more puzzling part of the larger set of "Mussa facts": while the lack of change in the volatility of nominal variables, like inflation, is inconsistent with models of monetary neutrality, the lack of change in the volatility of real variables, like consumption and output, is inconsistent with sticky-price models. Therefore, if we take the combined evidence, it does not seem to favor one type of models over the other, but rather rejects both types.

To provide immediate intuition for this logic, consider two equilibrium conditions. The first is simply the definition of the real exchange rate (in logs):

$$q_t = e_t + p_t^* - p_t, \tag{1}$$

where p_t and p_t^* are consumer price levels at home and abroad, and e_t and q_t are the nominal and real exchange rates respectively. In models with monetary neutrality (e.g., international RBC), a change to the monetary policy rule should *not* affect the process for q_t, and therefore (1) necessary implies that the volatility of $\pi_t - \pi_t^* \equiv \Delta p_t - \Delta p_t^*$ must change along with the volatility of Δe_t. In the data, the volatility of Δq_t and Δe_t increased simultaneously, while the volatility of $\pi_t - \pi_t^*$ remained stable and low (see Figure 3 and Table 1). This pattern can, however, be consistent with the conventional sticky-price models (see e.g. Monacelli 2004). This observation is at the core of the traditional interpretation of the Mussa puzzle, suggesting that sticky price models (NOEM) beat RBC models, and monetary policy must have real effects due to nominal rigidities.

This interpretation, however, misses the second half of the picture. Equilibrium dynamics in a general class of models satisfies the following cointegration property between relative consumption (with the rest of the world) and real exchange rate:

$$\sigma(c_t - c_t^*) = q_t + \zeta_t, \tag{2}$$

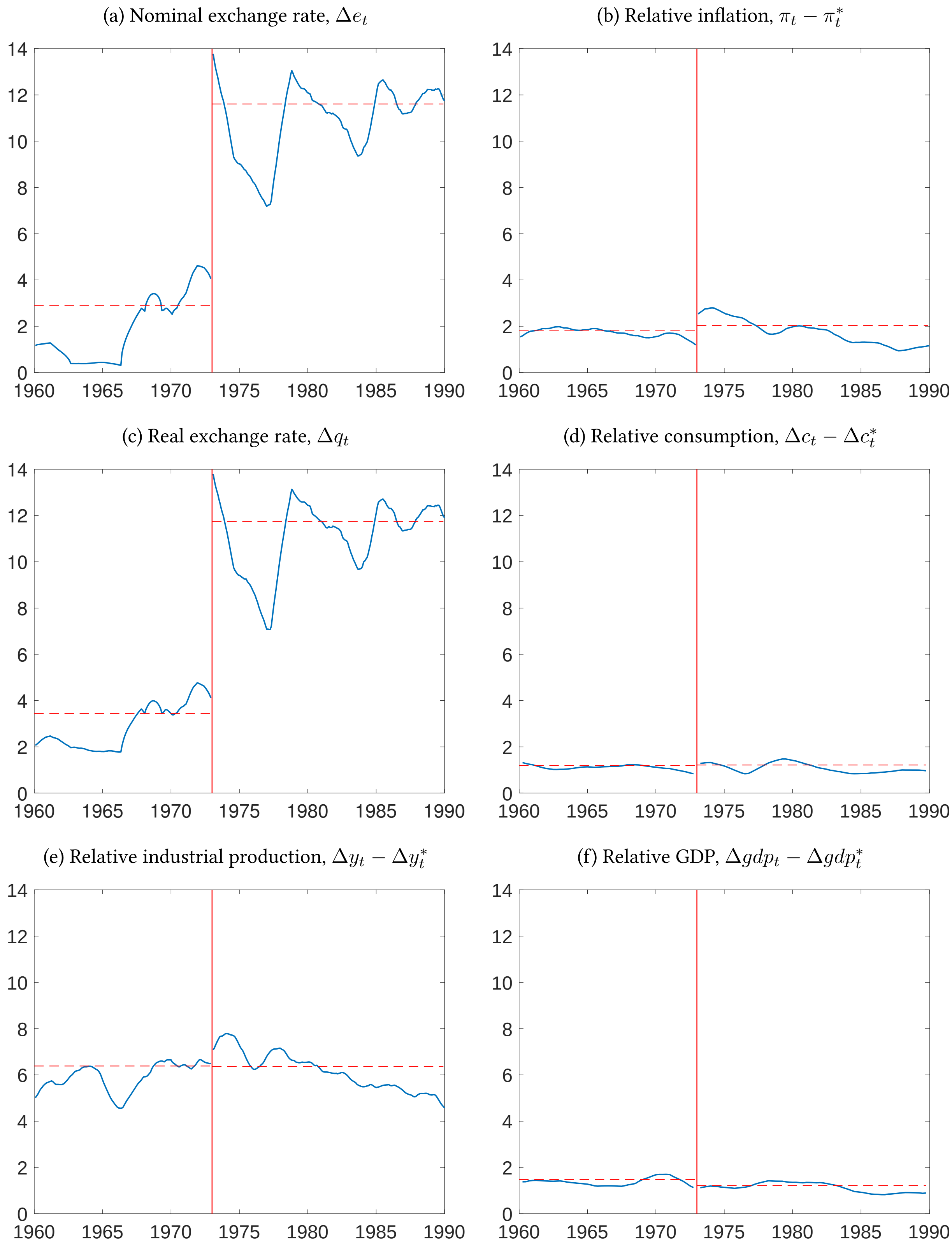


Figure 3: Volatility of macroeconomic variables over time

Note: All panels plot annualized standard deviations (of the log changes), estimated as triangular moving averages with a window over 18 months (or 10 quarters for quarterly data) before and after, treating 1973:01 as the end point for the two regimes; the dashed lines correspond to standard deviations measured over the entire subsamples (before and after 1973). US vs the rest of the world (as in Figure 1); monthly data from IFM IFS for panels a, b and e, and quarterly data from OECD in panels c, d and f. Appendix Figure A2 zooms in on the range of variation in panels b, d, e and f; Table 1 provides further details.

where $\sigma > 0$ and ζ_t can be interpreted as the equilibrium departure from the optimal international risk sharing.[3] Indeed, equation (2) with $\zeta_t \equiv 0$ corresponds to the classic Backus and Smith (1993) condition under separable utility with constant relative risk aversion σ. We show that equation (2) is considerably more general and emerges as an equilibrium cointegration relationship independently of asset market completeness and other features of the model. Furthermore, we show that in a large class of conventional models — including both IRBC and NOEM — the residual term ζ_t is independent of the monetary policy regime. Therefore, a shift in the monetary policy regime, which changes dramatically the volatility of Δq_t, should necessarily change the volatility of $\Delta c_t - \Delta c_t^*$. In the data, however, the volatility of relative consumption growth, just like that of inflation, remained both stable and small (see Figure 3).

To summarize, the models of monetary neutrality are consistent with the observed lack of change in the volatility of consumption, but for the wrong reason — as they fail to predict the change in the volatility of the real exchange rate. In contrast, models with nominal rigidities can explain the changing behavior of the real exchange rate, but have the counterfactual implications for the missing change in the volatility of the real variables. Therefore, the extended Mussa facts falsify the conventional RBC and New Keynesian models alike.

We then present a new resolution to the Mussa puzzle, which is simultaneously consistent with all the empirical facts. In particular, we show that in a model with segmented financial markets and limits to arbitrage developed in Itskhoki and Mukhin (2019), shifts in monetary policy regime affect the volatility of both nominal and real exchange rates, *even* when prices are fully flexible. Intuitively, the unpredictable movements in *nominal* exchange rate are the main source of uncertainty for financial intermediaries, who as a result are less aggressive under free floating exchange rates in taking large currency positions to ensure that uncovered interest parity (UIP) holds. By consequence, the equilibrium UIP violations are larger under the floating exchange rate regime, consistent with the data (see Kollmann 2005). A pegged exchange rate, in contrast, decreases uncertainty and stimulates arbitrageurs to take larger positions. As a result, the real exchange rate is less sensitive to shocks in the financial market and has lower volatility. At the same time, the financial shocks do not constitute the main source of volatility in the other macro variables under *either* monetary regime, and thus the model is consistent with nearly no change in the macroeconomic volatility, apart from the exchange rates.[4]

This logic is summarized in the *modified UIP* condition, which holds in equilibrium of our economy with a segmented financial market:

$$i_t - i_t^* - \mathbb{E}_t \Delta e_{t+1} = \chi_1 \psi_t - \chi_2 b_{t+1}, \tag{3}$$

where the left-hand side is the expected carry trade return, ψ_t is a demand shock for foreign-currency

[3] Note the parallel between ζ_t and q_t, which can be viewed as defined by identifies (2) and (1) respectively: just like q_t is the departure from *parity* in the goods market (namely, the purchasing power parity), ζ_t can be viewed as the departure from "parity" in the financial market (namely, the optimal risk sharing).

[4] This additionally requires that economies are sufficiently closed to international trade — an important feature of the world as argued by Obstfeld and Rogoff (2001) — so that real exchange rate volatility does not translate into a large volatility increase in the price level, production and consumption. This is consistent with the *exchange rate disconnect* mechanism under the floating (Taylor rule) regime developed in Itskhoki and Mukhin (2019).

bonds and b_{t+1} is the net foreign assets of the home country. Crucially, the coefficients on the right-hand side of (32) are endogenous to the monetary policy regime, and in particular

$$\chi_1, \chi_2 \propto \sigma_e^2 \equiv \text{var}_t(\Delta e_{t+1}), \tag{4}$$

that is increase proportionally with the unexpected exchange rate volatility. Equation (32) with endogenous coefficients (4) is the only unconventional equilibrium condition in an otherwise standard international DSGE model. A change in the monetary regime has a direct effect on the equilibrium in the financial market via (32), and this is what allows the model to be consistent with the umbrella of Mussa facts, independently of the presence of nominal rigidities and the source of the other shocks, as long as ψ_t is an important contributor to the exchange rate volatility under a floating regime.[5]

We conclude that rather than discriminating between models with sticky versus flexible prices, and monetary versus productivity shocks, the Mussa puzzle provides a strong evidence in favor of models with monetary non-neutrality arising due to *financial market segmentation* — a particular type of financial friction by which the bulk of the *nominal exchange rate risk* is held by a small group of financial intermediaries and not shared smoothly throughout the economy. Sticky prices are neither necessary, nor sufficient ingredient for the qualitative success of this model. Nonetheless, realistic price and wage stickiness can improve the model's quantitative fit. Our analysis emphasizes that monetary non-neutrality is *not exclusive* to nominal rigidities in price setting, as changes in equilibrium properties of the nominal variables — such as the nominal exchange rate — can change the degree of financial market (in)completeness, and hence have real consequences for the real equilibrium outcomes.

Overidentifying moments Backus-Smith correlation, Fama regression coefficient, Balassa-Samuelson...

