Sticky Import Prices or Sticky Export Prices: Theoretical and Empirical Investigation

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Abstract

The paper provides evidence on the relative merits of two assumptions: sticky export prices (producer currency pricing), and sticky import prices (local currency pricing). First, using vector-autoregressive methodology, I demonstrate that import prices react faster to money and exchange rate shocks than the general price level and export prices, which supports the hypothesis of rigid export prices.

Second, I test an important implication of producer currency pricing. In an open economy with a high level of import penetration, prices should be more responsive to shocks than they would be in a closed economy, due to immediate adjustment of import prices. Facing this adjustment of import prices, domestic producers find it costly to keep their prices fixed. In the case of fixed exchange rates, the opposite is true, and domestic firms should be be unwilling to adjust their prices. Hence, the short-run Phillips curve should be steeper in an open economy under a flexible exchange rate regime, and flatter under a fixed rate regime. I test this implication using a panel version of Ball, Mankiw and Romer (1988) procedure, and find support for this hypothesis.

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1 Introduction

In the second half of the 1990's, we have witnessed a rapidly growing body of literature, which incorporates sticky prices into general equilibrium models of cyclical fluctuations in open economies.[1] Although there is some consensus that the assumption of sticky prices is attractive because it helps achieve certain desirable results, such as the high correlation between real and nominal exchange rates, and more generally, the real effects of nominal shocks, there is less agreement about how to best model sticky prices in an international setting. Specifically, the disagreement is about the currency in which prices are assumed to be sticky. One possibility is to assume that prices of traded goods are sticky in the currency of the producer, while import prices fluctuate freely with the exchange rate, according to, for example, the Law of One Price (LOP) (Obstfeld and Rogoff 1995). This type of stickiness has been recently labeled "producer currency pricing" (PCP). Another way to go is to incorporate the concept of pricing-to-market (PTM) into the sticky price environment and assume that import prices are sticky in the importing country's currency, the idea frequently labeled LCP for "local currency pricing" (Betts and Devereux 2000, Bergin and Feenstra 2000).

In this paper, I report the results of two empirical investigations directed at evaluating the relative merits of the two assumptions. First, I study the responses of export and import price indices to monetary shocks. I draw the conclusion that although both types of behavior are present in the data, the PCP-based assumption of sticky export prices is closer to reality, as import prices are found to respond quicker to nominal shocks than export prices or the general price level. The second body of evidence provides empirical support for an important implication of the PCP-based models. In an open economy with a high level of import penetration, price rigidities result in bigger losses to firms than in a closed economy. Hence, in equilibrium, open economies should be characterized by a higher degree of flexibility of local prices than closed economies. Consequently, the short-run Phillips curve in such an economy should be closer to vertical. I evaluate the empirical support for this hypothesis by comparing estimated slopes of the short run Phillips Curves in a panel of countries. Apart from being a powerful result for purposes of policy-making, empirical evidence in support of this prediction is an additional indirect argument for usage of PCP-based models.

Before discussing the details of these two tests, let me make clear that I do not attempt to

[1] See a survey by Lane (1999) and Bryan Doyle's New Open Economy Macroeconomics Homepage at www.geocities.com/brian_m_doyle/open.html

argue that the law of one price holds at all times, nor do I argue that exchange rate pass-through is perfect. There is a substantial body of evidence against both the law of one price and perfect pass-through at the micro-level.[2] Although we can learn quite a bit from this literature, the implications of micro evidence for macroeconomic modeling is unclear. As a macroeconomist, I am interested in knowing at the aggregate level whether innovations in the exchange rate are passed through into the general import prices at a faster rate than domestic prices adjust to demand shocks within an economy. Dynamics of these responses are crucial, since price stickiness in one currency could potentially be short-lived relative to the stickiness in the other currency. Likewise, it is possible that both types of goods exist, and then it would be important to know which type is dominant in the aggregate. Knowledge about the reaction of aggregate variables to monetary innovations is essential for setting monetary policy in an open economy.

The first body of evidence I present in this paper is based on a vector autoregressive study of American and Canadian data. I study the responses of import prices, export prices, and terms of trade to exogenous money and exchange rate shocks. For these purposes, I use the aggregated indices of import and export prices, and find that both of them react faster to the exogenous shocks than the general price level in the economy. This finding in itself suggests that both types of behavior, the one suggested by PCP-based models and the one suggested by LCP-based models, are present in the real world. However, export-price stickiness is found to dominate, because the terms of trade, defined as the ratio of import to export prices, worsen in both countries following these shocks, as would be the case when PCP holds.

The choice of econometric methodology – vector autoregression – is driven by the fact that I am investigating the relative merits of the two assumptions for purposes of business cycle research. Hence, I am interested in the reaction of the aggregate price indices, as well as in the timing of the responses. VAR methodology allows me to identify, conditional on a set of assumptions, exogenous shocks to monetary policy or exchange rates. This method contrasts with those used in the microeconomic studies, which have demonstrated deviations from the law of one price and imperfect exchange rate path-through for a variety of individual goods.

The second body of evidence deals with the comparison of Phillips curve slopes in a set of countries with different levels of import penetration. Let me first explain, however, why import penetration should have this effect in the first place. This dependence is best seen in the New

[2] See survey by Goldberg and Knetter (1997).

Keynesian framework of endogenous nominal price rigidities. As Ball and Romer (1990) argued, prices tend to be sticky because no firm in an economy has a big incentive to adjust its price to the profit-maximizing one, when no one else adjusts. The cost to each individual firm of being away from the optimum is small. Thus, if price changes are costly, non-adjustment of prices can be a Nash equilibrium. Hence, monetary shocks translate into increased production and not inflation. Now consider an open economy. Following a positive money shock, the exchange rate depreciates immediately, pulling up the prices of imported goods. Now, each domestic firm has to make a decision about price-adjustment observing increased imports prices. Since a large fraction of prices has gone up, a firm is less afraid of losing its market share and is inclined to raise price following this decreased competition. In other words, the private cost to keeping price rigid is increased by the presence of imports sector.

Consequently, prices in an open economy with flexible exchange rates should be less sticky. The smaller degree of stickiness implies that the effects of an increase of the money supply should be more inflationary, and thus the Phillips Curve should be steeper. Smaller real effects of monetary shocks in an open economy do not need to be regarded as necessarily hampering the ability of central banks to conduct monetary policy. In fact, such conditions can be beneficial for a monetary authority, which attempts to cut the inflation rate in its country – with smaller real effects, disinflation brings less pain in terms of reduced economic activity. In general, large exposure of an economy to imports simply means that the central bank has to align its optimal actions with the fact of the economy's openness, and in no way deems monetary policy unimportant.

However, this argument breaks down in the fixed exchange rate environment. Of course, fixed exchange rates are thought to be incompatible with an independent monetary policy, but governments generally can afford some flexibility with respect to their money rules without forcing the exchange rate off the peg. Besides, one can think in terms of more general nominal aggregate demand shocks, which do not have to be results of monetary expansions. In case of fixed rates, the prices of imported goods do not change following a nominal shock even in the long run. Hence, domestic prices also have a smaller incentive to adjust to the new optimum, and are more sticky than they would be, were the economy closed.

I test this implication by estimating the panel version of the regression in Ball et al. (1988), and find that indeed in the post-Bretton Woods era, the real effects of nominal shocks are smaller in countries with a high level of import penetration. In the Bretton Woods subsample, however, the effects are exact opposite: higher degree of openness lead to a flatter Phillips Curve, as is predicted by the described logic.

The rest of the paper is organized as follows. Section 2 spells out the theoretical framework and predictions of the PCP and LCP based models. Section 3 demonstrates why the nominal rigidity of output prices should be smaller in an open economy, using several simplifying assumptions. In Appendix A, I then demonstrate that a formal micro-founded model of Obstfeld and Rogoff (1995) is capable of generating several results, which I assume in Section 3.

Then I move to the empirical analysis. In Section 4 I set-up the vector-autoregression and report the results, which are in favor of sticky export prices. In Section 5, I report my results of the Phillips curve regressions. Section 7 concludes.

2 PCP and LCP based models: theoretical framework

In order to demonstrate the different predictions of the two types of models regarding the responses of certain variables, let me set up a simple framework, in which variables will be defined. This framework will be consistent with that specified by Obstfeld and Rogoff (1995) (see Appendix A).

Imagine a two-country world with a continuum $[0,1]$ of goods produced in these two countries. Of these goods, fraction $[0,n]$ is produced in the Home country, and fraction $[n,1]$ in the Foreign country. These goods are all substitutable with each other with the same elasticity of substitution, and no two of them are identical. Thus, if the law of one price holds for each good individually, this means that a producer is unable to sell that particular good at different prices in the two countries. However, PCP does not imply that the Purchasing Power Parity needs to hold (real exchange rate needs not be unity), nor do the terms of trade need to be equal one, since both of these variables employ price aggregates, not prices of individual products.

Although the division of the production space into the two fractions implies nothing about the shares of home/foreign goods in consumption baskets of the two countries, in a symmetric steady state equilibrium with identical preferences these shares also should be n and $(1-n)$. Although they are endogenous to price and exchange rate fluctuations, they can be regarded as fixed to a first-order approximation. Any substitution effects are second-order, and disappear in log-linearized equations, as is the case in the model depicted in Appendix A.

I label a representative home good by letter "h", and a representative foreign good by letter "f". The price of these goods in home currency will be denoted $P(h), P(f)$, while the foreign-currency price will be denoted by a star: $P^*(h), P^*(f)$. The exchange rate $\mathcal{E}$ is defined as the price of one unit of foreign currency in terms of home currency.

