Monetary Policy Spillovers Through Invoicing Currencies

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Abstract

Monetary policy from the U.S.affects macro-financial outcomes globally. I study the role of invoicing currencies in these spillover effects. I introduce heterogeneity in invoicing currencies into an open economy New Keynesian model, and derive predictions linking the magnitude of monetary policy spillover effects and which currencies are used to invoice traded goods. In response to contractionary monetary policy from the U.S., countries with more Dollar invoiced trade see their their interest increase, their imports decrease and production fall relative to countries with less Dollar invoiced trade. As a result, it is harder for countries that invoice traded goods in foreign currency to use monetary policy to influence domestic outcomes. Using high frequency measures of monetary policy shocks, I find strong empirical support for the model's predictions. Countries' shares of Dollar invoiced imports significantly explain cross-sectional heterogeneity in monetary policy spillover effects from the U.S. Finally, I construct a new data set containing monetary policy shocks from three additional central banks, and I find the magnitude of monetary policy spillover effects from the U.S. are no larger than those from the other central banks after controlling for the share of trade invoiced in each currency.

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1 Introduction

The actions of the Federal Reserve Bank of the United States are a fundamental concern for central bankers around the world. A growing literature finds that monetary policy actions from the United States significantly impact macroeconomic conditions (Rey, 2013) and asset prices (Brusa et al., 2015) globally. However, this literature is largely silent on how the Federal Reserve is able to influence global macroeconomic conditions or to what extent do monetary policy actions from other central banks spill over internationally as well.

This paper analyzes one reason why the U.S. appears to have a large role in determining global macroeconomic outcomes: The vast majority of traded goods in the world are invoiced in U.S. Dollars (and Euros) and traded goods prices are sticky in their currency of invoicing in the short run. These two facts constitute the international price system described in Gopinath (2015), and they provide a natural channel for monetary policy transmission abroad.

I develop a static open economy New Keynesian model where prices of traded goods are fixed in their currency of invoicing. One country is labeled the United States, and its currency can be used by the rest of the world to invoice traded goods. Building upon earlier open economy New Keynesian models (Engel, 2011; Floden and Wilander, 2006), I introduce heterogeneity in the fraction of firms in each country that invoice their exports in domestic currency (producer currency pricing) and the fraction that invoice their exports in Dollars.

I study how heterogeneity in invoicing currencies affects how monetary policy shocks from the United States affects macroeconomic and financial outcomes in the rest of the world. In particular, I take the choice of invoicing currency as exogenous and I focus on the consequences of having Dollar invoiced trade. Whenever the U.S. engages in contractionary monetary policy, the nominal value of foreign currencies depreciate with respect to the Dollar, and the relative price of Dollar invoiced traded goods increases in those countries. The nominal price of Dollar invoiced traded goods remains fixed in Dollars. If the Dollar appreciates with respect to foreign currency, then the nominal price of the Dollar invoiced good increases in terms of foreign currency. Hence, foreign households import fewer and consume fewer Dollar invoiced traded goods. This decreases their overall level of consumption.

The strength the effect of U.S. monetary policy shocks on foreign consumption is directly proportional to the value of Dollar invoiced imports normalized by total consumption in the foreign country. This is the share of total consumption invoiced in Dollars. Countries with a larger share of Dollar invoiced consumption observe a larger increase in the relative cost of consuming traded goods, because the traded price increase affects a larger share of their consumption bundle. Hence, these countries will observe a larger decline in aggregate consumption.

Within the model, this heterogeneity in the spillover effects of monetary policy shocks on foreign consumption drives two main asset pricing predictions: In response to contractionary monetary policy shocks from the U.S., countries with a larger share of Dollar invoiced consumption observe their real exchange rate depreciate less and their real interest rates increase more. Countries with a larger share of Dollar invoiced consumption observe their marginal utility of total consumption increase more in response to a contractionary U.S. monetary policy shock. Countries with a larger share of Dollar invoiced consumption observe their real interest rates increase more, because their households want to consume more.

I also derive two predictions for macroeconomic responses to U.S. monetary policy shocks. First, countries with more Dollar invoiced imports decrease their consumption of traded goods, which reduces the country's total imports. Second, countries with a higher share of Dollar of invoiced exports will observe a larger decrease in production in response to a contractionary U.S. monetary policy shock. Firms that invoice their exports in Dollar will observe a decrease in demand for their products. Countries where a larger fraction of firms invoice their exports in Dollars will observe a larger fall in demand for its traded goods.

Finally, I show that after controlling for the shares of invoicing currencies, the magnitude of the spillover effects of U.S. monetary policy is the magnitude of the spillover effects from other central banks. The only reason that U.S. monetary policy shocks have larger spillover effects is because foreign countries use the Dollar to invoice their exports.