Related literature Baxter and Stockman (1989), Flood and Rose (1995), Jeanne and Rose (2002), Kollmann (2005), Alvarez, Atkeson, and Kehoe (2007), Colacito and Croce (2013),... Engel et al. (2018), Devereux-Hnatkovska, Kollmann, Frenkel-Levich...

2 Empirical Facts

Data We start by briefly describing the construction of our dataset, and provide further details in Appendix A.2. All monthly data (for nominal exchange rate, consumer prices and production index) come from the IFM IFS database, while all quarterly data (for GDP, consumption, imports and exports) are from the OECD database. All quantity variables (GDP, consumption, imports and exports) are real, annualized, seasonally-adjusted, and expressed in fixed 2010 US dollars, which allows to sum them across countries. Production index is also seasonally-adjusted, while nominal exchange rates and

[5] Itskhoki and Mukhin (2019) (and 2019b) show that financial shocks ψ_t are essential for a successful model of exchange rate disconnect under a Taylor rule regime, and resolve a variety of exchange rate puzzles, including Meese-Rogoff, PPP, Backus-Smith and UIP puzzles. Their presence *per se* is not sufficient to resolve the Mussa puzzle, which also requires the endogeneity of the coefficient in (32). We further show the relationship between (2) and (32), and how (4) implies the endogeneity of ζ_t to the exchange rate regime. Importantly, (32) does not rely on the assumption that an Euler equation holds for a representative consumer.

consumer price indexes are not. The *net export* variable is defined as the ratio of exports minus imports to the sum of exports and imports, in order to counter a mechanical increase in the volatility of net exports to GDP due to higher openness of the economies in later periods. All data are annualized to make volatilities (standard deviations) comparable across series.

There is ambiguity associated with identifying the exact end of the Bretton Woods System. In particular, during the Bretton Woods period, there are already large devaluations in the U.K. and Spain in November 1967, a devaluation in France and an appreciation in Germany in August–October 1969. While all countries officially allowed their exchange rates to float in February 1973, most of them were already adjusting their exchange rates since the "Nixon shock" in August 1971, which limited the direct convertibility of dollar to gold. Therefore, we label the period from 1960:01-1971:07 as "peg" and the period from 1973:01-1989:12 as "float", as used in tables and scatter plots below (which exclude the intermediate period 1971:08–1972:12).[6] The "regression discontinuity" graphs are done for two alternative break points — 1973:01 in the main figures and 1971:08 in the robustness figures in the appendix.

The rest of the world for the U.S. is constructed as a weighted average of percent changes in series across France, Germany, Italy, Japan, Spain and the U.K. (G7 countries except Canada plus Spain). GDP in 2010:Q1 is used to construct country weights.

Macroeconomic volatility Figure 3 displays the main empirical results of the paper. In the spirit of the regression discontinuity design (RDD), we estimate standard deviations of the variables using a rolling window that starts at 1973:01 and goes either forward or backward. In line with the seminal Mussa (1986) paper, the end of the Bretton Woods System is associated with a dramatic change in the volatility of both nominal and real exchange rates, from around 2% to 10% (more precisely, in units of annualized standard deviations of log changes). What makes this fact much more puzzling, however, is the absence of any comparable change in the volatility of the other variables — either nominal like inflation, or real like production and consumption.[7] Thus, while under the peg regime, the volatility of the real exchange rate is of the same order of magnitude as for the other macroeconomics variables, there is a clear "disconnect" between the real exchange rate and macroeconomic fundamentals in the floating regime. We emphasize the relative magnitudes of volatilities across different variables and regimes by keeping the same scale for standard deviations of all variables in Figure 3, while Appendix Figure A2 zooms in on the range of variation of individual macroeconomic variables to see (the lack of) the discontinuity in the behavior of inflation, consumption and output.[8]

The rest of the pictures and tables expend on this finding and provide some additional details. Figure A3 provides a robustness check using 1971:08 as the alternative break point. There is no evidence of

[6] In Canada, the two exchange rate regimes occurred over different periods with free floating before 1962:06 and after 1970:05, and a peg in between. This is why we exclude Canada from the construction of the "rest of the world" in the figures.

[7] Figure 3 presents the *relative* volatilities of macroeconomic variables between the US and the rest of the world, as these are the relevant objects emphasized by the theory in Section 3. Table 1 also present the results for individual country variables across a range of countries, which exhibit similar patterns as the relative variables for the US vs the ROW.

[8] Note a slight increase in the volatility of consumer price inflation in the brief period after the break up of the Bretton Woods System, which quickly comes back down so that the average relative inflation volatility before and after 1973 is about the same. This increase in the volatility of inflation in the second half of 1970s is likely a response to the two large oil price shocks. There is also a slight increase in the volatility of consumption briefly after 1973, due to the 1974 recession in Japan.

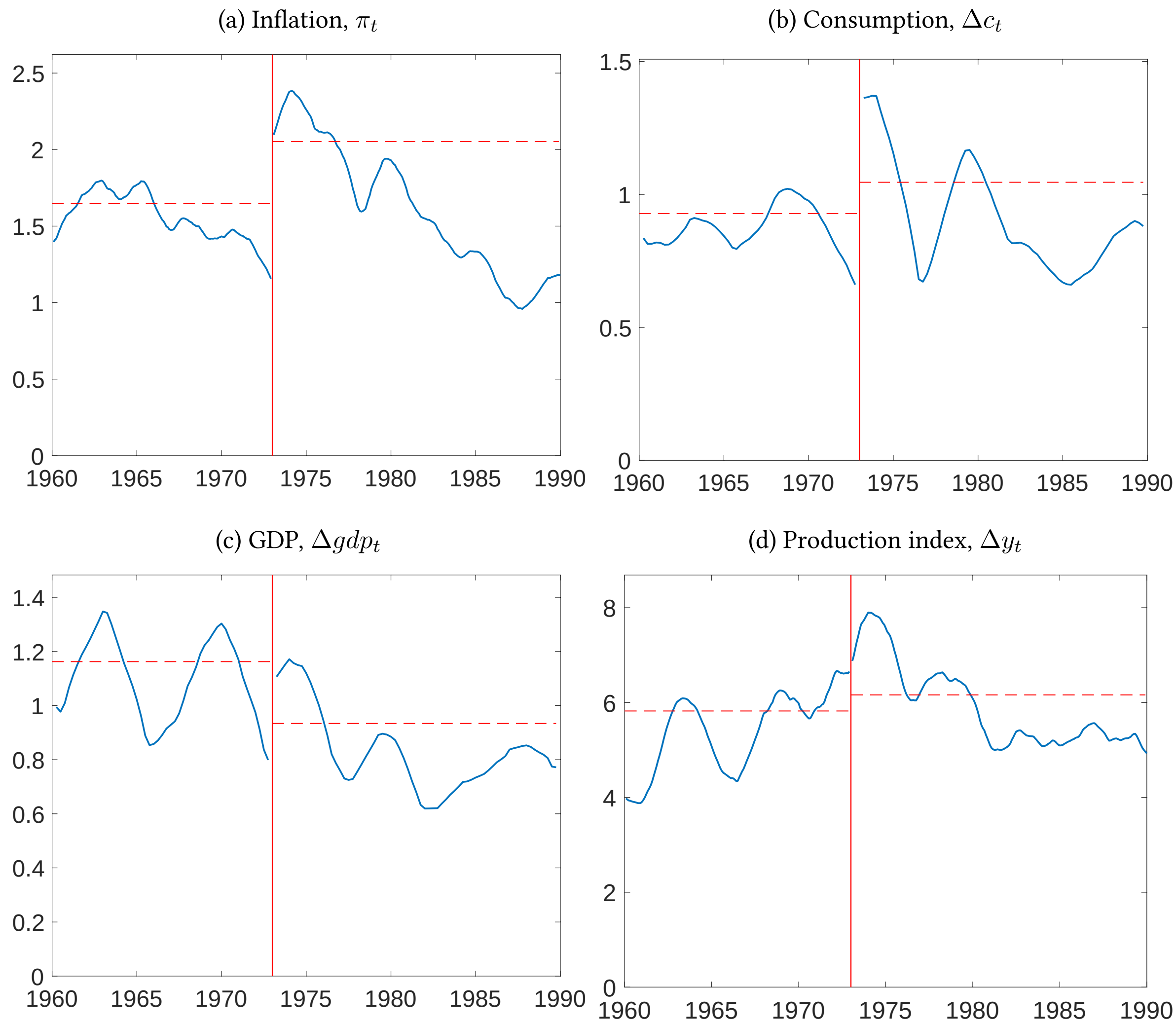


Figure 4: Macroeconomic volatility over time: country-level variables

Note: Trianglular moving averages of the standard deviations of macro variables, treating 1973:01 as the break point; average across countries (G7 except Canada plus Spain).

changing volatility for macroeconomic variables in this case either. The missing change in the volatility is true not only for the cross-country differences of variables, but also for the fundamentals at the country level. In particular, from Figure 4, there is almost no differences in the volatilities of macro variables.

We now unpack the rest of the world (RoW) into separate countries and show that the main results hold in the panel as well. Table 1 summarizes the standard deviation of various variables for each country in our sample across the two monetary regimes, as well as provides a formal test of the equality of the variances of variables under the two regimes. We confirm that the change in the volatility of the exchange rates was large and highly significant in every country, while changes in the volatility of the other variables were small and generally insignificant. Note that rather than emphasizing the lack of any change in other variables, we emphasize the difference in the order of magnitude. Table 1 shows that while nominal and real exchange rate volatility increased on average by about 8 and 6

Table 1: Empirical moments: standard deviations

	Δe_t			Δq_t			$\pi_t - \pi_t^*$			$\Delta c_t - \Delta c_t^*$		
	peg	float	ratio	peg	float	ratio	peg	float	ratio	peg	float	ratio
Canada	0.8	4.4	5.7*	1.5	4.7	3.0*	1.3	1.4	1.1	0.8	1.1	0.9
France	3.4	11.8	3.5*	3.7	11.8	3.2*	1.3	1.3	1.0	1.2	0.9	0.7*
Germany	2.4	12.3	5.0*	2.7	12.5	4.7*	1.4	1.3	0.9	1.3	1.2	0.9
Italy	0.5	10.4	18.8*	1.5	10.4	6.9*	1.4	1.9	1.3*	1.0	1.1	1.0
Japan	0.8	11.7	13.8*	2.7	11.9	4.4*	2.7	2.8	1.0	1.1	1.3	1.2
Spain	4.4	10.8	2.5*	4.7	10.8	2.3*	2.7	2.6	0.9	1.2	1.0	0.8
U.K.	4.1	11.5	2.8*	4.4	12.0	2.7*	1.7	2.5	1.5*	1.4	1.5	1.1
RoW	1.2	9.8	8.0*	1.8	9.9	5.6*	1.3	1.4	1.1	0.9	0.9	1.0