It is easy to see what predictions the PCP-based models and the LCP-based models have about import and export prices. In the PCP world, local prices of local goods $P(h), P^*(f)$ are fixed, while local prices of goods produces in the other country fluctuate freely with the exchange rate:

$$P(f) = \mathcal{E}P^*(f), \quad P^*(h) = P(h)/\mathcal{E}. \tag{1}$$

In the LCP type world, on the other hand, equalities (1) do not hold, and all four of the prices listed above are fixed and do not respond immediately to money shocks. However, the exchange rate does react to money shocks. In fact, all open economy models with sticky prices, from the overshooting result of Dornbusch (1976), to LOP model of Obstfeld and Rogoff (1995) and a LCP extension of their model by Betts and Devereux (2000), uniformly predict that the exchange rate depreciation should follow a positive money shock immediately. The only disagreement is the magnitude of the jump. Therefore, on the most basic level, PCP type models predict that prices of imported goods ($P(f)$ in Home country) respond to money shocks faster than prices of goods produced domestically. A model with complete LCP, on the other hand, would predict the exact opposite: since prices are fixed in the currency of the importing country, a positive money shock with a consequent depreciation of the currency will do nothing to the import prices but will increase domestic prices of exports immediately ($\mathcal{E}P^*(h)$ for the Home country).

If both export and import prices respond to money shocks, we can use terms of trade to gauge which response is stronger. As was noted in Obstfeld and Rogoff (2000), the effect of monetary shocks on the terms of trade is exactly opposite under the two assumptions. To see this, define terms of trade as

$$TOT \equiv \frac{P(f)}{\mathcal{E}P^*(h)}, \tag{2}$$

It is easy to see that terms of trade represent the ratio of the home currency prices of imports and exports.

If the LCP world is true, the prices are fixed in the importing country's currency. Thus, the only thing that moves in (2) is $\mathcal{E}$. Therefore, in the LCP setting, the terms of trade should go down, or improve, following a money shock. Conversely, PCP-type model would predict that the numerator in (2) should increase following a shock, since $P(f) = \mathcal{E}P^*(f)$ and $P^*(f)$ is fixed, while the denominator should not change at all. Thus, terms of trade should go up or worsen. This is the standard case that we all are used to: following an appreciation of a foreign currency, home consumers are worse off because foreign goods are more expensive. Obstfeld and Rogoff (2000) use this difference between predictions of the two models to make an informal empirical argument for usage of models based on PCP. They showed that the correlation coefficients between nominal exchange rates and terms of trade series are mostly positive in a sample of countries.

3 The Private Cost of Price Stickiness

In this section, I extend the logic of Section 2 to show a powerful implication of a model based on PCP or any similar assumption that produces a fair amount of relatively fast exchange rate pass-through. Specifically, I show that such models imply that the private cost of price rigidity is higher in a country with a high level of import penetration. I demonstrate this in the setting of Ball and Romer (1990), generalizing their case to allow the price level in the economy to vary in response to a money shock. The price level varies not because of the adjustment of prices of locally produced goods, but rather because of the response of the exchange rate and consequently imports prices. Then, I illustrate using a simple example what effect this has on the private cost of price non-adjustment for a producer.

Assume that each differentiated good is produced by a separate producer, and this producer's objective function is $W\left(\frac{M}{P}, \frac{p(j)}{P}\right)$, where M is the money supply, P is the general price level, and $p(j)$ is the price of the differentiated good produced by producer j. In the original equilibrium, $P = M = p(j) = p^{\#}(j) = 1$, where $p^{\#}(j)$ is the optimal price of the good made by the producer j. This objective function implies that the welfare of a producer depends on both the aggregate demand in the economy, represented here by the real money balances, and the relative price of his product. Thus, the function could represent a firm's profits, or a utility of a "yeoman farmer." In Appendix A, I show an exact expression for a function of such form. For now, however, it suffices to make restrictions that $W_2(1,1) = 0$, $W_{12}(1,1) > 0$, and $W_{22}(1,1) < 0$, which guarantee presence of an equilibrium.

Suppose the economy suffers a shock to M, and the price level adjusts because the exchange rate with the rest of the world changes. All of the individual prices expressed in the currency of the producing country remain constant. The cost of price non-adjustment for an individual, assuming no one else adjusts, is given by

$$W\left(\frac{M}{P},\frac{p^{\#}(j)}{P}\right)-W\left(\frac{M}{P},\frac{p(j)}{P}\right).$$

Taking second-order Taylor approximation of this expression around the symmetric equilibrium, observing that, according to the first-order condition of a profit-maximizing firm, $W_2(1,1)=0$, and simplifying, we get the approximate private cost of price rigidity:

$$\begin{aligned} PC \;\approx\; & \left[W_{12}\frac{\partial(M/P)}{\partial M}\left[\frac{\partial(M/P)}{\partial M}\frac{\partial(p^{\#}(j)/P)}{\partial(M/P)}-\frac{\partial(p(j)/P)}{\partial M}\right]\right. \\ + \; & \left.\frac{1}{2}W_{22}\left[\left(\frac{\partial(p^{\#}(j)/P)}{\partial(M/P)}\right)^2\left(\frac{\partial(M/P)}{\partial M}\right)^2-\left(\frac{\partial(p(j)/P)}{\partial M}\right)^2\right]\right](M-1)^2 \end{aligned} \tag{3}$$

Note that this expression reduces to that of Ball and Romer (1990) once one assumes, as they did, that $\frac{\partial(M/P)}{\partial M}=1$, $\frac{\partial(p(j)/P)}{\partial M}=0$, and therefore $\frac{\partial(p^{\#}(j)/P)}{\partial(M/P)}=\frac{\partial(p^{\#}(j)/P)}{\partial M}$.

All of the first-order terms in (3) cancel out, which shows that a firm's losses from price rigidity are second-order. The question is how this second-order cost, or the expression in brackets in (3), depends on the degree of openness of the economy, where "openness" refers to import penetration. In order to answer this question, I need to make additional assumptions about how the price level responds to money supply shocks. Just as Ball and Romer (1990), I want to assume that all domestic and foreign producers keep their prices unchanged. However, I make no such assumption about the exchange rate. Indeed, the general conclusion of sticky price open-economy business cycle models is that the exchange rate responds to monetary shocks immediately (see, for some examples, Obstfeld and Rogoff (1996), Chapters 9 and 10), as I discussed in Section 2.

Consider a simple example, in which the exchange rate adjusts immediately to its long-run equilibrium value, and hence the domestic prices of foreign goods react as in the money-neutral case: increase proportionally with M. In Appendix A, I present a model that generates a reaction of this kind, with the exception that exchange rate adjusts slightly less than proportionally. Following the framework of Section 2, domestic consumption basket consists of a constant fraction n of domestic goods and $(1-n)$ of foreign goods. This value $(1-n)$ serves as a measure of import penetration, although in a two-country setting can also be interpreted as a measure of the economy's size.

After a money shock away from the equilibrium, the new price level is then $P=(1-n)M+n$, since prices of domestic goods remain at 1. Then, at $M=1$,

$$\frac{\partial(M/P)}{\partial M}=n \qquad\qquad \frac{\partial(p(j)/P)}{\partial M}=(n-1),$$

and the real rigidity coefficient is defined as in Ball and Romer (1990):

$$\psi \equiv \frac{\partial(p^{\#}(j)/P)}{\partial(M/P)} = -\frac{W_{12}}{W_{22}}.$$

This coefficient shows how much a firm desires to adjust its real price following a demand shock.[3] Then, divide the expression in brackets in (3) through by $-W_{22}$ (note this is a positive number by assumption), and substitute the above expressions for the partials, to get

$$\left[\frac{1}{2}\psi^2 - \psi + \frac{1}{2}\right] n^2 + [\psi - 1]n + \frac{1}{2},$$

and the question remains whether this expression increases or decreases in n, and therefore, $(1-n)$. Differentiating with respect to n, we get

$$[\psi - 1]^2 n + [\psi - 1].$$

This expression is negative, and the cost of non-adjustment increases in $(1 - n)$, whenever $\psi < 1$. Otherwise, this expression is positive. Hence, when the real rigidity is large (small ψ), presence of imports in the economy makes the nominal rigidity smaller. This result makes sense intuitively. A large nominal rigidity comes from the presence of a real rigidity and the fact that no one else in the economy adjusts prices. In other words, real rigidity amplifies the effect of a menu cost. When the real rigidity is strong, that is, ψ is small, firms do not want to change real price, and this effect is lessened by foreign sector. When $\psi > 1$, on the other hand, there is what can be called a real *flexibility*, the firms are inclined to adjust prices by a greater percent than the demand shock, and it is this inclination that is lessened by the presence of the foreign sector. Of course, the observed rigidities of prices can only be justified by a small ψ.

In the model presented in Appendix A, however, the exchange rate responds less than proportionally to money shocks (although the factor of proportionality is very close to unity), while the aggregate demand responds precisely as above. In order to take this situation into account, I make the following generalization: suppose that the partial derivatives above are instead

$$\frac{\partial(M/P)}{\partial M} = an \qquad\qquad \frac{\partial(p(j)/P)}{\partial M} = b(n-1).$$

In this situation, it is straight-forward to show that the cost of price rigidity increases in $(1 - n)$ whenever $\psi < b/a$. In Appendix A, $a = 1$, while b is slightly less than unity.

[3] Of course, in an open economy setting, aggregate demand is not represented by domestic money balances, but rather by the world income. In Appendix A, I show that the world income responds by $n\%$ as well.

Potentially, one can also analyze the effects on costs of production. Such an analysis can make the above arguments stronger. If a fraction of intermediate goods involved in production is imported, and the price of these goods increases proportionally to the depreciation of the domestic currency, then the private cost to price stickiness is yet higher. Similarly, Romer (1993) conjectures that domestic wages, which also represent costs of inputs, should be pushed up by the depreciation and consequent increase in the price level. I do not focus my attention on the cost side, however, because the demand side is sufficient to demonstrate the main point of the paper.

Clearly, the above conclusion is based on the assumption of a substantial degree of the exchange rate pass-through, which is normally achieved by assuming the law of one price. If one assumes local currency pricing behavior instead, then exchange rate pass-through is zero, and the above logic does not hold. In such circumstances, the private cost of price rigidity would be the same as in a closed economy. Hence, if we observe that prices are less sticky in an economy with a large amount of imports, such an observation would render indirect support for the assumption of export price stickiness.

4 Vector-autoregressive investigation

In this section, I present the evidence obtained using vector-autoregressive (VAR) methodology, in order to examine the responses of import prices, export prices, and terms of trade to money and exchange rate shocks. Since I find that import prices respond fast to money shocks in comparison to the general price level, these results justify the analysis of nominal rigidities in Section 3, as well as help identify the correct assumption for sticky price models in general, as discussed in Section 2.