The theory section of the paper yields the following testable cross-sectional implications: Whenever the U.S. issues a contractionary monetary policy shocks, countries with a larger share of Dollar invoiced imports will observe (1) their nominal exchange rates depreciate less, (2) their nominal interest rates increase more and (3) their imports decrease more. Countries that invoice a larger share of their exports in Dollars observe (4) their production decrease more. Futhermore, I test the hypothesis (5) that the magnitude of monetary policy spillover effects from U.S. are no larger than than the magnitude of monetary policy spillover effects from other central banks, once I control for the shares of each country's imports that are invoiced in each currency.

In the empirical section of this paper I use data on monetary policy shocks from the Federal Reserve Bank, the European Central Bank, the Bank of Japan and the Bank of England to test the theoretical predictions of the model. In my first set of tests, I use high frequency monetary policy shock data from Nakamura and Steinsson (2015) to study the spillover effects from Federal

Reserve monetary policy shocks. Afterwards, I construct a consistent measure of monetary policy shocks for each central bank in my sample and test the whether Federal Reserve Bank spillover are uniquely different.

I construct a panel containing nominal exchange rates, nominal interest rates, imports and industrial production across 21 advanced economies [1]. Using these data, I characterize monetary policy spillover effects at both the high frequency level as well as the low frequency level. I measure changes in nominal exchange rates and nominal interest rates in a one day window around monetary policy announcements, because I am better able to identify the effects of monetary policy shocks at this higher frequency. Afterwards, I adopt methodology from Gertler and Karadi (2015) and test for the effects of monetary policy shocks on lower frequency macroeconomic outcomes.

Figure 1 provides motivation for the empirical exercises that I perform in this paper. In Figure 1, Using the sample of FRB monetary policy shocks from Nakamura and Steinsson (2015), and I run a panel regressions of changes in each country j's nominal exchange rates and nominal interest rates on country fixed effects, date fixed effects and an interaction term between the country fixed effect and the Federal Reserve Bank's monetary policy shock. I estimate the following relationship,

$$\Delta y_t^j = \alpha^j + \delta_t + \gamma^j m_{FRB,t} + \epsilon_t^j,$$

where Δy_t^j is the change in either country j's exchange rate or interest rate country j's on date t, α^j is a country level fixed effect, and δ_t is a date fixed effect.

The coefficients γ^j measure how much country j's dependent variable responds to monetary policy shocks from the U.S. relative to the average response on each date t. For example, when changes in nominal exchange rates are the dependent variable, a positive γ^j indicates that country j's depreciates more than the average country's nominal exchange rate in response to U.S. monetary policy shocks. I plot the coefficients γ^j against the value of each country's Dollar invoiced imports normalized by consumption.

The left-hand plot shows suggestive evidence of a negative association between a country's share of Dollar invoiced consumption and the change in a country's Dollar exchange rate in response to monetary policy shocks from the FRB. Since these exchange rates are stated as units

[1] I construct nominal interest rates for each country using the country's forward premia against the U.S. Dollar. Assuming covered interest rate parity holds, a country's forward premia against the U.S. Dollar is equal to the difference spread the foreign country's nominal interest rate and the U.S. nominal interest rate. I simply add the U.S. nominal interest rate from FRED back into my measurement of forward premia to recover the foreign country's nominal interest rateI construct nominal interest rates using forward premia to mitigate concerns that my results would be driven by the impact of monetary policy on country specific default risk.