	$\Delta gdp_t - \Delta gdp_t^*$			$\Delta y_t - \Delta y_t^*$			Δnx_t			$\sigma(\Delta c_t - \Delta c_t^*) - \Delta q_t$		
	peg	float	ratio	peg	float	ratio	peg	float	ratio	peg	float	ratio
Canada	1.0	1.0	1.0	3.8	4.9	1.3	1.7	1.6	0.9	2.4	4.5	1.9*
France	1.2	1.0	0.8	5.3	5.6	1.1	1.5	1.4	0.9	4.4	12.2	2.7*
Germany	1.8	1.2	0.7*	6.7	6.0	0.9	1.8	1.7	0.9	3.9	13.7	3.5*
Italy	1.5	1.3	0.8	8.1	9.7	1.2	2.5	2.2	0.9	2.8	11.4	4.1*
Japan	1.5	1.3	0.8	5.5	5.0	0.9	2.4	2.2	0.9	2.8	13.1	4.7*
Spain	1.6	1.2	0.7*	10.1	10.4	1.0	5.4	2.1	0.4*	5.8	11.4	2.0*
U.K.	1.4	1.4	0.9	3.9	6.0	1.5*	2.2	1.9	0.9	5.2	11.8	2.2*
RoW	1.1	1.0	0.8	3.9	3.5	0.9	1.1	1.0	0.9	2.5	10.7	4.3*

	π_t			Δc_t			Δgdp_t			Δy_t		
	peg	float	ratio	peg	float	ratio	peg	float	ratio	peg	float	ratio
Canada	1.3	1.4	1.1	0.8	0.9	1.1	0.9	0.9	1.0	4.1	5.1	1.2
France	1.1	1.3	1.2*	0.9	0.8	0.9	0.9	0.6	0.6*	4.2	5.4	1.3*
Germany	1.2	1.1	0.9	1.0	1.0	1.0	1.5	1.0	0.7	6.2	5.7	0.9
Italy	1.0	2.1	2.0*	0.7	0.8	1.2	1.3	1.0	0.8	7.5	9.5	1.3*
Japan	2.6	2.9	1.1	1.0	1.3	1.3	1.1	1.1	0.9	4.6	4.9	1.1
Spain	2.5	2.5	1.0	1.0	0.7	0.7	1.4	0.7	0.5*	10.1	10.1	1.0
U.K.	1.6	2.6	1.6*	1.2	1.4	1.2	1.0	1.3	1.2	3.5	5.9	1.7*
U.S.	0.9	1.3	1.5*	0.7	0.8	1.1	0.9	1.0	1.1	2.9	2.9	1.0
Average												

Note: "peg" corresponds to the period from 1960:01-1971:07 (except for Canada where it is from 1962:04-1970:01); "float" is from 1973:08-1989:12. The RoW corresponds to France, Germany, Italy, Japan, Spain, and the U.K., aggregated using 2010 GDP as weights. nx_t is the ratio of export minus imports to the sum of imports and exports. We use $\sigma = 2$ in panel eight. * indicates significance of the difference between peg and float at the 5% level (`robvar` test in Stata).

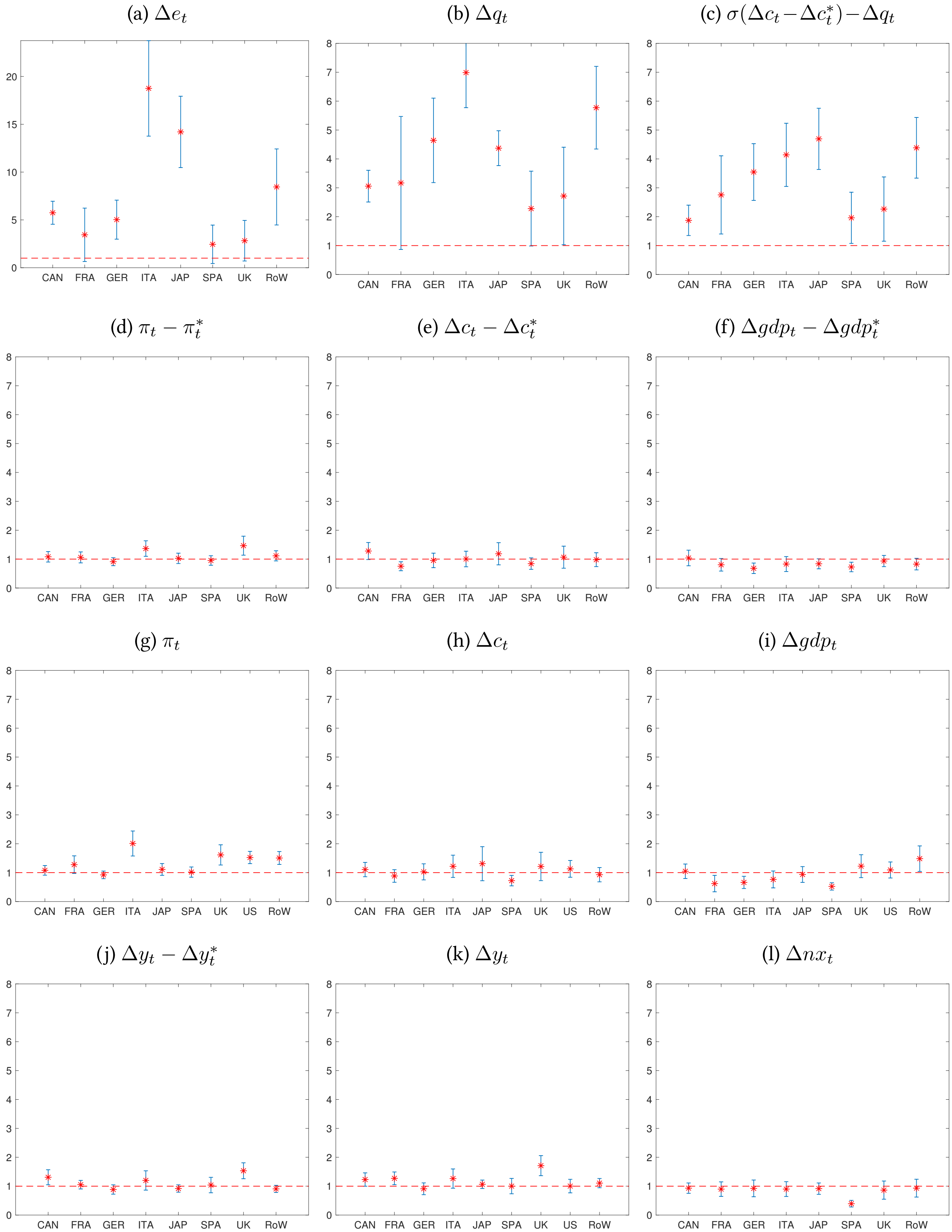


Figure 5: Volatility ratio float/peg, across variables and countries

Note: plots show the ratios of standard deviations under floating and peg regimes across individual countries with 90% confidence intervals estimated using Newey-West (HAC) standard errors. y-axis has the same scale for all plots except Δe_t.

times respectively, the volatility of the other variables changed in different direction across countries and by an order of magnitude of about 10% — a stark difference. We further illustrate this point in Figure 5 which plots the ratio of the volatilities under the two regimes for each variable and country, on a common scale for comparability, with a Newey-West (HAC) robust 90% confidence interval (see also Appendix Figures A5 and A6).

Perhaps most surprisingly, there is no increase in the volatility of net exports, despite a large increase in the volatility of the real exchange rate (see Figures A2(e) and 5(l) and Table 1). Systematic data on terms of trade is not available for this period, however, in the FRED data we see that the volatility of the US terms of trade increased only twofold, while the volatility of the US real exchange rate increased six times. Therefore, we conjecture that the lack of the increased volatility in net exports is in part due to a much muted response of the behavior of the terms of trade and in part due to muted response of net exports themselves to international relative prices.

Lastly, following the prediction of the theory (recall (2)), we focus on the volatility of $\Delta\zeta_t = \sigma(\Delta c_t - \Delta c_t^*) - \Delta q_t$, which in a wide range of models remains unchanged across monetary policy regimes. Table 1 shows that for $\sigma = 2$, we reject the null of no change in the volatility of $\Delta\zeta_t$ for every country in our sample. Further, Figure 7 shows that the ratio of $\mathrm{std}(\Delta\zeta_t)$ under the float relative to the peg is large for a wide range of values of $\sigma \in [0, 5]$, providing evidence in favor of lower volatility of the "risk-sharing shocks" ζ_t under the peg relative to the float.

Correlations Figure 6 plots the correlations between the nominal and real exchange rates, as well as their correlations with macro variables — relative inflation and relative consumption growth — over time, calculated as triangular moving average with a break point at 1973:01. The first two panels identify two clear shifts with the break of the fixed exchange rate regime. In particular, the correlation between nominal and real exchange rates is positive but not very strong during the peg, where nominal exchange rates barely moved before 1967, and it becomes virtually perfect (0.98) after the early 1970s. The latter correlation is around 0.7 and does not change significantly with the end of the Bretton Woods System. In contrast, the real exchange rate is tightly correlated with the relative inflation during the peg, yet it quickly becomes nearly orthogonal with relative inflation as soon as nominal exchange rates begin to float. At the same time, the nominal exchange rate is orthogonal with the relative inflation both before and after the 1973. While the pattern of correlation during the peg is mechanical — since $\Delta e_t \approx 0$ and thus $\Delta q_t \approx -(\pi_t - \pi_t^*)$ — the comovement of variables during the float is rather puzzling, as nominal depreciations if anything are negatively correlated with relative domestic inflation.

The last panel of Figure 6 shows that the correlation between real exchange rate and relative consumption growth, while somewhat positive under the peg, has become noticeably negative under the float, suggesting that the Backus-Smith puzzle became more pronounced with floating exchange rates.[9] While the correlations are not very large, this pattern is observed robustly across the countries, as we document in Table 2.

[9] This observation is consistent with the findings of Devereux and Hnatkovska (2014) that the Backus-Smith condition holds better across regions within countries, in contrast with its cross-country violations. Another pattern emphasized by Berka, Devereux, and Engel (2012) is a substantially greater role of the non-tradable (Balassa-Samuelson) component in the RER variation under a nominal peg.

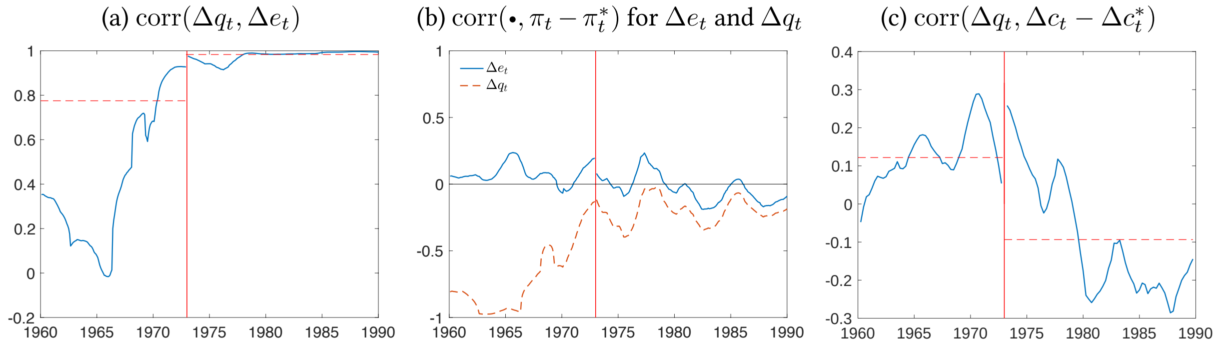


Figure 6: Correlations of exchange rates over time

Note: Triangular moving average correlations, treating 1973:01 as the end point for the two regimes.