I estimate the VAR separately for the United States and Canada. It is interesting to analyze a country other than the U.S., because the U.S. is an out-lier in the sense that it has a large fraction of imports invoiced in U.S. dollars (Obstfeld and Rogoff 2000). Hence, the U.S. can potentially exhibit more of local currency pricing behavior than other countries. However, the evidence below indicates that in both U.S. and Canada, import prices react faster to money shocks than do export prices.

4.1 Methodology

The identification of the VAR is tricky and cannot be the same for both the United States and Canada. The United States is a big and relatively closed economy, and the monetary authority is likely to ignore the contemporaneous movements in foreign variables and exchange rates. Therefore, following Eichenbaum and Evans (1995), I put exchange rates after the policy instrument variable. Canada, on the other hand, is a small open economy and is heavily influenced by the neighboring United States. Therefore it is important that a contemporaneous vector of American variables, as well as the exchange rates, appear in the Canadian Central Bank's information set, or more exactly, the part of the information set that is relevant for decision making. This view was argued forcefully by Cushman and Zha (1997).[4]

Further, since the effects of the money shock are transfered onto the prices of imports and exports through the exchange rate, I need to make sure that the exchange rate responds to money shock as predicted by the theory; that is, the chosen specification must not have the "exchange rate puzzle," which refers to an appreciation of the home currency following a positive domestic money shock. Likewise, I should be careful about the presence of the "price puzzle," which refers to a frequently observed sustained reduction of the general price level following a positive money shock.

In light of the above considerations, I choose the following specifications. For the baseline United States regression, the variables are ordered [Y, P, PIMP-P, PEXP-P, FFR, E], where Y is the log of GDP, P is the log of implicit GDP deflater, PIMP and PEXP are the logs of an import and export price indices, correspondingly, FFR is the federal funds rate, which is the policy tool, E is the log of the nominal exchange rate, defined as the domestic price of one unit of a foreign currency. For purposes of studying terms of trade response, I switch to the vector [Y, P, PIMP-P, TOT, FFR, E], where TOT = PIMP-PEXP is the log of the terms of trade as was defined in Section 2. I can also include the real exchange rate in the regression so that I can compare the response of that variable to the response of the terms of trade.

The described system is semi-identified. I will not spell out the theory behind such VARs, as it has become a standard technique, and the description can be found in a number of articles (Christiano, Eichenbaum and Evans 1999, Bernanke and Mihov 1998). The idea is that I do not

[4] Cushman and Zha (1997) went further and utilized a block-recursive structure in their identification, which I do not do in this paper.

have to impose a full set of restrictions to identify responses to shocks to the variables other than the policy tool. Hence, their ordering in the VAR is irrelevant. What is important is whether they come before or after the policy variable, in this case, the federal funds rate. Thus, the system above assumes that the Fed observes contemporaneously and reacts to innovations in the following variables: the level of GDP, price level, and prices of imports and exports. Exchange rates, on the other hand, do not have any contemporaneous effect on the monetary policy. The assumption, of course, is not that the variable is unobservable (in fact, this variable is by far the easiest to observe quickly), but rather is not important for the monetary authority of a large country such as the United States. Furthermore, the only reason to include exchange rates in the system at all is to see their responses to money shocks and make sure that they comply with general theoretical predictions.

The choice of the Federal Funds Rate as the policy tool is motivated by the idea that this variable captures closely the amount and availability of liquidity in the banking system, which indicates the stance of the monetary policy. Therefore, this variable has been perhaps the most popular one to use in VAR studies of monetary shocks (see Bernanke and Blinder (1992) or Bernanke and Mihov (1998) for arguments for usage of this variable), although other variables, such as non-borrowed reserves or their ratio to total reserves, have also been proposed.

A common way to remove the price puzzle is to include an index of commodity prices in the VAR, which supposedly carries information about future changes in some of the variables, such as the price level. However, it turns out that this method does not work for the sample period 1972-1999, which would be preferable for my purposes because I want to start after the abandonment of fixed exchange rate regime of the Bretton Woods. In fact, the price puzzle is sensitive to the sample choice and disappears in the late 1970-s - early 1980-s (Hanson 1999). Therefore, I choose to start the sample in 1979, at which point the commodity price index no longer makes a difference in the results. This sensitivity to the choice of sample is worrisome, but at the same time can be explained within the historical context. The end of 70's and early 80's were characterized by a substantial change in how the monetary policy was performed in the United States. Hence, estimation of the same policy reaction function throughout the 70's and 80's could lead to misspecification of money shocks. Due to this reasoning, it may make sense to start the sample in 1982, rather than 1979, but the results do not seem to be sensitive to this choice.[5]

[5]Another explanation for the strange behavior in the sample starting in mid-70's could be the turmoil in the

For Canada, the corresponding specification is [Y, P, PIMP-P, PEXP-P, RUS, E, IBank, M1], where the overnight inter-bank rate IBank serves as the policy tool, RUS stands for the U.S. interest rate (3-months Treasury bill yield), and M1 is, of course, the money supply. Inclusion of the American interest rate, exchange rates, and the money supply take care of most of the price puzzle, which otherwise is present in the data. Thus, I use the available post-Bretton Woods time period 1975-1999. Before 1975, Datastream does not report the inter-bank rate, but using the 3-month Treasury Bill rate instead does not alter the results in any significant way. The identification is similar to that of the United States, but now the exchange rate precedes the policy tool, which means that Canadian monetary authorities are assumed to pay close attention and react to contemporaneous movements in the exchange rates, as well as to the American interest rates. The choice of the policy instrument, namely, overnight inter-bank lending rate, is driven by the same logic as FFR for the United States regression.

I use five lags of the variables in the regressions, although the results do not appear to be qualitatively sensitive to the assumed lag structure.

4.2 Empirical Results

All of the data are quarterly and are taken from the country data in Datastream.[6] Figure 1 depicts the responses of the variables to a FFR shock (a contractionary monetary policy shock) for the United States, with Canadian exchange rate. The dashed lines represent the 95% confidence interval for the impulse responses estimated using the bootstrap-after-bootstrap procedure of Kilian (1998).[7] The responses of output and price level are consistent with the standard results. The response of the exchange rate is marginally significant and is in the "correct" direction contemporaneously, and signifies an appreciation of the domestic currency. This response is only marginally significant and short-lived, however. In later periods, the exchange rate seems to depreciate, but this effect is not

American economy during that decade caused by the oil price shocks.

[6] For the United States, the price indices for imports and exports are reported in the database under codes "USIP1975F" and "USEP1975F" and are taken from the Department of Commerce. For Canada, the codes in Datastream are "CNB1200." and "CNB1226." and the data come from Cansim database.

[7] The bootstrap procedure involved 1,000 simulations for the bias estimator and 2000 simulations for the impulse response estimations. The coefficients in simulated series were bias-corrected using the bias estimate from the actual data; thus, I used the short-cut method proposed by Kilian (1998).

statistically significant.[8] Thus, although the exchange rate reaction is not as predicted by standard theory, the impulse response does not pose a significant puzzle either. The relative price of imports seems to take a deep dive in the short run, thus supporting the view that import prices react faster to money shocks than do domestic prices. The price of exports goes down as well, but the effect is definitely smaller and not statistically significant.

Figure 2 depicts the same variables, only with terms of trade instead of prices of exports in the regression, and real exchange rate instead of the nominal rate. Since terms of trade are a linear combination of prices of imports and exports, all other variables react identically. As should be expected based on Figure 1, the terms of trade go down soon after the shock.

One can see from here that the real exchange rate behaves similarly to the nominal rate, which is a rather robust finding in the literature. The surprising result in this regression, however, is that the responses of both exchange rates are small and short-lived. Eichenbaum and Evans (1995) obtain much stronger responses, but their sample starts in 1974 and is subject to a significant price puzzle at quarterly frequency. In the sample used here, however, the responses are largely statistically insignificant.

The similarity of the responses of the real and nominal exchange rates, or more generally, the high correlations between these two variables, could lead one to interpret the results to be in favor of local currency pricing hypothesis: with import prices being sticky, CPI's in both countries remain unaltered and hence all of the nominal exchange rate fluctuations are carried through into the real exchange rate. However, this argument is countered by the responses of import/export prices and the terms of trade. Import prices do react strongly to money shocks, and hence the high correlation of the real and nominal exchange rates has to be explained in a different way, for example, by presence of nontradable goods in consumption baskets of the two countries.

The same results are even more pronounced for the Canadian case, as is shown in Figure 3. Once again, it makes sense to analyze a country other than the United States, because the United States is an exception in terms of the portion of imports invoiced in local currency units (Obstfeld and Rogoff 2000). While in the United States the overwhelming majority of both exports and imports are invoiced in the U.S. Dollars, in most other countries, including Canada, only a small portion of imports and a large portion of exports are invoiced in Canadian Dollars. Hence, one could

[8] If the regression also included the real exchange rate, the response of the nominal exchange rate would be negative and significant somewhat longer. If the exchange rate were to be put before the federal funds rate, we would find a substantial amount of "exchange rate puzzle," that is, significant and lasting depreciation of the dollar.

potentially expect more of PCP-type behavior in Canada. Indeed, impulse responses are in favor of PCP, but not any more strongly than in the U.S. data. Thus, both relative import and export prices go down quite rapidly following a negative monetary policy shock, thus suggesting that a fair amount of both export and import price stickiness is present. The sticky export price assumption, however, once again slightly outweighs the sticky import prices, as can be seen from the terms of trade response: the variable first dips down lightly, as imports prices respond more strongly than do export prices.[9] The surprising feature of the terms of trade is that they go significantly up in the long run, whereas according to the theory they should end up at the pre-shock level once all the prices are adjusted. A potential explanation could be that the inter-bank rate demonstrates a substantial amount of oscillation in response to its own shock and in the long run goes below its original value, almost significantly so. Likewise, other variables, such as the exchange rates, and the prices of imports and exports, also show a large amount of mean reversion, which may seem surprising.