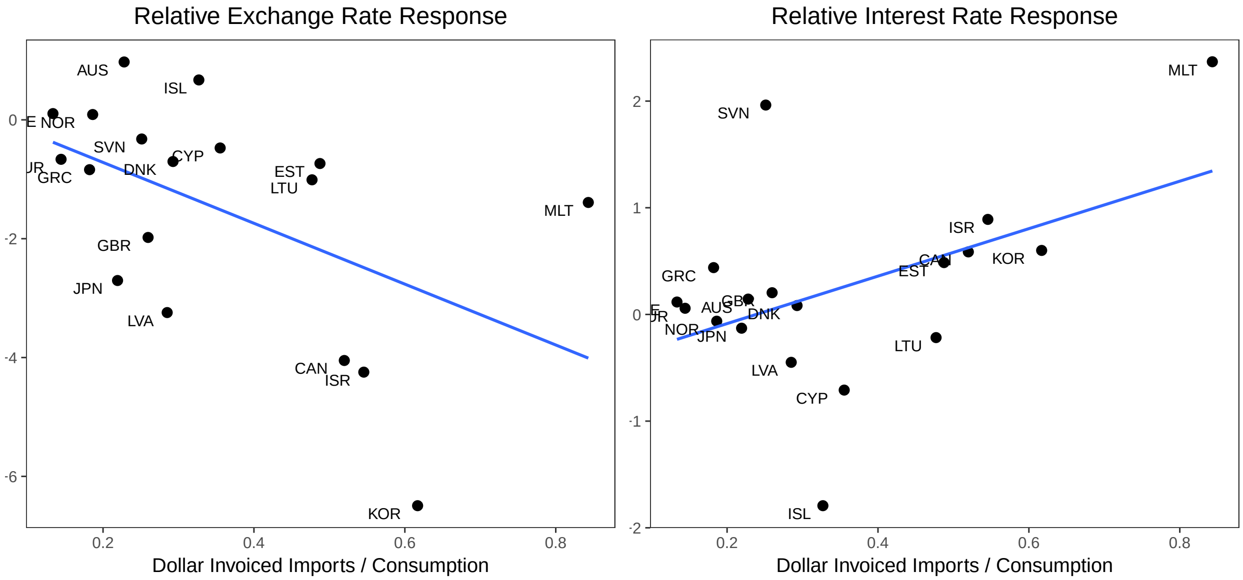

Figure 1: I run the following panel regression $\Delta y_t^j = \alpha^j + \delta_t + \gamma^j m_{FRB,t} + \epsilon_t^j$. Δy_t^j represents the change in country j's Dollar exchange rate or the change in country j's one-year nominal interest rate on date t, α^j is a country level fixed effect and δ_t is a date fixed effect. γ^j measures the average response of country j's dependent to monetary policy shocks from the FRB, $m_{FRB,t}$. In the left-hand panel, I plot the coefficients γ^j from the regression of changes in nominal exchange rates against the country's Dollar invoiced imports, normalized by consumption. $\beta = -5.121$, $R^2 = 0.25$. In the right-hand panel, I plot the coefficients γ^j from the regression of changes in nominal interest rates against the country's Dollar invoiced imports normalized by consumption. $\beta = 2.225$, $R^2 = 0.21$.

of foreign currency per Dollar, the left-hand plot shows that currencies of countries with more Dollar invoiced imports depreciate less in response to contractionary monetary policy shocks.

The right-hand plot in Figure 1 shows suggestive evidence that nominal interest rates in countries with a larger share of Dollar invoiced consumption tend to increase more in response to U.S. monetary policy shocks. I formally test for these relationships in the empirical section of the paper.

In the empirical section of the paper, I find strong support for each of the model's predictions. Countries with more Dollar invoiced imports observe their currencies depreciate less and their nominal interest rates increase more in response to contractionary monetary policy shocks from the Federal Reserve. If a country experiences a one standard deviation increase in the value of its Dollar invoiced imports normalized by consumption, then a one percent contractionary monetary policy shock will cause its nominal exchange rate to depreciate by 72 fewer basis points and will cause its nominal interest rate to increase by an additional 32 basis points.

These results are robust across a variety of specifications and cuts of the data. In particular, I show that a country's import invoicing currency significantly explains cross-sectional variation in monetary policy spillovers after controlling distances between countries, the share of trade one country conducts with another and measures of the price stickiness of a country's imports. These results provide direct evidence against alternative hypotheses that monetary spillover effects are larger simply because the U.S. is a more important trading partner for some countries.

I find support for the model's empirical predictions in lower frequency macroeconomic data as well. In response to contractionary monetary policy shocks from the U.S., countries with larger shares of Dollar invoiced imports experience a larger decrease in imports and countries with larger shares of Dollar invoiced exports experience a larger decrease in industrial production. Consistent with the literature, I find the strongest effects occur with a two to three year lag.

Finally, I provide evidence that currency invoicing is important for explaining variation in monetary policy spillovers across other central banks as well as the FRB. Across the central banks in my sample, monetary policy shocks significantly impact a country's nominal exchange rate and nominal interest rate more if that country invoices a larger fraction of its imports in the central bank's currency. After controlling for the share of imports invoiced in each currency, I can no longer reject the hypothesis that monetary policy shocks from the Federal Reserve create larger spillover effects than those from other central banks.

This result has strong practical implications. It suggests the primary reason central bankers should worry about the actions of the Federal Reserve is because the vast majority of global trade is conducted in Dollars. Monetary policy actions affect macroeconomic outcomes in the rest of the world by affecting the demand for traded goods. However, if the world suddenly switched into invoicing international goods in Euros, instead of Dollars, then monetary policy shocks from the ECB will have stronger effects on global outcomes.

This paper is closely related to the literature studying monetary policy in an open economy setting. However, this literature has largely focused on models where countries are symmetric (Clarida et al., 2002; Bacchetta and van Wincoop, 2005; Floden and Wilander, 2006; Engel, 2011) or where all countries are of measure zero and each country's monetary policy has no externalities on other countries (Gali and Monacelli, 2005, 2008; Farhi and Werning, 2013). This paper contributes to this literature by analyzing the macroeconomic and asset pricing consequences of one asymmetry across countries: heterogeneity in currency invoicing. Furthermore, much of the focus in this literature revolves models where countries invoice traded goods in domestic currency (producer currency pricing) or the currency of the country importing the traded goods (local currency pricing). A notable exception is Casas et al. (2017) where authors allow for "dominant currency invoicing" in a small open economy setting. I further this literature by analyzing the consequences of dominant currency invoicing in a setup where countries have positive mass.