Table 2 reports correlations between various variables under the two exchange rate regimes, while Appendix Figure A4 plots the evolution of these correlation over time. Table 2 identifies another robust correlation pattern — between consumption and GDP growth, which is stable around 0.7 and does not change at all with the end of the Bretton Woods System. The other correlations, including that between RER and net exports, as well as for GDP (consumption) growth between countries, are generally not very strong and not particularly stable over time, suggesting only weak patterns of change across the two monetary regimes. The correlation between the real exchange rate and net exports switches from negative under the peg to positive under the float, but in both cases it is close to zero for most countries in our sample.

Table 2: Empirical moments: correlations

	$\Delta q_t, \Delta e_t$		$\Delta q_t, \Delta c_t - \Delta c_t^*$		$\Delta q_t, \Delta nx_t$		$\Delta gdp_t, \Delta gdp_t^*$		$\Delta c_t, \Delta c_t^*$		$\Delta c_t, \Delta gdp_t$	
	peg	float	peg	float	peg	float	peg	float	peg	float	peg	float
Canada	0.77	0.92	0.03	−0.07	0.01	0.05	0.31	0.47	0.40	0.25	0.28	0.57
France	0.96	0.99	0.05	−0.08	0.23	0.12	0.09	0.30	−0.24	0.29	0.51	0.48
Germany	0.87	0.99	0.04	−0.19	−0.06	0.00	−0.01	0.28	−0.11	0.11	0.57	0.58
Italy	0.54	0.97	0.07	−0.13	0.02	−0.01	0.04	0.17	−0.18	0.13	0.64	0.45
Japan	0.76	0.98	0.21	−0.00	0.03	0.21	−0.08	0.24	0.11	0.23	0.70	0.71
Spain	0.83	0.96	−0.09	−0.18	−0.06	0.16	0.05	0.09	−0.06	0.05	0.56	0.63
U.K.	0.94	0.96	0.09	−0.10	−0.39	−0.16	−0.11	0.30	−0.02	0.22	0.59	0.71
RoW	0.80	0.98	0.05	−0.19	−0.20	0.21	−0.03	0.39	−0.11	0.31	0.68	0.72

Note: see notes to Table 1. Cross-country correlation are with the U.S. as the foreign counterpart indicated with a star.

Finally, both GDP growth and consumption growth are uncorrelated or mildly negatively correlated across countries (with the exception of Canada) before 1970s and since then become sizably positively correlated, especially the GDP growth rates — a surprising pattern emphasized by Kollmann (2005). Figure A4 reveals that this is, however, largely driven by the high correlation of growth rates across countries in the late 1970s, a period of large global oil price shocks.

Fama regression coefficient and volatility of relative interest rates and stock market..

3 Conventional Models

Conventional models are defined by the following property: if prices are flexible, a switch in the monetary regime does not affect the behavior of real variables, including the real exchange rate q_t, consumption c_t and output y_t. Therefore, we only consider the case of sticky prices in this section, as flexible-price version of these models is falsified by the changing property of the real exchange rate (Figure 1). We first describe the model setup and then prove a negative result that even the sticky-price version of these models is falsified by the extended set of Mussa facts documented above.

3.1 Model setup

We build on a standard New Keynesian open-economy model (NOEM) with productivity shocks, PCP Calvo price stickiness, flexible wages and no capital. In our quantitative exploration in Section 5, we generalize this environment by introducing intermediate goods, capital, sticky wages and considering alternative variants of price stickiness including LCP and DCP, as well as monetary shocks. The model features home bias in consumption and exogeneous shocks to international risk sharing. We allow for various degrees of financial market (in)completeness, including complete markets, bonds-only and financial autarky.

There are two mostly symmetric countries — home (Europe) and foreign (US, denoted with a $*$). Each country has its nominal unit of account in which the local prices are quoted: for example, the home wage rate is W_t euros and the foreign wage rate is W_t^* dollars. The nominal exchange rate $\mathcal{E}_t$ is the price of dollars in terms of euros, hence an increase in $\mathcal{E}_t$ signifies a nominal devaluation of the euro (the home currency).

The monetary policy is conducted according to a conventional Taylor rule targeting inflation or nominal exchange rate — depending on the monetary regime. In particular, the foreign country (US) always targets inflation, while the home country (Europe) switches from an exchange rate peg ('peg') to an inflation targeting ('float'). We consider the limiting case where the monetary authorities have the ability to fully stabilize prices or the exchange rate, depending on the regime.

Households A representative home household maximizes the discounted expected utility over consumption and labor:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{1}{1+1/\nu} L_t^{1+1/\nu} \right), \tag{5}$$

where σ is the relative risk aversion parameter and ν is the Frisch elasticity of labor supply. The flow budget constraint is given by:

$$P_t C_t + \sum_{j \in J_t} \Theta_t^j B_{t+1}^j \leq W_t L_t + \sum_{j \in J_{t-1}} e^{-\zeta_t^j} D_t^j B_t^j + \Pi_t + T_t, \tag{6}$$

where P_t is the consumer price index and W_t is the nominal wage rate, Π_t are profits of home firms, T_t are lump-sum transfers from the government, and B_{t+1}^j is quantity of asset $j \in J_t$ purchased at time t

at price Θ_t^j and paying out a state-contingent dividend D_{t+1}^j at $t+1$ taxed at rate ζ_t^j (which we think of as Chari, Kehoe, and McGrattan 2007 wedges).[10]

Household optimization results in standard optimality conditions for labor supply:

$$C_t^{\sigma} L_t^{1/\nu} = \frac{W_t}{P_t}, \tag{7}$$

Euler equations for state-contingent bonds:

$$\Theta_t^j = \beta \mathbb{E}_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} e^{-\zeta_{t+1}^j} D_{t+1}^j \right\} \qquad \text{for all} \quad j \in J_t. \tag{8}$$

The foreign households are symmetric, having access to a set J_t^* of state contingent assets with dividends taxed at country-specific tax rate ζ_t^{j*}. The assets $j \in J_t \cap J_t^*$ can be purchased by households of both countries at a common price Θ_t^j in units of home currency.[11]

Expenditure and demand The domestic households allocate their within-period consumption expenditure between home and foreign varieties of the goods, $P_t C_t = \int_0^1 \Big[P_{Ht}(i) C_{Ht}(i) + P_{Ft}(i) C_{Ft}(i) \Big] \mathrm{d}i$ to maximize the CES consumption aggregator:

$$C_t = \left[\int_0^1 \left(\left[(1-\gamma) e^{-\gamma \xi_t} \right]^{1/\theta} C_{Ht}(i)^{\frac{\theta-1}{\theta}} + \left[\gamma e^{(1-\gamma)\xi_t} \right]^{1/\theta} C_{Ft}(i)^{\frac{\theta-1}{\theta}} \right) \mathrm{d}i \right]^{\frac{\theta}{\theta-1}}, \tag{9}$$

with parameter $\gamma \in [0, 1/2)$ capturing the level of the *home bias*, which can be due to a combination of home bias in preferences, trade costs and non-tradable goods (see Obstfeld and Rogoff 2001) and ξ_t denoting the relative demand shock for the foreign good or other sources of time-varying home bias (see Pavlova and Rigobon 2007).[12] The solution to the optimal expenditure allocation results in the conventional constant-elasticity demand schedules:

$$C_{Ht}(i) = (1-\gamma) e^{-\gamma \xi_t} \left(\frac{P_{Ht}(i)}{P_t} \right)^{-\theta} C_t \qquad \text{and} \qquad C_{Ft}(j) = \gamma e^{(1-\gamma)\xi_t} \left(\frac{P_{Ft}(j)}{P_t} \right)^{-\theta} C_t, \tag{10}$$

where the price index is given by $P_t = \left[\int_0^1 \left((1-\gamma) e^{-\gamma \xi_t} P_{Ht}(i)^{1-\theta} + \gamma e^{(1-\gamma)\xi_t} P_{Ft}(i)^{1-\theta} \right) \mathrm{d}i \right]^{1/(1-\theta)}$.

[10] When set J_t contains a home-currency risk-free bond B_{t+1}^f, its price is one over gross nominal interest rate $\Theta_t^f = 1/R_t$ and it pays out one unit of home currency in every state of the world next period, $D_{t+1}^f \equiv 1$; when it contains a foreign-currency risk-free bond B_{t+1}^{f*}, its price is $\mathcal{E}_t / R_t^*$ and its dividend is $D_{t+1}^{f*} = \mathcal{E}_{t+1}$.

[11] From the point of view of foreign households, the foreign currency price of asset j is $\Theta_t^j / \mathcal{E}_t$ in units of foreign currency, and the Euler equation is correspondingly $\frac{\Theta_t^j}{\mathcal{E}_t} = \beta \mathbb{E}_t \left\{ \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \frac{P_t^*}{P_{t+1}^*} e^{-\zeta_{t+1}^{j*}} \frac{D_{t+1}^j}{\mathcal{E}_{t+1}} \right\}$ for $j \in J_t^*$.

[12] The particular way in which we introduce the foreign-good demand shock ξ_t in (9) ensures that changes in ξ_t shift the relative demand between home and foreign goods without having a first-order effect on the price level. The aggregate implications of the model do not dependent on whether the home bias emerges on the extensive margin due to non-tradable goods or on the intensive margin due to trade costs and preferences, and therefore we do not explicitly introduce the non-tradables.

The expenditure allocation of the foreign households is symmetrically given by:

$$C^*_{Ht}(i) = \gamma e^{(1-\gamma)\xi^*_t} \left(\frac{P^*_{Ht}(i)}{P^*_t}\right)^{-\theta} C^*_t \qquad \text{and} \qquad C^*_{Ft}(j) = (1-\gamma)e^{-\gamma\xi^*_t} \left(\frac{P^*_{Ft}(j)}{P^*_t}\right)^{-\theta} C^*_t, \tag{11}$$

where ξ^*_t is the foreign demand shock for home goods, $P^*_{Ht}(i)$ and $P^*_{Ft}(j)$ are the foreign-currency prices of the home and foreign goods in the foreign market, and P^*_t is the foreign price level. The *real exchange rate* is the relative consumer price level in the two countries:

$$\mathcal{Q}_t \equiv \frac{P^*_t \mathcal{E}_t}{P_t}, \tag{12}$$

with an increase in $\mathcal{Q}_t$ corresponding to a real depreciation, that is a decrease in the relative price of the home consumption basket (note that (1) is the log version of (12)).