4.3 Responses to Exchange Rate Shocks

Another interesting exercise is to consider responses of the export and imports prices indices to exchange rate shocks. An immediate problem, of course, is the difficulty with interpretation of such shocks. Exchange rate is normally thought of as responding to macroeconomic variables, including prices, interest rates, and output. However, all of these variables can explain only a small portion of the movement in exchange rates, and therefore, one can treat jumps in exchange rates unexplained by a vector of economic variables as "exchange rate shocks." Since I want to identify movements in the exchange rates not explained by other variables, I have to put the exchange rate last in the recursive specification, thus sacrificing a fair amount of degrees of freedom.

In order to have the same expected direction for the responses of price indices, I consider negative shocks to the nominal exchange rate, by simply including -E rather than E in the regressions.[10] Thus, following such a shock, I should expect prices of imports and exports to fall.

For the United States, selected responses are shown in the Figure 4. One can see that relative price indices of both export and imports react strongly to exchange rate shocks, thus again indicat-

[9] The last two sub-plots with terms of trade and the real exchange rate were actually produced in separate regressions and then included with the other responses.

[10] For the United States, the shock is to a trade-weighted exchange rates against major currencies; for Canada, the shock is to the U.S. Dollar exchange rate.

ing presence of both types of goods. It is not clear, however, which of the responses dominates: in this case, the terms of trade response is mostly not significant, although has an evident downward direction.

Figure 5 depicts the responses for the Canadian data. The responses of import prices and terms of trade are negative but barely significant. Export prices, on the other hand, hardly react at all. Thus, we once again see support for the hypothesis of sticky export prices, or models based on the PCP assumption.

5 Phillips Curve Regressions

The VAR investigation has demonstrated that the exchange rate pass-through is fast at the macroeconomic level. This finding provides strong empirical support for the analysis of the price rigidities in Section 3. The results in that section, in turn, have very powerful implications for policymakers, as rigidity of prices has direct implications for the real effects of monetary shocks. In other words, import penetration has direct implications for the slope of the short-run Phillips Curve. The Phillips Curve should be steeper in countries that are more open, provided that the exchange rate is flexible.[11] This implication can be tested by comparing the inflation-output trade-off across countries, which differ in degree of import penetration.

Another implication of Section 3 is that the Phillips Curve should be steeper in countries with flexible exchange rates than in countries that have currency boards or some other types of fixed rates regimes. This is true because the exchange rate reaction to nominal shocks is only possible in a flexible rate environment. Moreover, the exchange rate regime should determine the direction of the effect of openness on the slope of the Phillips Curve. In case of a flexible exchange rate, as described in the previous paragraph, imports should make the real effects of the money shocks smaller, as described above. If the exchange rate is fixed, on the other hand, this implies that a large part of prices in the consumption basket (imports) *never* responds to nominal shocks, which should keep the local producers from changing prices as well. Hence, the real effects of money shocks should be increasing with import penetration – the opposite from the flexible rate case.

Therefore, empirical evidence on the relationship between import penetration and the slope of the Phillips curve, is desirable for two reasons. Directly, such evidence provides food for thought

[11]This result is consistent with the models proposed by Romer (1993) and Karras (1999), but is based on different intuition.

for the policy makers; indirectly, the evidence can render additional support for usage of models based on the assumption of export price stickiness.

In order to test these implications, I run the widely used Phillips Curve regression considered, among others, by Ball et al. (1988):

$$y_{it} = constant_i + \tau_{it}\Delta x_{it} + \lambda y_{i,t-1} + \gamma time + \epsilon_{it}, \tag{4}$$

where y_t is the log or real GDP and x_t is the log of nominal GDP. Indices i and t denote country and time, respectively. The coefficient τ_{it} is the statistic of interest: this coefficient shows how much of a change in nominal GDP is transmitted into the real output over a year. Thus, this Phillips curve estimation is relevant, for example, for staggered price setting, in which the frequency of price adjustment is endogenous. In countries where the cost of price rigidity is high, firms adjust prices frequently, and in countries where such costs are low, prices remain rigid longer. Thus, I want to emphasize that (4) should not be thought about as an instantaneous Phillips Curve relationship. Rather, it tells how much of a nominal shock is transmitted into real sector over a course of a period, which is here a year.

In (4), I allow the constant term to vary across countries. I also make τ_{it} depend on both time and country, because τ_{it} is influenced by the degree of openness and exchange rate regime.[12]

In order to see the effects of openness on τ_{it} , I decompose τ_{it} in the following way:

$$\tau_{it} = \tau_0 + \tau_1 OPEN_{it} + \tau_2 INF_{it}, \tag{5}$$

where $OPEN$ is a measure of openness, and INF_t is a measure of inflation. An error term could be added to this expression, but it should not be of major importance in the estimation, as long as this error term is independent of Δx. Inflation needs to be included for two reasons. First, Ball et al. (1988) showed that higher inflation reduces τ_{it}: their theoretical explanation was that in high inflation countries producers adjust their prices to shocks more quickly, and hence, the real effects of money shocks should be smaller. Thus, inflation should have explanatory power in itself. Secondly, open economies arguably have a tendency to have lower inflation, as was shown by Romer (1993): since real effects of monetary shocks are smaller in open economies, the monetary

[12] Of course, (4) is not the most up-to-date Phillips Curve regression (see, for example, King and Watson (1994) for a structural vector-autoregressive method of estimating the Phillips curve). However, the more advanced methods are not suitable for cross-country comparisons, because they do not produce a convenient single coefficient that can be regarded as the slope of the Phillips Curve.

authorities of those countries have a smaller incentive to inflate. In order to control for this effect of openness, I include inflation itself in (5).

Regression (4) can then be re-written as

$$y_{it} = constant_i + \tau_0 \Delta x_{it} + \tau_1 OPEN_{it} \Delta x_{it} + \tau_2 INF_{it} \Delta x_{it} + \lambda y_{i,t-1} + \gamma time + \epsilon_{it}. \tag{6}$$

I also run the above regression with three other methods of detrending real output. In case of first differencing, the equation simply becomes:

$$\Delta y_{it} = constant_i + \tau_{it} \Delta x_{it} + \epsilon_{it}. \tag{7}$$

Note that in this specification $constant_i$ has a totally different meaning than in (4). Now this term represents the drift, that is, how much real GDP grows in absence of nominal shocks. Thus, it has more to do with the coefficient γ from the previous specification. However, I do not focus on this statistic in this paper, and therefore do not change notation.

In the case of Hodrick-Prescott and high-pass filters, I use the specification (4) and drop the time trend variable from the regression.[13]

There are two ways to estimate these equations. Ball et al. (1988) estimated (4) for each country individually, and then regressed the estimates of τ on mean levels of inflation in those countries. Alternatively, one could incorporate both of these stages in panel estimation of (6). Fixed effects estimation seems to be suitable here to make sure that $constant_i$ varies between countries. This methodology would prevent a loss of degrees of freedom and was advocated, for example, by Akerlof, Rose, and Yellen in their comments to Ball et al. (1988). The problem with this kind of estimation is that both inflation and imports are cyclical variables, while I would like to concentrate on cross-sectional regime comparisons. I address this problem by getting rid of the cyclical component in inflation and openness variables by either taking their averages across the time period studied, or putting the series through a low-pass filter which eliminates fluctuations of frequencies higher than eight years.

The panel estimation approach also allows me to look at the effect of the exchange rate regime. For these purposes, the decomposition of τ_{it} can be changed into:

$$\tau_{it} = \tau_0 + \tau_1 OPEN_{it} + \tau_2 FIXED_{it} OPEN_{it} + \tau_3 INF_{it}. \tag{8}$$

[13] The Hodrick-Prescott filter uses the smoothness parameter of 100, since the data are annual; the high-pass filter uses truncation lag of 3 and highest frequency of eight years.

This is seen to be a regime-switching specification. The effect of openness is different in the two regimes (fixed or flexible) and the dummy $FIXED$ determines the regime, rather than have an effect of its own. When exchange rate is flexible, $FIXED = 0$ and the coefficient in front of openness is simply τ_1, which in theory should be negative. When the exchange rate is fixed, $FIXED = 1$, and the coefficient in front of openness variable is $\tau_1 + \tau_2$, which should be positive. So we should expect τ_1 to be negative, and τ_2 positive and bigger than τ_1 in absolute value.

6 Empirical Evidence

6.1 The Data

I compile a dataset of 35 countries, with annual observations from 1948 to 1998. The countries are a subset of those used by Ball et al. (1988). However, I only use those for which I can find all relevant data starting at least from 1960. The list of the countries and summary statistics are shown in Table 1. For neither individual country do I actually observe the full 1948-1998 data set, so I take whichever sample is available. I get the nominal GDP and total imports from the *International Financial Statistics* (IFS) of the International Monetary Fund, and real GDP, exchange rate against the U.S. dollar, and a measure of openness from Penn World Tables (PWT). Since the PWT provide data only through 1992, I augment those data by series from the IFS whenever possible. The measure of openness from the PWT is defined to be the sum of exports and imports as a fraction of GDP. The alternative measure is imports alone as a fraction of GDP. This measure is available for a somewhat smaller sample of observations, but is more relevant given the theory. The summary of this statistic is provided in Table 1.

Measurement of openness by imports/GDP ratio is intended to capture the exposure of the economy to foreign goods, and has been used quite frequently in literature, for example, in Romer (1993). At the same time, "openness" is a loose term, and if one thinks about it as exposure to foreign competition, then fraction of imports is an imperfect measure: lack of imports does not imply the inability to trade; rather, amount of imports is simply the observed optimum, which in principle could be altered by exchange rates variations. In effect, imports/GDP ratio gives an idea about the quantity of *traded*, rather than *tradable* goods. For this reason, alternative measures of openness, such as an index of trade restrictions, could be considered.

At the same time, although imports/GDP ratio does not capture all of the aspects of openness, I want to argue that it is in fact the appropriate statistic for the purposes of this analysis. In the theoretical part above, stickiness of prices is affected not by the mere exposure to foreign competition, but rather by the presence of foreign goods in domestic consumption. Of course, the fraction of these goods is endogenous and can change with the change in the terms of trade. However, this effect is second-order, as is implicitly suggested in Appendix A: substitution to domestic goods following the money shock does not take place in the log-linearized framework. Therefore, the statistic of interest is a particular measurement of openness, namely, import penetration.

The dummy $FIXED$ is constructed using the information from the Annual Report on Exchange Arrangements and Exchange Restrictions series of the IMF, as well as a visual observation of the monthly exchange rate series for all countries. For the purposes of this paper, I would like to construct a variable that equals to 1 if the exchange rate is not free to respond to market shocks, which could be the case either when the currency is pegged or follows a crawling peg. The IMF reports provide information about the officially declared policies, but I nevertheless check the actual series to see whether these intentions were followed. Indeed, I find cases when the officially floating exchange rate is clearly pegged, or vice-versa, floats or is frequently adjusted when it is declared pegged (as was the case with the early years of the European Monetary System, for example). In these cases, I check the robustness of results with both values of the dummy variable $FIXED$, and find that the results are not sensitive (perhaps because these cases constitute only a small part of the sample).

6.2 Effects of Openness During the Bretton Woods Era and After

First of all, I run the specification of the regression that does not include the exchange rate regime variable, but I run it separately for the Bretton Woods era and for the following period. The Bretton Woods period is a clean case of universally fixed exchange rates, while afterwards most of the exchange rates were either completely flexible or at least partially flexible. The results for the period up to 1971 are reported in Table 2, and for the following years – in Table 3. The variables $OPENtrend$ and $INFtrend$ here refer to the low-pass filtered measures of openness and inflation, while $OPENavg$ and $INFavg$ are their averages.[14] Both inflation and openness are measured in percentage points. Thus, 0.006 in the first column of the Table 2 means that in a country, whose imports are 1% of GDP, 0.6% more of a nominal shock is transmitted into real GDP change than

[14] Low pass filter uses truncation lag of three and the highest frequency equal to eight years.

in a completely closed economy. The White heteroscedasticity consistent standard errors appear in parentheses.

Inflation is obtained from the GDP deflater $p = x - y$. A star indicates statistical significance at 10% level, while square brackets are used to indicate that the estimate keeps or obtains the predicted sign and significance after inclusion of higher powers of inflation. It is important to fully specify inflation in these regressions because, as I said before, openness could be correlated with inflation and have an effect on τ_{it} through that channel alone.

The important finding reported in these tables is that the openness variable generally has the correct sign and in most cases is significant. The results are better when using ad-hoc filtering such as linear detrending and first differencing, and are less robust with Hodrick-Prescott and high-pass filters. Thus, the regression with HP-filtered real output and $OPENtrend$ yields a coefficient for openness that is not robust to inclusion of higher powers of inflation. High-pass filtered output yields significant coefficient in front of openness only when using $OPENavg$ and including the third power of inflation.

Likewise, the openness coefficient in the time period after 1971 is always negative and significant in all cases except for HP-filtered output with $OPENtrend$. Also, with all four detrending procedures, $OPENtrend$ variable loses significance with higher powers of inflation included, while $OPENavg$ seems to be robust.

Ball et al. (1988) also conclude that the variance of nominal GDP growth should have explanatory power for the coefficient τ. Therefore, it is interesting to examine whether the above results are robust to inclusion of this variable in the regression. Table 4 demonstrates that the results are robust when one uses the average measure of openness and inflation in the regression. The standard deviation of GDP growth in country i during the studied period is denoted as $\sigma_{\Delta x,i}$. If one were to use the trend measure, however, coefficient τ_1 would lose statistical significance.

It also might make sense to include the interactions terms, $OPEN_{it}$ and INF_{it} in the regressions by themselves, without the multiplication by Δx_{it}. There is no theoretical reason to do so, but one might argue that lower-order terms should be included together with their products. However, inclusion of this terms produces no significant effect on the results for the low-passed filtered $OPENtrend_{it}$ and $INFtrend_{it}$ (exact figures not reported due to similarity). The average measures of openness and inflation cannot be used, on the other hand, because they are perfectly collinear with the country-specific intercept term.

6.3 The Effect of the Exchange Rate Regime

Of course, treating the post-Bretton Woods period as universally flexible exchange rate time is incorrect. Many countries stayed on currency boards for a big part or even all of this period. Certain European countries at different times were members of the European Monetary System. To address this concern, I now turn to the estimation of regression (4) with τ_{it} decomposed as in (8).

The results with the regime switching specification are reported in the Table 5. I run this regression for the whole sample, using the trend measure of openness and inflation. I do not use the average measure, because the fixed exchange rate regime is certainly correlated with inflation, and possibly with openness. Thus, it is better to have a measure of those variables that can control for these correlations. I also check robustness to the inclusion of the slope dummy $FIXED_{it}\Delta x_{it}$. There is no theoretical reason to include this variable, but I include it as a lower-order term together with the same variable multiplied by openness.

Again, in the table star denotes rejection at 10% level of significance, and square brackets imply robustness to inclusion of higher powers of inflation (applied only to openness and fixed exchange rates variables). We see that the coefficients have almost uniformly the expected signs, but significance is not robust to all specifications. Furthermore, the sum of the coefficients in front of $OPEN$ and $FIXED * OPEN$ variables is not positive as expected. Yet, generally, the results seem to support the predictions of the theory: openness has a negative effect on the real response to nominal shocks whenever the exchange rate is flexible. This effect is reduced or even reversed in economies with fixed exchange rates.

7 Conclusion

I demonstrate in this paper that for purposes of macroeconomic analysis of the international business cycle, the assumption of sticky export prices, normally obtained from the law of one price, is superior to the assumption of sticky import prices, implied by local currency pricing behavior. I demonstrate this superiority directly in a vector-autoregressive model for the United States and Canada, which shows that import prices react faster than the general price level to negative money and exchange rate shocks, and the terms of trade worsen, which is consistent with sticky export prices. At the same time, export prices also react fast to such shocks, which finding suggests that a certain fraction of goods is priced in local currency. An implication of these finding for business cycle modeling is that a fraction of goods should be assumed to have prices sticky in the exporter's currency, and a fraction in importer's currency, with an understanding that this second fraction is likely to be smaller. If one needs to choose only one kind of rigidity on grounds of simplicity, sticky import prices (PCP assumption) are a better way to go.

I then test a powerful implication of the PCP assumption that a high fraction of imports in the consumption basket of a country makes prices in the economy overall less sticky and hence short-run Phillips Curve steeper. This result comes out of the New Keynesian treatment of price rigidities, which posits that firms endogenously choose not to alter prices after a nominal demand shock, when the general price level in the economy is unchanged. In an open economy, on the other hand, a fraction of goods (imports) do become more expensive soon after a money shock and exchange rate adjustment, and hence, domestic firms are more likely to alter their prices as well facing this reduced competition. This logic works only for the case of flexible exchange rates. If the rates are fixed, the opposite is true: import prices never respond to money shocks, and hence make domestic prices less likely to change as well.

I use macroeconomic data to test these implications: if the cost of price stickiness is higher in open economies, then prices in these economies should be less rigid, and hence, real effects of nominal shocks smaller. I test this implication using a Phillips Curve regression of Ball et al. (1988), but using panel estimation. The results suggest that in the Bretton Woods era, import penetration increased real effects of nominal shocks, while afterwards, import penetration decreased that effect.

A The Model

In this appendix, I show a formal model, which demonstrates some of the claims made in Section 3, and provides a justification for the use of the objective function $W\left(\frac{M}{P}, \frac{p(j)}{P}\right)$. I will, however, need to substitute world output for real money balances in the function, as a more relevant measure of aggregate demand in an open economy setting. The model is that of Obstfeld and Rogoff (1995), which today is considered to be the benchmark model for sticky-price international business cycle research. The deviation I make, however, is to allow for a costly price adjustment by each individual firm at the beginning of each period, whereas costless price-adjustment is available at the end of a period. Thus, prices are endogenously fixed for one period, unless firms choose to pay the menu cost and adjust. The rest of the model is identical to the one in Obstfeld and Rogoff (1995), and therefore I will not spell out all of the details, and simply refer the reader to the original source.[15]

Of course, a mismatch exists between the static analysis of Section 3 and the following dynamic model. The reason for this mismatch is that the private cost of price rigidity is a per-period cost, and its analysis in dynamic setting is highly complex, while adds little to the basic intuition.[16] The exchange rate behavior, on the other hand, cannot be studied in a static environment, because the expectations of future movements in economic fundamentals are the primary source of exchange rate fluctuations.

A.1 Set-up

Consider a two-country world populated by a continuum of households, of which n live in the home country, and $(1-n)$ in the foreign country. Each household j produces a single differentiated good, and maximizes the objective function

$$U_t^j = \sum_{s=t}^{\infty} \beta^{s-t} \left[\log C_s^j + \chi \log \frac{M_s^j}{P_s} - \frac{\kappa}{2} y_s(j)^2 - z D_s^j \right], \tag{9}$$

where the first term indicates consumption, the second holdings of real money balances, and the third disutility from production. The last term is the fixed menu cost z multiplied by the dummy D_t^j, which equals one if producer j adjusts his product's price at the *beginning* of period t and zero otherwise (I will discuss this rigidity in more detail in Section A.3). Consumption variable is a CES aggregate of all goods with the corresponding price index expressed as

$$C^j = \left[\int_0^1 c^j(l)^{\frac{\theta-1}{\theta}} dl \right]^{\frac{\theta}{\theta-1}} \quad \text{and} \quad P = \left[\int_0^1 p(l)^{1-\theta} dl \right]^{\frac{1}{1-\theta}}, \tag{10}$$

where $c^j(l)$ is the amount of good l consumed by the individual j, and $p(l)$ is the domestic price of that good, independently of where it has been produced. The correspondence between the domestic and foreign prices is given by the law of one price (1):

$$p(l) = \mathcal{E} p^*(l), \tag{11}$$

with stars indicating foreign variables throughout, and $\mathcal{E}$ being the exchange rate.

The individual budget constraint is

$$P_t B_{t+1}^j + M_t^j = P_t(1+r_t) B_t^j + M_{t-1}^j + p_t(j) y_t(j) - P_t C_t^j - P_t \tau_t, \tag{12}$$

[15] The model also has been described well in Obstfeld and Rogoff (1996), Chapter 10.