Production and price setting Home output is produced by a given pool of symmetric firms according to a linear technology in labor:

$$Y_t(i) = e^{a_t} L_t(i), \tag{13}$$

where a_t is the aggregate productivity shock, which implies that the marginal cost of production is:

$$MC_t = e^{-a_t} W_t, \tag{14}$$

identical for all firms.

The firms adjust prices infrequently à la Calvo with a constant per-period hazard rate λ of price nonadjustment, that is $P_{Ht}(i) = P_{H,t-1}(i)$ with probability λ and with complementary probability $(1-\lambda)$ the firm resets its price to $\bar{P}_{Ht}(i)$. For concreteness, we assume producer-currency pricing (PCP), which implies that the law of one price holds:

$$P_{Ht}(i)^* = P_{Ht}(i)/\mathcal{E}_t. \tag{15}$$

The per-period profit of the firm is given by

$$\Pi_t(i) = \big(P_{Ht}(i) - MC_t\big)\big(C_{Ht}(i) + C^*_{Ht}(i)\big) \tag{16}$$

where consumer demand $C_{Ht}(i)$ and $C^*_{Ht}(i)$ satisfies (10) and (11). The aggregate profits of the domestic firms, $\Pi_t = \int_0^1 \Pi_t(i)\mathrm{d}i$, are distributed to the domestic households.

The firms set prices $\bar{P}_{Ht}(i)$ as the solution of the following optimization problem:

$$\bar{P}_{Ht}(i) = \arg\max\, \mathbb{E}_t \sum\nolimits_{k=0}^{\infty} (\beta\lambda)^k \left(\frac{C_{t+k}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+k}}\, \Pi_{t+k}(i), \tag{17}$$

where future profits are discounted using the SDF of the households and the probability of the reset price $\bar{P}_{Ht}(i)$ staying in effect k periods after it has been set. Since firms are symmetric (conditional on the last date they adjusted prices), they all set the price at the same reset level, $\bar{P}_{Ht}(i) = \bar{P}_{Ht}$ for all i.

Government The fiscal authority collects taxes on financial dividends and returns them lump-sum to the households:

$$T_t = \sum_{j\in J_{t-1}} \big(1-e^{-\zeta_t^j}\big) D_t^j B_t^j. \tag{18}$$

The monetary policy is implemented by means of a Taylor rule:

$$i_t = \rho_m i_{t-1} + (1-\rho_m)\big[\phi_\pi \pi_t + \phi_e(e_t - \bar{e})\big] + \sigma_m \varepsilon_t^m, \tag{19}$$

where $i_t = \log R_t$ is the log nominal interest rate, $\pi_t = \Delta \log P_t$ is the inflation rate, $\varepsilon_t^m \sim iid(0,1)$ is the monetary policy shock with volatility parameter $\sigma_m \geq 0$, and the parameter ρ_m characterizes the persistence of the monetary policy rule. The coefficients $\phi_\pi > 1$ and ϕ_e are the Taylor rule parameters which weight the two nominal objectives of the monetary policy — inflation and exchange rate stabilization. We assume that the monetary authority can fully achieve the chosen goal (by increasing ϕ_π or ϕ_e unboundedly) — that is, either $\pi_t \equiv 0$ or $e_t \equiv \bar{e}$, depending on the regime. We further assume that the foreign country (the US) only has the inflation objective, so that $\phi_e^* = 0$, and $\pi_t^* \equiv 0$. We study the differential behavior of the macro variables across the two monetary regimes of the home country.

Equilibrium conditions The labor market clearing requires that the labor supplied by households according to (7) equals the aggregate labor demand of the home firm, $L_t = e^{-a_t}\int_0^1 Y_t(i)\mathrm{d}i$, where we used the production function (13). The goods market clearing for each firm i requires $Y_t(i) = C_{Ht}(i) + C_{Ht}^*(i)$, defined in (10)–(11), and given prices $P_{Ht}(i)$. Symmetric market clearing conditions hold in the foreign country. All assets B_{t+1}^j are in zero net supply, and for $j \in J_t \cap J_t^*$, we have $B_{t+1}^j + B_{t+1}^{j*} = 0$ given a common home-currency price Θ_t^j.

We focus here on two equilibrium conditions — the country budget constraint and the equilibrium in the financial market. The latter set of conditions can be written using (8) and their foreign counterparts as follows:

$$\mathbb{E}_t\left\{e^{-\zeta_{t+1}^j} D_{t+1}^j \frac{P_t}{P_{t+1}}\left[\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} - \left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\sigma}\frac{\mathcal{Q}_t}{\mathcal{Q}_{t+1}} e^{\tilde{\zeta}_{t+1}^j}\right]\right\} = 0, \qquad \forall j \in J_t \cap J_t^*, \tag{20}$$

where by convention we denote $\tilde{\zeta}_{t+1}^j \equiv \zeta_{t+1}^j - \zeta_{t+1}^{j*}$ the relative wedge across countries. This condition simply states that home and foreign households agree on the price Θ_t^j of all assets j that they can mutually trade. This allows the household to equalize the stochastic discount factors across the two countries in the best possible way given the available set of internationally-traded assets.

The country budget constraint derives from substituting firm profits (16) and government transfers (18) into the household budget constraint (6):

$$\mathcal{B}_{t+1} - \mathcal{R}_t \mathcal{B}_t = NX_t, \tag{21}$$

where the right-hand side is net exports $NX_t = \int_0^1 P_{Ht}(i)C_{Ht}^*(i)\mathrm{d}i - \mathcal{E}_t\int_0^1 P_{Ft}^*(i)C_{Ft}(i)\mathrm{d}i$ and the left hand-side is the evolution of net foreign assets $\mathcal{B}_{t+1} \equiv \sum_{j\in J_t}\Theta_t^j B_{t+1}^j$ with the cumulative realized return $\mathcal{R}_t \equiv \frac{\sum_{j \in J_{t-1}} D_t^j B_t^j}{\sum_{j \in J_{t-1}} \Theta_{t-1}^j B_t^j}$. The foreign budget constraint is redundant by Walras Law. Substituting the demand schedules (10)–(11) into the expression for net exports and combining prices into CES price indexes of exports P_{Ht} and imports P_{Ft}^*, we can rewrite the country budget constraint (21) as:

$$\mathcal{B}_{t+1} - \mathcal{R}_t \mathcal{B}_t = \gamma e^{(1-\gamma)\xi_t} (\mathcal{E}_t P_{Ft}^*)^{1-\theta} P_t^\theta C_t \left[e^{-(1-\gamma)\tilde{\xi}_t} \mathcal{S}_t^{\theta-1} \mathcal{Q}_t^\theta \frac{C_t^*}{C_t} - 1 \right], \tag{22}$$

where again $\tilde{\xi}_t \equiv \xi_t - \xi_t^*$, $\mathcal{Q}_t$ is the real exchange rate, and $\mathcal{S}_t \equiv \frac{\mathcal{E}_t P_{Ft}^*}{P_{Ht}}$ is the terms of trade, which in light of PCP Calvo price setting and the implied law of one price (15) satisfies:

$$\mathcal{S}_t \equiv \frac{\mathcal{E}_t P_{Ft}^*}{P_{Ht}} = \mathcal{Q}_t \left[\frac{(1-\gamma)e^{-\gamma\xi_t^*} + \gamma e^{(1-\gamma)\xi_t^*} \mathcal{S}_t^{-(1-\theta)}}{(1-\gamma)e^{-\gamma\xi_t} + \gamma e^{(1-\gamma)\xi_t} \mathcal{S}_t^{1-\theta}} \right]^{\frac{1}{1-\theta}} \quad \Rightarrow \quad \mathcal{S}_t \approx \mathcal{Q}_t^{\frac{1}{1-2\gamma}}, \tag{23}$$

where the approximation is a log-linearization around symmetric equilibrium with $\mathcal{Q}_t = \mathcal{S}_t = 1$ and $\xi_t = \xi_t^* = 0$. Conditions (20) and (22) allow to study a variety of cases with different degree of financial openness of the economies.

3.2 Empirical Falsification

We now show that under a variety of circumstances, there exists a constant ν such that the equilibrium process for $\nu(\Delta c_t - \Delta c_t^*) - \Delta q_t$ is independent of the monetary regime. In other words, a change in the statistical process for the real exchange rate Δq_t should result in a change in the statistical process for the relative consumption growth $\Delta c_t - \Delta c_t^*$. We consider a number of special cases in turn.

Financial autarky Consider first the special case when $J_t \cap J_t^* = \emptyset$ at all t, so that net foreign assets $\mathcal{B}_t \equiv 0$, and therefore $NX_t \equiv 0$ in every state and period. Equation (22) then implies, $C_t / C_t^* = e^{-(1-\gamma)\tilde{\xi}_t} \mathcal{S}_t^{\theta-1} \mathcal{Q}_t^\theta$, and using (23), we have:

$$c_t - c_t^* = -(1-\gamma)\tilde{\xi}_t + \left[\theta + \frac{\theta - 1}{1 - 2\gamma} \right] q_t. \tag{24}$$

If the process for taste shocks (home bias) for goods $\tilde{\xi}_t$ is independent from the monetary regime, it must be that the process for $\nu(\Delta c_t - \Delta c_t^*) - \Delta q_t$ with $\nu = \frac{1-2\gamma}{2(1-\gamma)\theta - 1}$ is also independent from the monetary regime. Note that for $\theta > 1$, $\nu < 1$ and is independent from relative risk aversion σ.

Complete markets Now consider a situation where there exists a $j \in J_t \cap J_t^*$ for every state of the world (Arrow securities), so that (20) holds as equality not just in expectation, but also state-by-state, $\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \equiv \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \frac{\mathcal{Q}_t}{\mathcal{Q}_{t+1}} e^{\tilde{\zeta}_{t+1}}$, where $\tilde{\zeta}_{t+1}$ is the state-specific realization of the relative wedge, or equivalently:

$$\sigma(\Delta c_t - \Delta c_t^*) = \Delta q_t + \tilde{\zeta}_t. \tag{25}$$

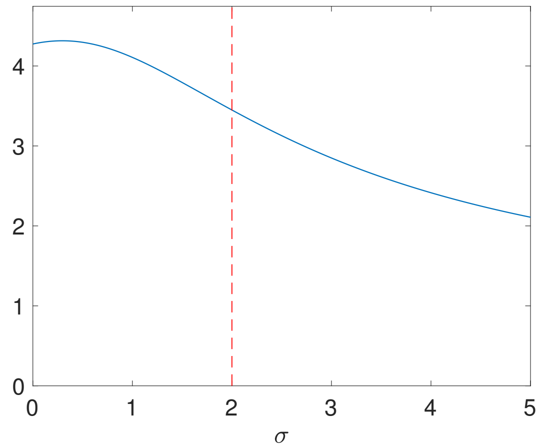


Figure 7: Ratio of $\text{std}(\tilde{\zeta}_t)$ after/during the Bretton Woods System, where $\tilde{\zeta}_t \equiv \sigma\Delta\tilde{c}_t - \Delta q_t$

Note: $\text{std}(\sigma(\Delta c_t - \Delta c_t^*) - \Delta q_t)$ is computed for 1960–72 and 1973–89 for the RoW vs the U.S. for different value of σ.

This corresponds to the first difference of (2) in the introduction. Assuming that wedges $\tilde{\zeta}_t$ do not change with the monetary regime, it must be that $\sigma(\Delta c_t - \Delta c_t^*) - \Delta q_t$ does not change as well. Of course, this nests the case of perfect international risk-sharing with $\tilde{\zeta}_t \equiv 0$.

Cole-Obstfeld case This is a special case with $\sigma = \theta = 1$, which is commonly used in the literature, as in this case equilibrium allocation does not depend on the degree of asset market completeness. For now, assume that additionally for all j, $\tilde{\zeta}_t^j = \tilde{\xi}_t \equiv 0$, and the formal result below relaxes this additional assumption. Note that under these circumstances balanced trade, $NX_t \equiv 0$, implies $C_t/C_t^* = \mathcal{Q}_t$, which ensures financial market equilibrium (20) independently of what assets j are in the set $J_t \cap J_t^*$. Therefore, this case is equivalent to the two cases considered above, but the logic of the Cole-Obstfeld case is more general, as we show below.

General asset markets Consider a case where $J_t \cap J_t^*$ contains at least one asset, namely the foreign-currency (US dollar) risk-free bond. Considering the risk-sharing condition (20) for this bond:

$$\mathbb{E}_t \left\{ \frac{P_t^*}{P_{t+1}^*} \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{\mathcal{Q}_{t+1}}{\mathcal{Q}_t} e^{-\tilde{\zeta}_{t+1}} - \left(\frac{C_{t+1}^*}{C_t^*} \right)^{-\sigma} \right] \right\} = 0, \tag{26}$$

where we additionally assumed for concreteness $\zeta_{t+1}^* \equiv 0$, that is foreigners do not face a wedge when trading the foreign-currency bond.[13] DO THE MARTINGALE TRICK!

[13]If we assume that home households can additionally trade a home-currency bond with each other, then we can derive a UIP condition... to interpret ψ_t...

4 Segmented Financial Market

Financial market There are three types of agents participating in the financial market: households, noise traders and professional intermediaries. The home and foreign households trade local currency bonds only. In particular, the home households demand at time t a quantity B_{t+1} of the home-currency bonds, as appears in their budget constraint (6). Similarly, foreign households demand a quantity B^*_{t+1} of the foreign-currency bonds. Both B_{t+1} and B^*_{t+1} can take positive or negative values, depending on whether the households save or borrow respectively.

The trades of the households are intermediated by risk-averse intermediaries, or market makers. There are m symmetric intermediaries, who adopt a zero-capital *carry trade* strategy, that is take a long position in the foreign-currency bonds and a short position of equal value in the home-currency bonds, or vice versa. The return on this carry trade is therefore:

$$\tilde{R}^*_{t+1} = R^*_t - R_t \frac{\mathcal{E}_t}{\mathcal{E}_{t+1}} \tag{27}$$

per one dollar invested in the foreign-currency bond and $\mathcal{E}_t$ euros sold of home-currency bonds at time t. We denote the size of their position by d^*_{t+1}, which may take positive or negative values depending on whether they are long or short in the foreign-currency bond, and assume that intermediaries maximize the CARA utility of the real return on their investment in units of the foreign consumption good:

$$\max_{d^*_{t+1}} \mathbb{E}_t \left\{ -\frac{1}{\omega} \exp\left(-\omega \frac{\tilde{R}^*_{t+1}}{P^*_{t+1}} d^*_{t+1} \right) \right\}, \tag{28}$$

where $\omega \geq 0$ is the risk aversion parameter.[14] In aggregate, all m intermediaries invest $\frac{D^*_{t+1}}{R^*_t} = m d^*_{t+1}$ dollars in foreign-currency bonds, as one dollar at time t affords a quantity R^*_t of dollar bonds D^*_{t+1}, each paying out one dollar at $t+1$. The intermediaries also take an offsetting position of $\frac{D_{t+1}}{R_t} = -\mathcal{E}_t \frac{D^*_{t+1}}{R^*_t}$ euros in home-currency bonds, resulting in a zero-value portfolio at time t.

Finally, there are n symmetric noise (or liquidity) traders, who have an exogenously-evolving demand for the foreign currency.[15] Like intermediaries, noise traders take a zero-capital position long in the foreign currency and short equal value in the home currency, or vice versa if they have an excess demand for the home currency. The overall position of the noise traders is

$$\frac{N^*_{t+1}}{R^*_t} = n \left(e^{\psi_t} - 1 \right) \tag{29}$$

in foreign-currency bonds and respectively $\frac{N_{t+1}}{R_t} = -\mathcal{E}_t \frac{N^*_{t+1}}{R^*_t}$ in home-currency bonds. We refer to the

[14] A property of the portfolio choice under CARA utility is that the solution does not depend on the level of wealth of the intermediaries, thus avoiding the need to carry it as an additional state variable, which would be the case under CRRA utility.

[15] The noise traders demand a certain position in home and foreign currency independently of the expected return on this portfolio, $\mathbb{E}_t \tilde{R}^*_{t+1}$, and of the other macroeconomic fundamentals reflected in the state variables of the home and foreign economies. Their demand for currency can be motivated as a liquidity demand, or alternatively as emerging from biased expectations about the exchange rate, $\mathbb{E}^n_t \mathcal{E}_{t+1} \neq \mathbb{E}_t \mathcal{E}_{t+1}$, as in Jeanne and Rose (2002).

noise trader shock ψ_t as the *financial shock*, and assume it follows an AR(1) process:

$$\psi_t = \rho\psi_{t-1} + \sigma_\psi \varepsilon_t, \qquad \varepsilon_t \sim iid(0,1), \tag{30}$$

where $\rho \in [0,1]$ is the persistence of the financial shock and $\sigma_\psi \geq 0$ is its volatility. The incomes (and losses) of both intermediaries and noise traders are returned in the end of each trading period to the foreign households as lump sum payments together with the dividends of the foreign firms, Π^*_{t+1}.[16]

Both currency bonds are in zero net supply, and therefore financial market clearing requires that the positions of the households, intermediaries and the noise traders balance out:

$$B_{t+1} + N_{t+1} + D_{t+1} = 0 \qquad \text{and} \qquad B^*_{t+1} + N^*_{t+1} + D^*_{t+1} = 0. \tag{31}$$

As both noise traders and intermediaries hold zero-capital positions, financial market clearing (31) implies a balanced position for the home and foreign households combined, $\frac{B_{t+1}}{R_t} + \mathcal{E}_t \frac{B^*_{t+1}}{R^*_t} = 0$. In other words, the financial market merely intermediates the intertemporal borrowing between home and foreign households.

In equilibrium, the intermediaries absorb the demand for home and foreign currency of both households and noise traders. If intermediaries were risk neutral, $\omega = 0$, they would be happy to do so without risk premia, resulting in the *uncovered interest parity* (UIP), or equivalently a zero expected return on the carry trade, $\mathbb{E}_t \frac{\tilde{R}^*_{t+1}}{P^*_{t+1}} = 0$. However, under risk aversion, $\omega > 0$, the intermediaries are not willing to take a risky carry trade position without an appropriate compensation, resulting in equilibrium risk premia and deviations from the UIP. We characterize the equilibrium in the financial market in:

Lemma 1 *The equilibrium condition in the financial market, log-linearized around a symmetric steady state with $\bar{B} = \bar{B}^* = 0$, $\bar{R} = \bar{R}^* = 1/\beta$ and assuming that $\omega\sigma_e^2$ is asymptotically finite and non-zero, is:*

$$i_t - i^*_t - \mathbb{E}_t \Delta e_{t+1} = \chi_1 \psi_t - \chi_2 b_{t+1}, \tag{32}$$

where $i_t \equiv \log R_t$, $i^*_t \equiv \log R^*_t$, $b_{t+1} \equiv \frac{1}{\bar{P}_H \bar{Y}} B_{t+1} = -\frac{\bar{\mathcal{E}}}{\bar{P}_H \bar{Y}} B^*_{t+1}$, the coefficients $\chi_1 \equiv \frac{n}{m}\omega\sigma_e^2$ and $\chi_2 \equiv \frac{\bar{P}_H \bar{Y}}{m}\beta\omega\sigma_e^2$, and $\sigma_e^2 \equiv \mathrm{var}_t(\Delta e_{t+1})$ is the conditional volatility of the nominal exchange rate.

The equilibrium condition (32) is the *modified UIP* in our model with imperfect financial intermediation, where the right hand side corresponds to the departures from the UIP. Condition (32) arises from the combination of the financial market clearing (31) with the solution to the portfolio choice problem of the intermediaries (28), as we formally show in Appendix **??**. Intuitively, the optimal portfolio of the intermediaries d^*_{t+1} is proportional to the expected log return on the carry trade, $i_t - i^*_t - \mathbb{E}_t \Delta e_{t+1}$, scaled by the risk absorption capacity of the intermediaries, $\omega\sigma_e^2$, i.e. the product of their risk aversion and the volatility of the carry trade return (namely, the exchange rate risk). As $\omega\sigma_e^2 \to 0$, the risk

[16]This generates an additional income of $\frac{D^*_{t+1}+N^*_{t+1}}{R^*_t}\tilde{R}^*_{t+1}$ dollars for the foreign households. As a result of this transfer, the foreign country budget constraint becomes the same as the home country budget constraint (21), despite that foreign households face a generally different rate of return $R^*_t \neq R_t$. See Appendix **??** for details, where we also show that this transfer is second order and hence does not affect the first order dynamics of the equilibrium system.

absorption capacity of the intermediaries increases, and the UIP deviations disappear in the limit as $\chi_1, \chi_2 \to 0$. With $\omega\sigma_e^2 > 0$, the UIP deviations remain first order and hence affect the first-order equilibrium dynamics. The noise-trader shocks ψ_t create exogenous UIP deviations, while all other shocks result in endogenous UIP deviations by means of their effect on the external imbalances b_{t+1}, which need to be intermediated by the financial sector. Note that both $\psi_t > 0$ and $b_{t+1} < 0$ correspond to the excess demand for the foreign-currency bond — by the noise traders and households, respectively — and hence result in a negative expected return on the foreign currency bond.[17]

Lastly, we discuss briefly the equilibrium pricing of the currency forwards and the resulting *covered interest parity* (CIP). Consider a period t forward price $\mathcal{F}_t$ of one unit of foreign currency in units of home currency at $t+1$. The financial intermediaries price it at $\mathcal{F}_t = \mathcal{E}_t R_t / R_t^*$, as any other price would result in riskless arbitrage, and in the absence of financial constraints the intermediaries would take unbounded positions buying or selling such forward contracts.[18] Therefore, CIP holds in equilibrium, even though UIP is generally violated. In this model, the imperfection in the financial market emerges due to market segmentation and the limited risk absorption capacity of the financial intermediaries due to their risk aversion. Taking advantage of the UIP deviations by means of a carry trade involves taking risk and hence requires an equilibrium risk premium, while departures from the CIP generate riskless arbitrage opportunities. This is in contrast with the models of financial frictions, as in Gabaix and Maggiori (2015), where the departures from both UIP and CIP are not due to risk, but due to the binding constraints on the balance sheet of the financial intermediaries.