[16] See Kimball (1995) for such an analysis.

where B_t^j is the net holdings of foreign bonds – the only financial asset in this model. The risk-free interest rate on these bonds r_t is the same for individuals of both countries. Since there is no investment in the model, the purpose of the bonds is simply international consumption smoothing. τ_t is the lump-sum taxes which satisfy the government's budget constraint

$$\tau_t + \frac{M_t - M_{t-1}}{P_t} = 0$$

The demand for each differentiated good produced by an individual can be expressed as

$$y^d(l) = \left[\frac{p(l)}{P}\right]^{-\theta} C^w \tag{13}$$

where C^w denotes world consumption

$C^w \equiv \int_0^n C^j dj + \int_n^1 C^{*j} dj = nC + (1-n)C^*$.

Plugging this demand into the budget constrain (12), then the resulting budget constraint into the utility function and maximizing, one obtains the following first-order conditions:

$$C_{t+1} = \beta(1 + r_{t+1})C_t, \tag{14}$$

$$\frac{M_t}{P_t} = \chi C_t \left(\frac{1 + i_{t+1}}{i_{t+1}}\right), \tag{15}$$

$$y_t^{\frac{\theta+1}{\theta}} = \frac{\theta - 1}{\theta\kappa}(C_t^w)^{\frac{1}{\theta}} \frac{1}{C_t}, \tag{16}$$

where the indices are suppressed due to the symmetry of the model. Equation (14) is a standard Euler equation for consumption, (15) is the money demand, while (16) is the labor-leisure trade-off. The nominal interest rate is defined as $1 + i_{t+1} \equiv \frac{P_{t+1}}{P_t}(1 + r_{t+1})$

In order to solve the model further, we need to log-linearize the above equations around the steady-state. Therefore, we first need to characterize the steady state. The Euler equation suggests that $\bar{r} = \delta \equiv \frac{1-\beta}{\beta}$, with barred variables denoting steady state values throughout. The relationship between consumption and income is given by

$$\bar{C} = \delta\bar{B} + \frac{\bar{p}(h)\bar{y}}{\bar{P}}, \tag{17}$$

$$\bar{C}^* = -\left(\frac{n}{1-n}\right)\delta\bar{B} + \frac{\bar{p}^*(f)\bar{y}^*}{\bar{P}^*}, \tag{18}$$

where $p(h)$ and $p^*(f)$ refer to the local-currency prices of the home and foreign goods, respectively. However, Obstfeld and Rogoff (1996) have to make one more simplifying assumption in order to obtain a closed-form solution: assume that at the original pre-shock steady state, the current account is balanced, that is, $\bar{B} = 0$. This assumptions allows to use the symmetry to show that

$$\bar{p}(h)/\bar{P} = \bar{p}^*(f)/\bar{P}^* = 1 \tag{19}$$

$$\bar{C} = \bar{C}^* = \bar{y} = \bar{y}^* = \bar{C}^w. \tag{20}$$

This symmetric steady state allows us to perform the log-linearization and analyze the effect of a one-time permanent money shock.

A.2 Log-linearized equations

In the following equations, I will denote a percent deviation from the steady state of a variable X by $\tilde{x}$.

The price levels are

$$\tilde{p}_t = n\tilde{p}_t(h) + (1-n)[\tilde{e}_t + \tilde{p}^*_t(f)], \tag{21}$$

$$\tilde{p}^*_t = n[\tilde{p}_t(h) - \tilde{e}_t] + (1-n)\tilde{p}^*_t(f)]. \tag{22}$$

From here, it is easy to obtain the PPP condition

$$\tilde{e}_t = \tilde{p}_t - \tilde{p}^*_t, \tag{23}$$

which, in combination with the assumption of a common real interest forces the Interest Rate Parity (IRP) to hold as well.

The demand side, which is important for the sticky-price setting, is characterized by the consumption Euler equations from (14)

$$\tilde{c}_{t+1} = \tilde{c}_t + \frac{\delta}{1+\delta}\tilde{r}_{t+1}, \tag{24}$$

$$\tilde{c}^*_{t+1} = \tilde{c}^*_t + \frac{\delta}{1+\delta}\tilde{r}_{t+1}, \tag{25}$$

and the money demand from (15)

$$\tilde{m}_t - \tilde{p}_t = \tilde{c}_t - \frac{\tilde{r}_{t+1}}{1+\delta} - \frac{\tilde{p}_{t+1} - \tilde{p}_t}{\delta}, \tag{26}$$

$$\tilde{m}^*_t - \tilde{p}^*_t = \tilde{c}^*_t - \frac{\tilde{r}_{t+1}}{1+\delta} - \frac{\tilde{p}^*_{t+1} - \tilde{p}^*_t}{\delta},. \tag{27}$$

The important result to be obtained from these two pairs of equations is that a permanent shock to relative money supply leads to an immediate and permanent shock to the exchange rate, independently of the form of price rigidity (although the size of the exchange rate adjustment can depend on the form of price rigidity). That is, exchange rate adjusts to its new long-run equilibrium immediately. To see this, subtract (27) from (26) and impose the PPP condition (23) to get

$$\tilde{e}_t = (\tilde{m}_t - \tilde{m}_t^*) - (\tilde{c}_t - \tilde{c}_t^*) + \frac{1}{\delta}(\tilde{e}_{t+1} - \tilde{e}_t). \tag{28}$$

Here, the shock to relative money supply is permanent by assumption, and the change in relative consumption can be shown to be permanent by subtracting foreign Euler equation (25) from domestic (24) to get

$$(\tilde{c}_{t+1} - \tilde{c}_{t+1}^*) = (\tilde{c}_t - \tilde{c}_t^*).$$

That is, relative consumption follows a random walk, as Obstfeld and Rogoff put it. In case of anticipated money shock, relative consumption does not react; if the shock is not anticipated, however, relative consumption adjusts immediately to its new steady state.

To show that the change in the exchange rate is also permanent, rewrite (28) as

$$\tilde{e}_{t+1} = (\delta + 1)\tilde{e}_t - (\tilde{m}_t - \tilde{m}_t^*) + (\tilde{c}_t - \tilde{c}_t^*).$$

Since the last two terms of this expression are constant following the shock, exchange rate follows an explosive AR(1) process, so if the price is sticky only temporarily and the economy is to get back to steady state at some point, exchange rate has to jump to the new steady state value immediately, or else it explodes into infinity. Therefore, this reaction of the exchange rate does not depend on the behavior of prices. Prices can be sticky in any fashion, be that a one-period fixing as in Obstfeld and Rogoff (1995), or staggered adjustment.

In order to see why the exchange rate adjusts immediately even with sticky prices, take a difference of log-linearized versions of (13) for both countries, and apply PPP condition to get

$$\tilde{y}_t - \tilde{y}_t^* = \theta(\tilde{e}_t + \tilde{p}_t^*(f) - \tilde{p}_t(h)). \tag{29}$$

What this equation shows is that the relative demand for the goods produced in two countries depends on the terms of trade. So if there is a distortion in relative supply, as happens following an asymmetric money shock, the equilibrium has to be achieved through an adjustment in terms of trade. Since prices are sticky, terms of trade have to adjust through the exchange rate. Therefore, the effect of an exchange rate depreciation can be obtained even in a static version of Obstfeld and Rogoff (1995) with money demand modeled by a quantity equation such as $\tilde{m} = \tilde{y} + \tilde{p}$. However, one can easily see that the adjustment would be much smaller in the static case. Exchange rate in such a setting goes up only by the fraction $\frac{1}{1+\theta}$ of the money supply increase, which is less than half when $\theta > 1$. Only when the price-adjustment is complete, would the full appreciation of the foreign currency take place. This comparison allows us to understand why it is important to have a dynamic model of exchange rates: expectations make the immediate response of the exchange rate much higher than what is simply implied by supply and demand for the traded goods of the two countries. In the special case of the above model, exchange rate adjusts to the long-run equilibrium value immediately. This intuition is similar to that of the Cagan model, in which today's value of foreign currency equals to the present value of future money.

A.3 The nominal rigidity

Here, I will argue that the simple objective function W from Ball and Romer (1990) presented in Section 3 is relevant in this setting, once one considers a one-period utility of an individual, with a corresponding one-period budget constraint. For simplicity, I will consider only the real part of the utility, since the monetary component is linked to the interest rate, which is dynamic in nature (Obstfeld and Rogoff (1995) have argued that the monetary component of the utility has only a small importance in welfare analysis). This utility is given by

$$\begin{aligned} U^j &\approx \log C^j - \frac{\kappa}{2} y(j)^2 - zD^j = \\ &(1-\theta)\log\left(\frac{p(j)}{P}\right) + \log Y^w - \frac{\kappa}{2}\left(\frac{p(j)}{P}\right)^{-2\theta}(Y^w)^2 - zD^j \end{aligned} \qquad (30)$$

and the latter expression we can define as $W\left(Y^w, \frac{p(j)}{P}\right)$.

To obtain the equality in (30), I used (13), and the static budget constraint $PC^j = p(j)y(j)$. Further, I substituted the world income Y^w for world consumption C^w since in equilibrium they should be the same. The reason why the budget constraint also needs to be made static is that one-period price rigidity in dynamic setting has no cost because the period is infinitesimal and consumption of a permanent-income consumer is not affected (see Kimball (1995) for a treatment of private *flow* cost of price rigidity in dynamic setting). The static budget constraint basically says that the individual has to consume all of the income today, without the ability to postpone consumption until later. Thus, he is "punished" by reduced consumption for having the price away from optimum. This approximates the "punishment" of a permanent-income consumer, who gives up consumption some time in the future by spending part of the income on bonds contemporaneously.

Function W in (30) has a different aggregate demand argument than the one discussed in Section 3, Y^w instead of M/P. This is not surprising, because in this setting, the aggregate demand is represented by the world output, as opposed to the domestic output in a closed economy, which in Ball and Romer's setting was equal to the money balances M/P. The per-person money balances also enter the expression. However, we do not need to worry about this term, as well as the interest rate term, in calculating the cost of not being at the optimal price, because the terms are exogenous to the choice of $p(j)$ and enter in an additively separable way. Hence, the terms will drop out in the calculation of the private cost of non-adjustment.

We need to make sure, however, that the requirements are satisfied that following a one percent money shock with $p(h)$ and $p(f)$ remaining constant, P will adjust by $(1-n)$ percent, while Y^w by n percent, provided that exchange rate moves proportionally with money.[17] The first property immediately follows from (21). The second takes some more equations to demonstrate, and we need to make an additional assumption about the specific form of price rigidity. The form that I assume is that each firm gets a chance to adjust its price costlessly at the end of a period, after suffering the losses of non-optimal price during this period. The menu cost z is applied only if the producer chooses to change the price at the beginning of the period, and not suffer the losses. This kind of price rigidity is immediately relevant to my analysis in Section 3.[18]

Aggregating the Euler equations (24) and (25),

$\tilde{c}^w_{t+1} = \tilde{c}^w_t + \frac{\delta}{1+\delta}\tilde{r}_{t+1}$.

However, after one period, everyone can costlessly adjust price, and hence we return to the steady state. Thus, $\tilde{c}^w_{t+1} = \bar{c}^w$, which is the log change in the steady state value. To show that $\bar{c}^w = 0$, we log-linearize labor-leisure trade-off, which holds only in the steady-state, and aggregate to get

[17]Strictly speaking, in this model the exchange rate does not move proportionally with money, and therefore P adjusts by slightly less than $1-n$ percent, while Y^w adjusts by full n percent. However, this situation was discussed in Section 3, and the results do not change.

[18]I could, in principle, avoid the reliance on this particular form of price stickiness by switching from the money-in-the-utility framework to a cash-in-advance type constraint $\frac{M_t}{P_t} = C_t$. In this case, the size of the immediate reaction of world consumption does not depend on the form of price stickiness. However, such way of modeling of money demand is probably less realistic.

$(1+\theta)\tilde{y}_t^w = (1-\theta)\tilde{c}_t^w$.

Then, in steady state, $\bar{c}^w = 0$, since $\tilde{c}^w = \tilde{y}^w$.

Thus, we get that

$\tilde{c}_t^w = -\frac{\delta}{1+\delta}\tilde{r}_{t+1}$.

Analogously, aggregate the money demand equation (26) and (27), and using the fact that individual prices are sticky in (21) and (22):

$\tilde{m}_t^w = \tilde{c}_t^w - \frac{\tilde{r}_{t+1}}{1+\delta} - \frac{\tilde{m}_t^w}{\delta}$

Combining these last two equations, we get that

$\tilde{y}^w = \tilde{c}^w = \tilde{m}^w$.

However, $\tilde{m}^w = n\tilde{m} + (1-n)\tilde{m}^* = n\tilde{m}$, since the foreign money supply does not change. Thus, we see that the world income increases by fraction n of the percentage increase in the domestic money supply. This result makes sense intuitively: with lack of investment, real world money balances can be spent only on consumption goods, and hence an increase in these balances should be proportional to increase in consumption.

Another property of the function in (30) that needs to be checked is the degree of the real rigidity. After making the necessary normalization of parameter κ in order to force $W(.,.)$ to satisfy the requirements spelled out in Section 3, it is easy to derive the value of real rigidity $\psi = 1/\theta$. The model of Obstfeld and Rogoff (1995) requires $\theta > 1$, and thus condition $\psi < 1$ holds. Furthermore, Ball and Romer (1990) quote an empirically estimated value $\theta = 7.7$, which makes the real rigidity coefficient ψ significantly smaller than unity.

Thus, we see that the objective function W from Section 3 is derivable in a micro-founded model. Equation (30) gives the specific form of the utility of an individual producer for any $p(j)$. As was shown in Section 3 for a general class of such functions, the cost of deviation from the optimal $p(j)$ increases in the fraction of imported goods $(1-n)$. Hence, a larger menu cost z is necessary in an open economy to keep prices sticky. Therefore, one should expect the equilibrium degree of price stickiness to be smaller in a more open country.

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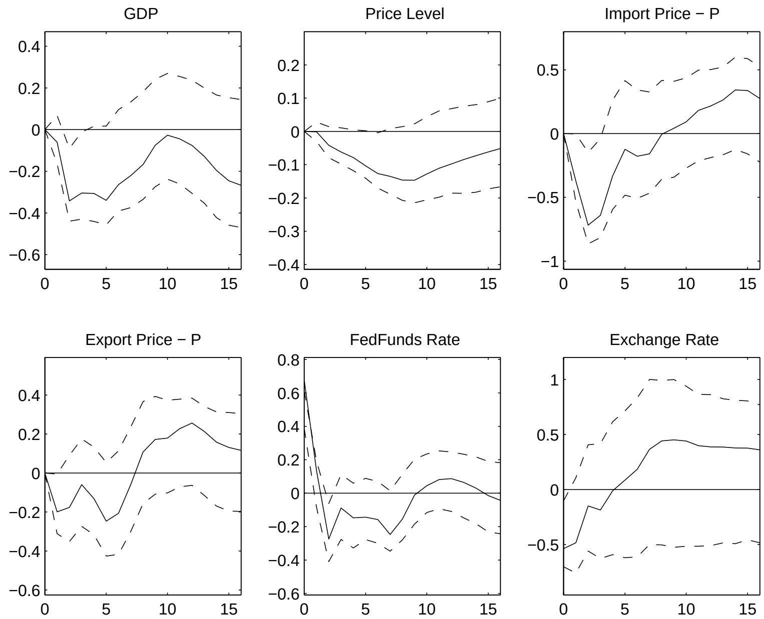
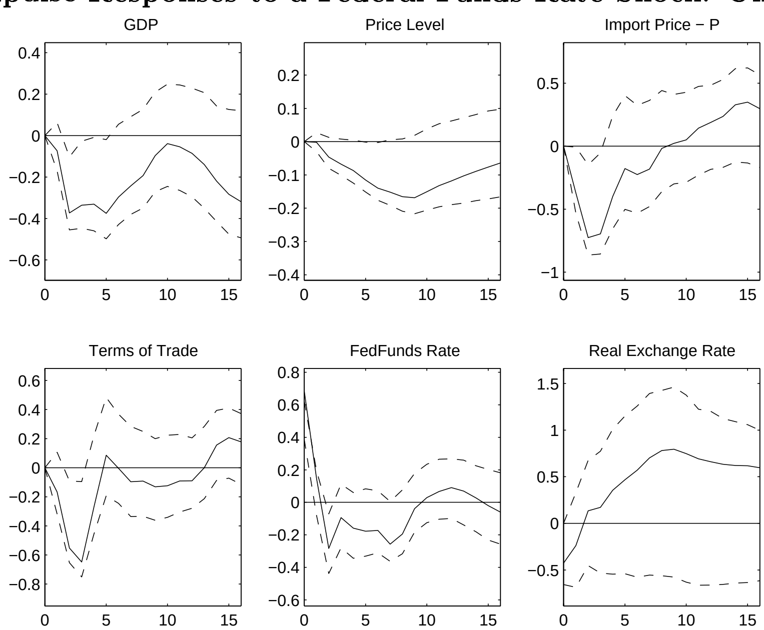
Figure 1: Impulse Responses to a Federal Funds Rate Shock: United States[a]



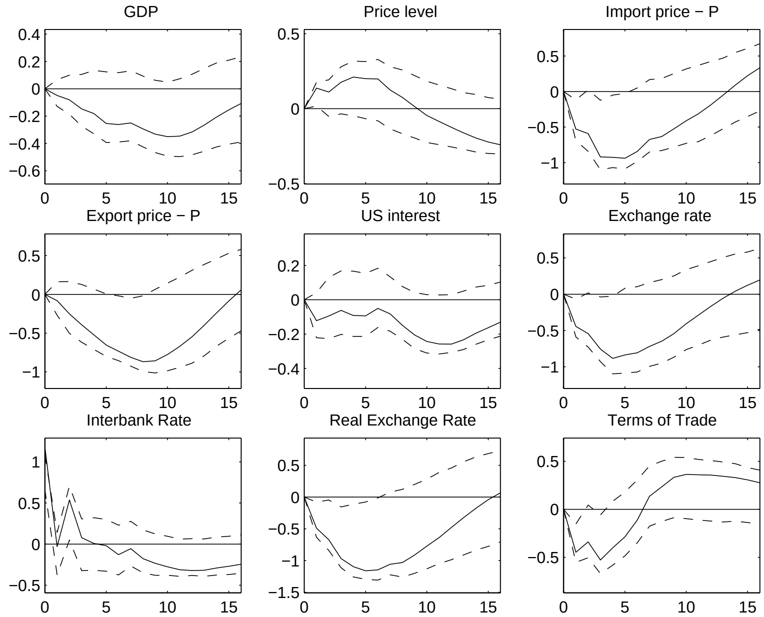
[a]The dashed lines show bootstrap 95% confidence intervals.

Figure 2: Impulse Responses to a Federal Funds Rate Shock: United States[a]



[a]The dashed lines show bootstrap 95% confidence intervals.

Figure 3: Impulse Responses to an Inter-bank Rate Shock: Canada[a]

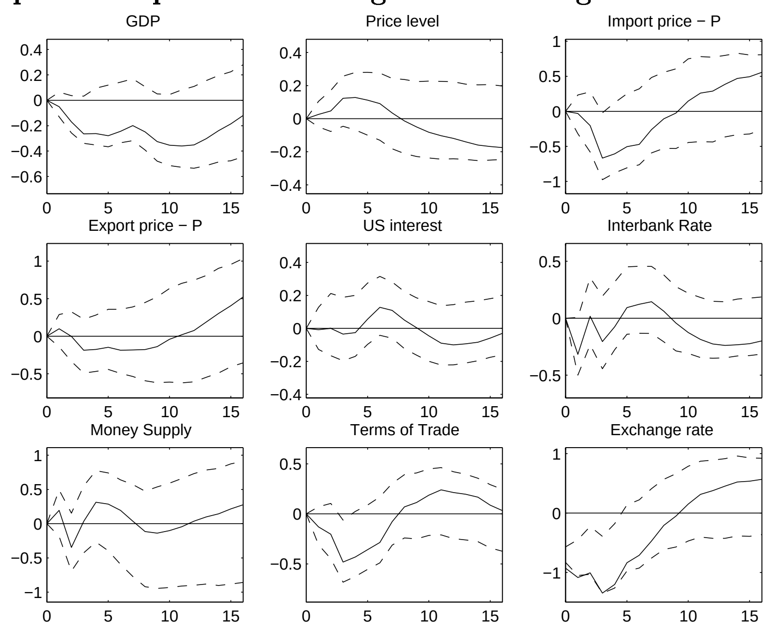


[a]The terms of trade and real exchange rate responses were generated in separate regressions. The dashed lines show bootstrap 95% confidence intervals.