5 Quantitative Exploration

[17] Imperfect risk absorption capacity of the intermediaries results in the expected deviations from the UIP and thus expected profits in the financial market, which are returned lump sum to the foreign households. While the resulting UIP wedge is first order, the expected profits from the carry trade are second order (as the optimal portfolio is proportional to the expected UIP deviation), and hence it is negligible from the point of view of the linearized budget constraint of the foreign country (see Appendix **??**).

[18] Indeed, one unit of home currency at t together with a forward contract yields $R_t/\mathcal{F}_t$ units of foreign currency at $t+1$, or alternatively it can yield $R_t^*/\mathcal{E}_t$ units of foreign currency. If $R_t/\mathcal{F}_t > R_t^*/\mathcal{E}_t$, the intermediaries would be taking unbounded long positions in forwards and home-currency bonds and corresponding unbounded short positions in foreign-currency bonds, and vice versa. We formalize this argument by generalizing the portfolio problem (28) in Appendix **??**.

A Appendix

A.1 Additional Figures and Tables

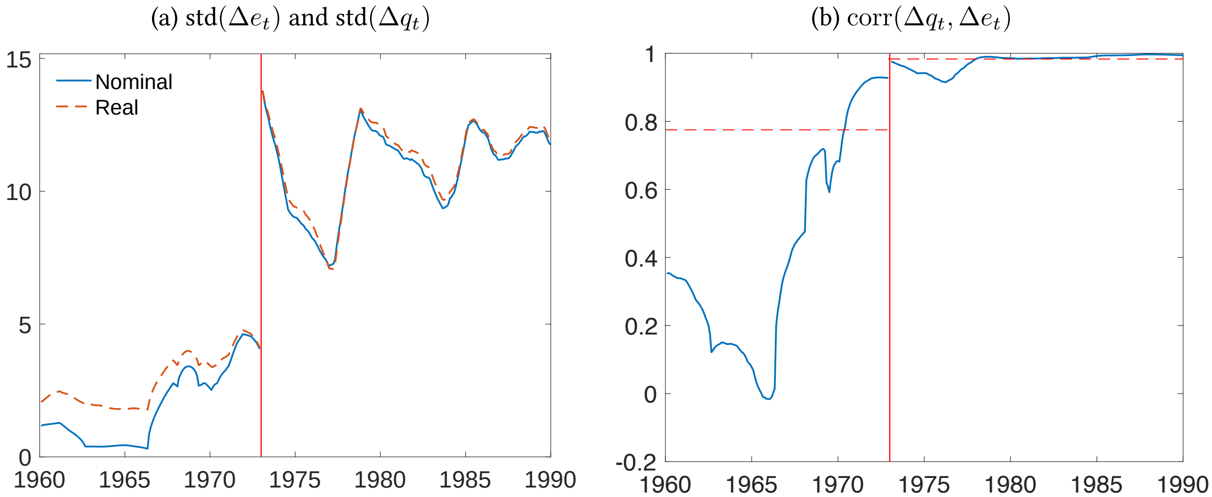


Figure A1: Volatility and correlation of nominal and real exchange rates over time

Note: The left panel plots standard deviations and the right panel plots correlation of Δe_t and Δq_t over time. Series from Figure 1; triangular moving averages with a window over 18 months before and after the date, treating 1973:01 as the end point for the two regimes (see Figure 3 and Appendix Figure A4 for other variables).

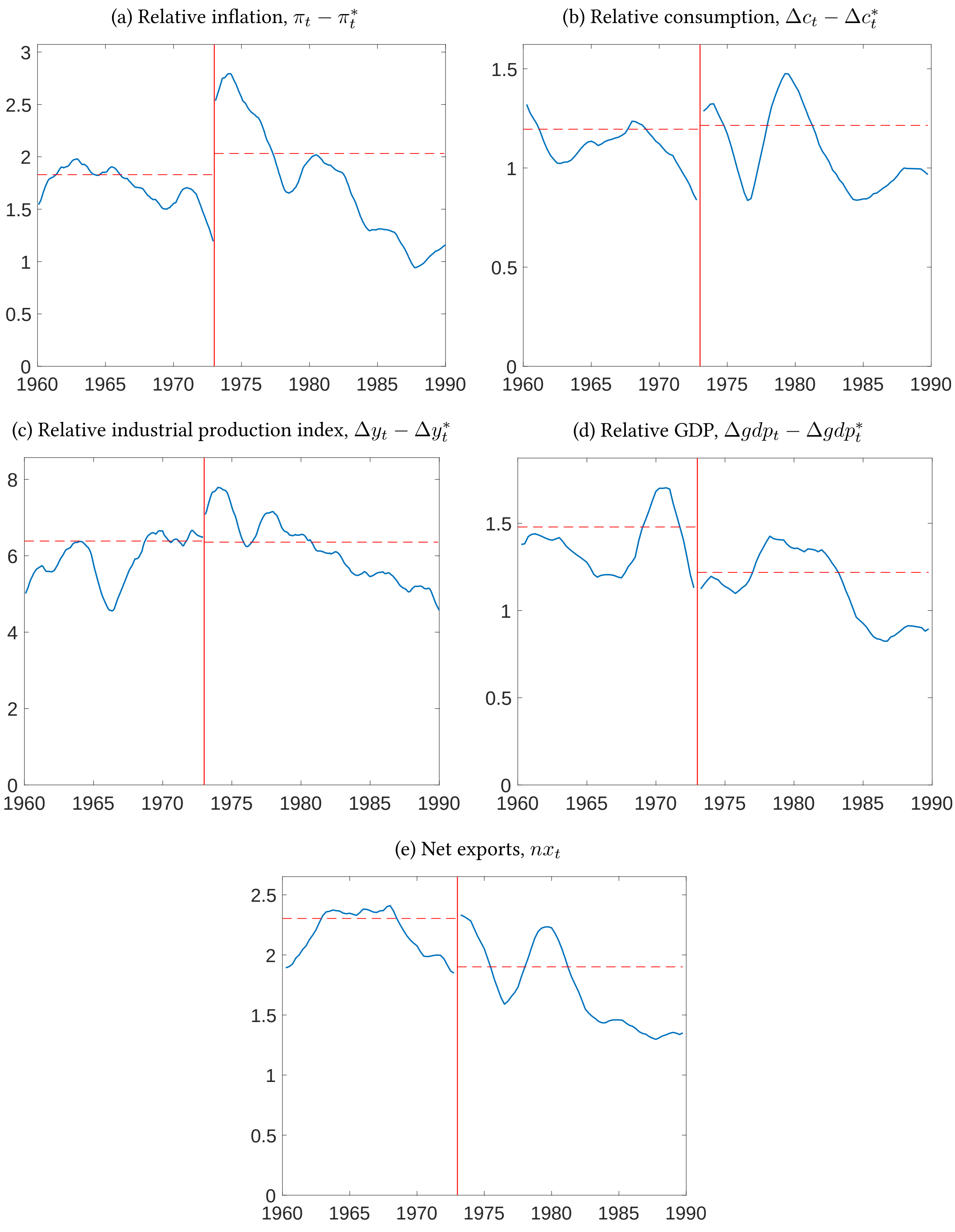


Figure A2: Volatility of macroeconomic variables over time

Note: The top four panels zoom in on the panels b, d, e and f in Figure 3. The bottom panel plots the standard deviations of nx_t defined as the ratio of export minus imports to the sum of exports and imports, for the US against the rest of the world.

Figure A3: Volatility over time: alternative break at 1971:08

Note: Like Appendix Figure A2, but with an alternative break date in 1971:08 (1971:Q3). DIFFERENT DEFINITION

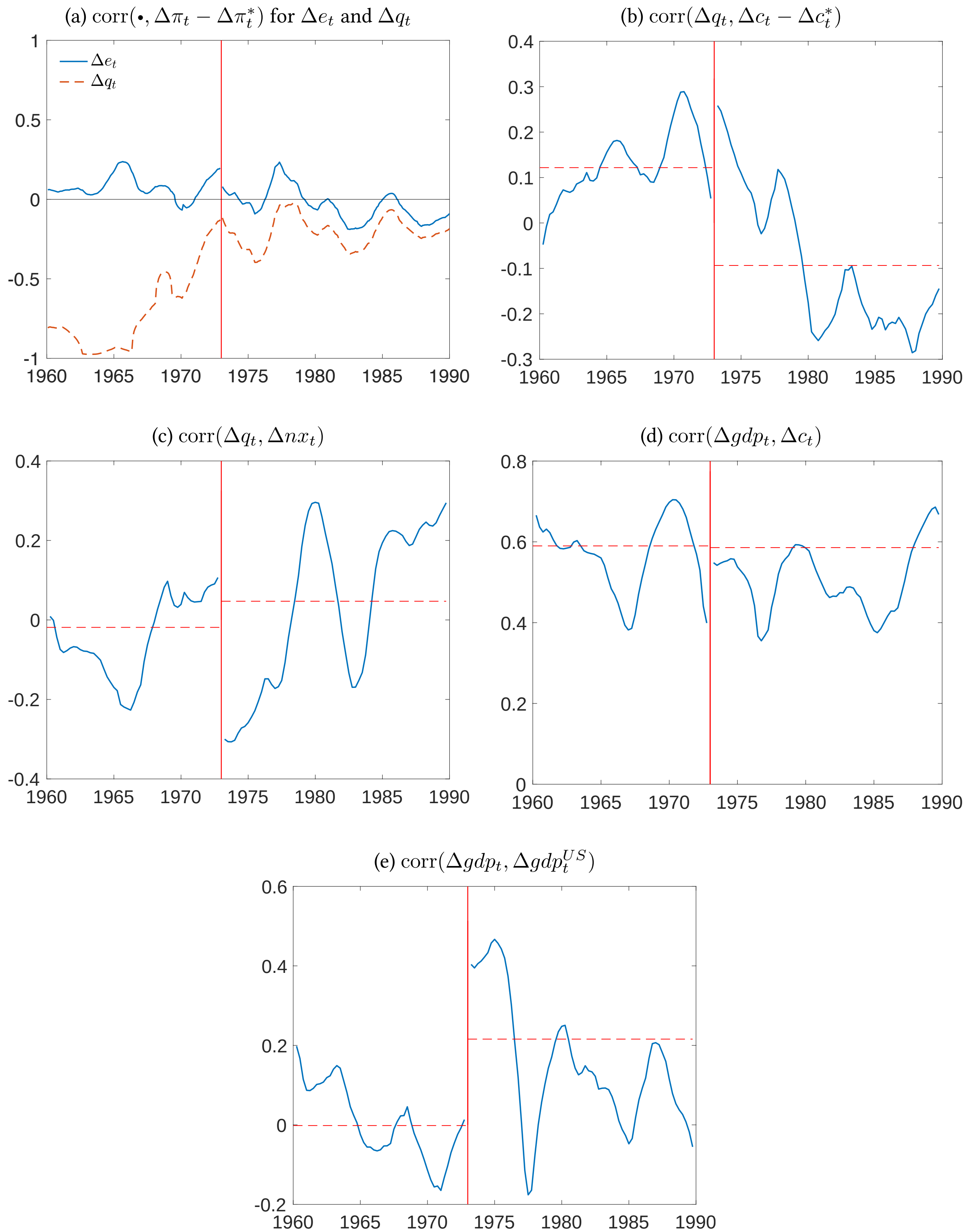
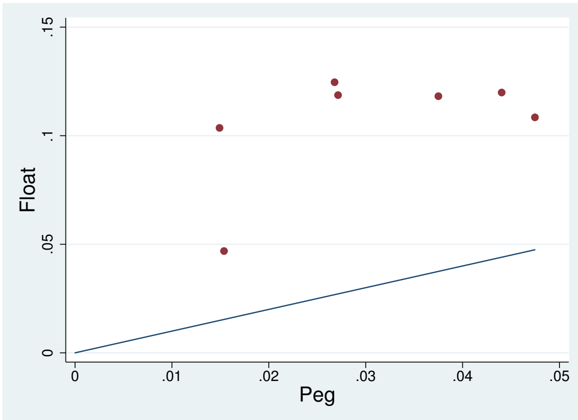