Figure 4: Impulse Responses to a Negative Exchange Rate Shock: United States[a]

[a]The terms of trade response was obtained in a separate regression. The dashed lines show bootstrap 95% confidence intervals.

Figure 5: Impulse Responses to a Negative Exchange Rate Shock: Canada[a]



[a]The terms of trade response was obtained in a separate regression. The dashed lines show bootstrap 95% confidence intervals.

Table 1: Average Measure of Import Penetration. Summary.

Country	Sample	Full sample	Up to 1971	Post-1971
Australia	1949-1998	17.54	17.38	17.55
Austria	1950-1998	30.73	23.60	36.30
Belgium	1953-1997	50.74	35.17	61.35
Canada	1948-1998	23.59	19.56	26.64
Colombia	1950-1996	14.17	13.57	14.74
Costa Rica	1950-1996	34.35	28.49	39.23
Denmark	1950-1997	31.78	31.82	31.65
Dominican Republic	1950-1995	24.86	20.77	28.45
Ecuador	1950-1995	22.41	18.76	26.42
El Salvador	1951-1998	28.93	24.14	32.43
Finland	1950-1997	25.15	21.76	27.96
France	1950-1997	17.37	12.97	20.88
Germany	1950-1992	20.11	16.19	29.90
Greece	1948-1994	22.38	17.58	26.62
Guatemala	1950-1998	19.66	15.84	22.63
Iceland	1950-1998	36.57	37.54	36.13
Iran	1959-1995	16.39	15.66	16.94
Ireland	1948-1997	49.80	41.25	56.52
Italy	1951-1992	17.23	13.68	20.54
Jamaica	1953-1993	46.03	40.02	50.77
Japan	1952-1998	10.20	10.02	10.27
Mexico	1950-1998	13.37	12.32	14.02
Netherlands	1950-1995	48.12	47.04	48.97
Norway	1949-1995	41.02	42.87	39.48
Panama	1950-1979	39.58	36.55	47.13
Philippines	1948-1995	21.50	14.93	27.18
Portugal	1953-1997	32.26	25.54	36.92
South Africa	1949-1998	25.75	27.42	24.40
Spain	1954-1998	16.12	10.66	19.53
Sweden	1950-1995	26.55	22.74	29.77
Switzerland	1948-1995	31.99	29.31	34.47
Tunisia	1960-1998	38.10	28.53	41.86
United Kingdom	1948-1997	24.42	21.54	26.64
United States	1948-1998	7.79	4.59	10.22
Venezuela	1950-1998	22.92	21.58	23.85
The data are imports as percent of GDP				

Table 2: Determinants of Real Output: up to 1971. Panel Estimation. Fixed Effects.

Regressor	Linear Detrending		First differencing		HP-filter		High-Pass	
Δx_{it}	0.553*	0.394*	0.573*	0.384*	0.507*	0.325*	0.416*	0.266*
	(0.054)	(0.061)	(0.055)	(0.065)	(0.047)	(0.058)	(0.039)	(0.047)
$OPENtrend_{it}\Delta x_{it}$	[0.006*]		[0.005*]		0.0018		-0.0006	
	(0.002)		(0.002)		(0.0017)		(0.0014)	
$OPENavg_i\Delta x_{it}$		[0.007*]		[0.007*]		[0.004*]		0.0014
		(0.002)		(0.002)		(0.002)		(0.0017)
$INFtrend_{it}\Delta x_{it}$	-0.041*		-0.042*		-0.032*		-0.025*	
	(0.004)		(0.004)		(0.003)		(0.003)	
$INFavg_i\Delta x_{it}$		-0.042*		-0.041*		-0.023*		-0.020*
		(0.005)		(0.005)		(0.007)		(0.007)
$y_{i,t-1}$	0.937*	0.940*			0.601*	0.576*	0.276*	0.233*
	(0.012)	(0.011)			(0.030)	(0.032)	(0.035)	(0.037)
$time$	0.003*	0.003*						
	(0.001)	(0.001)						
The dependent variable is y_t, except for first differencing case, where it is Δy_t. Star indicates rejection at 10% level of significance, [ ] indicate robustness to inclusion of higher powers of inflation. White heteroscedasticity-robust standard errors in parentheses.								

Table 3: Determinants of Real Output: After 1971. Panel Estimation. Fixed Effects.

Regressor	Linear Detrending		First differencing		HP-filter		High-Pass	
Δx_{it}	0.410*	0.410*	0.489*	0.487*	0.277*	0.343*	0.157*	0.225*
	(0.051)	(0.089)	(0.049)	(0.067)	(0.041)	(0.054)	(0.031)	(0.046)
$OPENtrend_{it}\Delta x_{it}$	-0.004*		-0.004*		-0.002*		-0.0013	
	(0.001)		(0.001)		(0.001)		(0.0008)	
$OPENavg_i\Delta x_{it}$		[-0.006*]		[-0.005*]		[-0.004*]		[-0.002*]
		(0.001)		(0.001)		(0.001)		(0.001)
$INFtrend_{it}\Delta x_{it}$	-0.007*		-0.008*		-0.005*		-0.003*	
	(0.001)		(0.001)		(0.001)		(0.0004)	
$INFavg_i\Delta x_{it}$		-0.014*		-0.016*		-0.012*		-0.008*
		(0.002)		(0.002)		(0.002)		(0.001)
$y_{i,t-1}$	0.894*	0.890*			0.679*	0.652*	0.329*	0.314*
	(0.014)	(0.013)			(0.026)	(0.025)	(0.035)	(0.035)
$time$	0.003*	0.003*						
	(0.000)	(0.0004						
The dependent variable is y_t, except for first differencing case, where it is Δy_t. Star indicates rejection at 10% level of significance, [ ] indicate robustness to inclusion of higher powers of inflation. White heteroscedasticity-robust standard errors in parentheses.								

Table 4: Determinants of Real Output with Inclusion of GDP Growth Variance

Regressor	Linear Detrending		First differencing		HP-filter		High-Pass	
	Pre-BW	Post-BW	Pre-BW	Post-BW	Pre-BW	Post-BW	Pre-BW	Post-BW
Δx_{it}	0.255*	0.396*	0.195*	0.395*	0.191*	0.323*	0.453*	0.311*
	(0.123)	(0.096)	(0.123)	(0.090)	(0.102)	(0.072)	(0.148)	(0.059)
$OPENavg_i \Delta x_{it}$	[0.006*]	[-0.006*]	[0.007*]	[-0.005*]	[0.003*]	[-0.004*]	0.0015	[-0.0011]
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.0017)	(0.0011)
$INFavg_i \Delta x_{it}$	-0.037*	-0.020*	-0.034*	-0.025*	-0.026*	-0.015*	-0.014*	-0.010*
	(0.009)	(0.005)	(0.009)	(0.005)	(0.008)	(0.004)	(0.008)	(0.003)
$\sigma_{\Delta x,i} \Delta x_{it}$	3.698	2.668	4.996*	3.630*	3.919*	0.976	-7.987	-2.075*
	(2.706)	(1.905)	(2.704)	(1.906)	(2.246)	(1.542)	(6.565)	(1.010)
$\sigma^2_{\Delta x,i} \Delta x_{it}$	-20.33	-7.345	-27.29*	-9.894	-22.12*	-2.139	63.07	10.78*
	(14.46)	(7.297)	(14.45)	(7.269)	(12.00)	(5.897)	(55.14)	(4.24)
$y_{i,t-1}$	0.940*	0.893*			0.536*	0.650*	0.235*	0.309*
	(0.012)	(0.013)			(0.030)	(0.026)	(0.038)	(0.035)
$time$	0.002*	0.003*						
	(0.001)	(0.0004)						

The dependent variable is y_t, except for first differencing case, where it is Δy_t. Star indicates rejection at 10% level of significance, [ ] indicate robustness to inclusion of higher powers of inflation. White heteroscedasticity-robust standard errors in parentheses.

Table 5: Determinants of Real Output with Exchange Rate Regime Effect. Full Sample.

Regressor	Linear Detrending		First differencing		HP-filter		High-Pass	
Δx_{it}	0.451*	0.463*	0.538*	0.484	0.314*	0.350*	0.204*	0.226*
	(0.033)	(0.039)	(0.035)	(0.041)	(0.027)	(0.032)	(0.021)	(0.025)
$OPENit \Delta x_{it}$	-0.004*	-0.004*	-0.007*	-0.006*	-0.002*	-0.003*	-0.002*	-0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$FIXED_{it} OPEN_{it} \Delta x_{it}$	0.001*	0.002	0.002*	-0.001	0.0004	[0.002*]	0.0001	0.0012*
	(0.0004)	(0.001)	(0.001)	(0.001)	(0.0003)	(0.001)	(0.0003)	(0.0007)
$FIXED_{it} \Delta x_{it}$		-0.021		[0.087*]		[-0.059*]		[-0.036*]
		(0.034)		(0.035)		(0.027)		(0.021)
$INF_{it} \Delta x_{it}$	-0.008*	-0.008	-0.010*	-0.009*	-0.006*	-0.006*	-0.0036*	-0.004*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.0004)	(0.001)	(0.0003)	(0.0004)
$y_{i,t-1}$	0.960*	0.959*			0.645*	0.643*	0.284*	0.283*
	(0.006)	(0.006)			(0.020)	(0.020)	(0.025)	(0.025)
$time$	0.001*	0.0007*						
	(0.0002)	(0.0002)						

The dependent variable is y_t, except for first differencing case, where it is Δy_t. Openness and inflation are high-pass filtered. Star indicates rejection at 10% level of significance, [ ] indicate robustness to inclusion of higher powers of inflation. Standard errors in parentheses.