Figure A4: Correlations over time

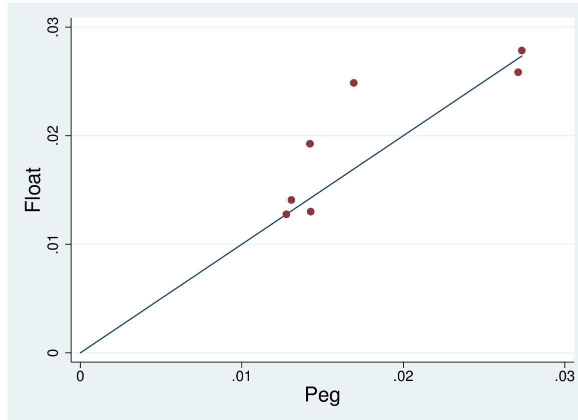
Note: the pictures shows the correlations for the RoW estimated separately before and after January 1973. The rolling window is up to 5 years for quarterly series – shorter at the corners – with linearly decreasing weights.

Figure A5: Scatter plots: volatility before and after the end of the Bretton-Woods System

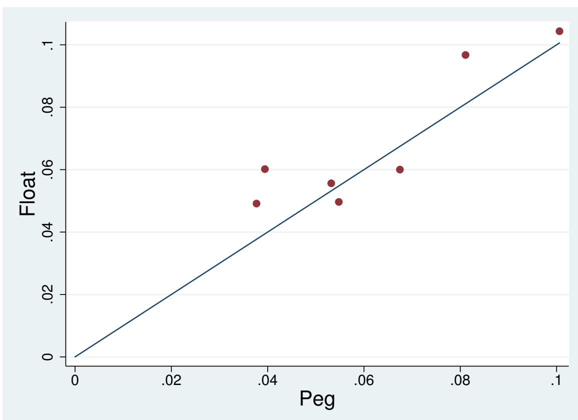
(a) RER



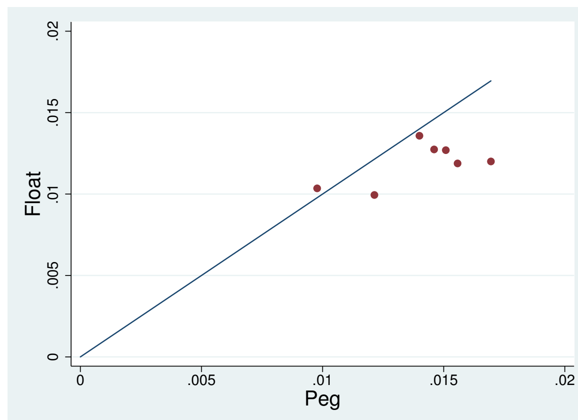
(b) inflation



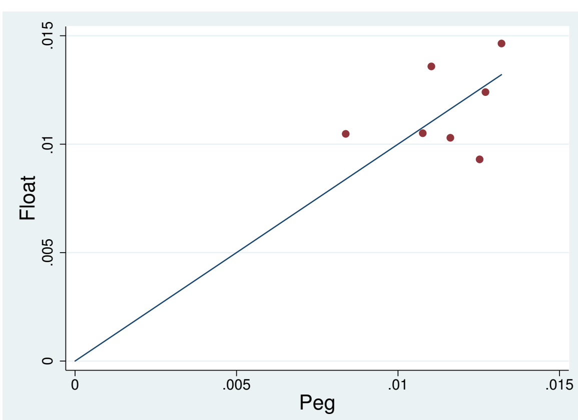
(c) production index



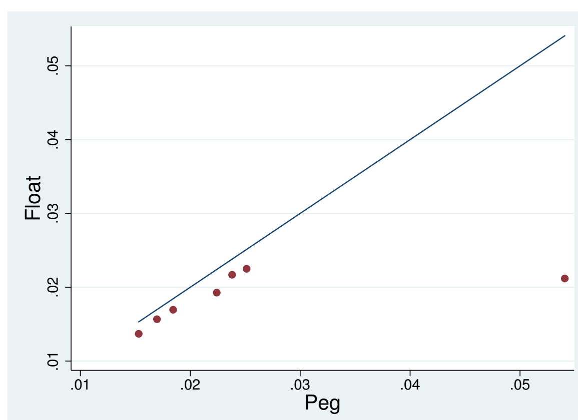
(d) GDP



(e) consumption



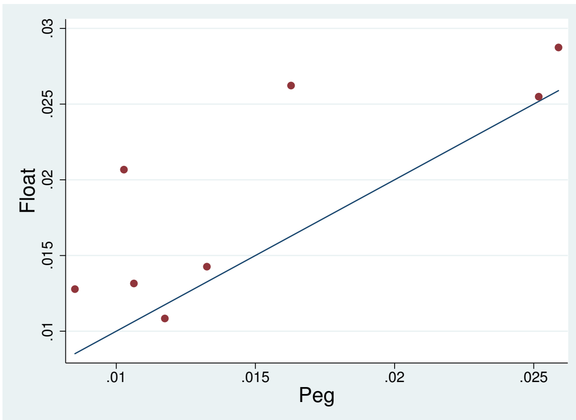
(f) net exports



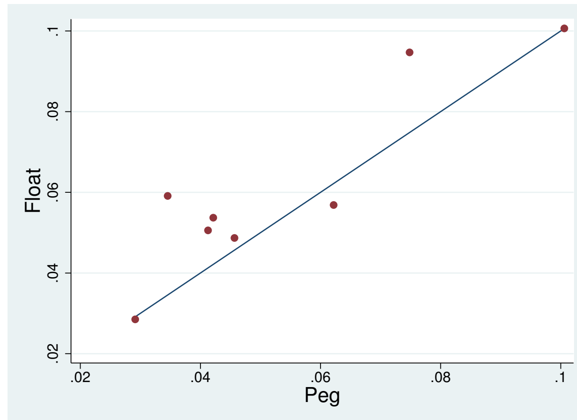
Note: the plot shows standard deviations of different variables for 1960-71:07 vs. 1973-1989 across individual countries. Canada is the outlier in terms of float-RER volatility and Spain is the outlier in terms of peg-NX volatility.

Figure A6: Scatter plots: country-level instead of cross-differences

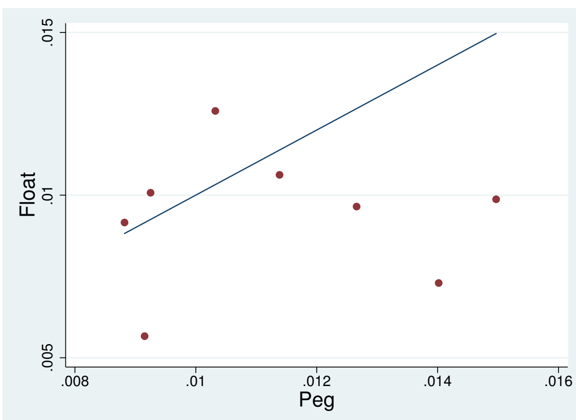
(a) inflation



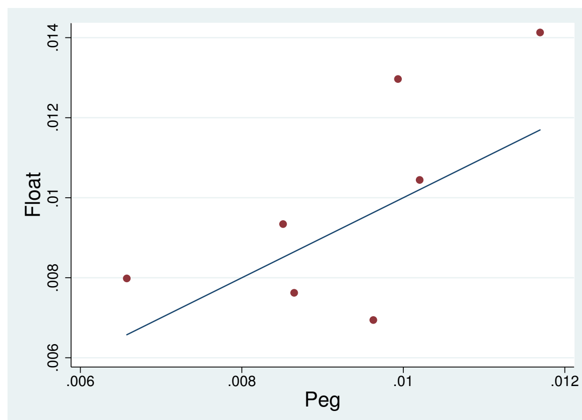
(b) production index



(c) GDP



(d) consumption



Note: the plot shows standard deviations of different variables for 1960-71:07 vs. 1973-1989 across individual countries. Canada is the outlier in terms of float-RER volatility and Spain is the outlier in terms of peg-NX volatility.

The scatter plots from Figures A5 show that the volatility of the RER is higher under the float than under the peg for every single country in our sample. Interestingly, the floating regime results in almost equal volatility of exchange rates across countries except for Canada, which retained partial peg to the dollar during 1970-80s. At the same time, the countries concentrate tightly along the 45-degree line for other macroeconomic variables indicating small changes in their volatilities across the regimes.(The only exception is Spain with an abnormally high volatility of net exports in 1960s.) Interestingly, there is more variation for country-level series instead of the cross-country differences (see Figure A6), but again we find no systematic differences for fundamentals between two regimes.

A.2 Data

Additional details for Section 2:

1. CPI data for Canada in 1960 is from OECD, but is downloaded from FRED and made consistent with the rest of the series.
2. **Outliers**:
   (a) civil unrests in France in May–June 1968 led to a more than 20% fall in production; France also had abnormally volatile production index during the whole 1960s;
   (b) earthquake and tsunami in Japan in March–April 2011 led to 17% fall in production. Since these observations are required for aggregation across non-U.S. countries, I replaced them with extrapolations using the values before and after the episodes.
   (c) The same applies to Germany production index in 1984:06, which constitutes a clear measurement error, and Spain production index in 1960, which is missing.

A.3 Derivations

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