This paper also relates to a number of empirical papers in the trade literature that analyze the economic consequences of exchange rate pass through. Contributions in this area include Gopinath and Rigobon (2008); Burstein and Gopinath (2014); Gopinath (2015) and Boz et al. (2017). Within this literature, my paper is most similar to Boz et al. (2017). Boz et al. (2017) also uses currency invoicing data from Gopinath (2015) to understand heterogeneity in exchange rate pass through. In general, this literature focuses on measuring long run consequences of exchange rate movements in macroeconomic variables. I contribute to this literature by providing new results that show how monetary policy shocks affect asset prices at higher frequencies. By focusing on high measures monetary policy shocks, I better identify causal relationships between monetary policy, exchange rates movements and changes in interest rates. My results for nominal exchange rates corroborate lower frequency evidence from Boz et al. (2017). I provide new results showing the impact of monetary policy spillovers to foreign nominal interest rates, import quantities and industrial production.

The empirical methodology in my paper borrows from the literature that uses high frequency movements in futures to identify monetary policy shocks (Kuttner, 2001; Gurkaynak et al., 2005; Gertler and Karadi, 2015). The methodology in my paper is most similar to that of Nakamura and Steinsson (2015). However, this literature primarily focuses on measuring monetary policy shocks from the Federal Reserve and estimating the reaction of a variety of domestic macroeconomic and domestic financial variables to the FRB's monetary policy actions. A notable exception is Rey (2014), which extends the methodology in Gertler and Karadi (2015) to measure the effect of FRB monetary policy shocks on macroeconomic variables in a sample of four foreign countres. My main contribution to this literature is to measure monetary policy shocks consistently across the set of large central banks that issue regularly scheduled monetary policy announcements and examine the effects over a large sample of advanced countries.

A separate literature looks at returns on asset prices on monetary policy announcement days (Savor and Wilson, 2013; Lucca and Moench, 2015; Brusa et al., 2015) This paper is most related to Brusa et al. (2015), in which the authors measure international stock market returns on scheduled monetary policy announcement days for four central banks: the Federal Reserve, the European Central Bank, the Bank of Japan and the Bank of England. Brusa et al. (2015) find that global investors demand a premium to bear risks associated with Federal Reserve decisions, but not for other major central banks. This paper extends this literature by studying monetary policy announcements from a larger sample of central banks and by showing that the magnitudes of monetary policy spillover effects do exist after controlling for the variation in currency invoicing across countries.

The rest of the paper is organized as follows: Section 2 presents the model. Section 3 characterizes the equilibrium and derives the asset pricing implications of having nominal rigidities in traded goods. Section 4 presents the data and empirical methodology. Section 5 presents empirical results and Section 6 concludes.

2 The Model

In this section, I develop a static open economy New Keynesian that captures key features of the distribution in currency invoicing. There exist three countries of equal size. I label these countries the United States, the Eurozone and Japan. Their currencies are the Dollar, the Euro and the Yen. Each country contains a unit mass of firms who produce a continuum of differentiated intermediate traded goods. These intermediate traded goods are traded internationally and consumed by households in all countries. The prices of intermediate traded goods are set prior to the realization of shocks in their currency of invoicing. This model builds upon the work of Engel (2011) by allowing heterogeneity in currency invoicing within countries. In each country, a fraction of firms invoice their exports in domestic currency while the remainder of firms invoice their exports in Dollars. In this sense, I exogenously designate the Dollar as the global currency for trade.

2.1 Households and Technology

There are two time periods, $t = 1, 2$. There exist three countries, each inhabited with a unit mass of households. Households have utility from consuming traded goods and non-traded goods and disutility from providing labor services. In each country, there also exists a unit mass of firms and each firm produces a unique intermediate traded good. Households supply labor to all firms within their own country in the production of intermediate traded goods and share in the profits of all sales of intermediate traded goods. Hence, all households in within a country are identical.

Each household in country n has following utility function,

$$U^n = \mathbb{E} \sum_{t=1,2} \beta^{t-1} \left\{ \frac{(C_t^n)^{1-\gamma}}{1-\gamma} - \frac{(N_t^n)^2}{2} \right\}. \tag{1}$$

N_t^n is the amount of labor supplied by each household in country n in period t and C_t^n is the period t aggregate consumption bundle consumed by a household in country n. The aggregate consumption bundle is given by

$$C_t^n = \left(C_{T,t}^n\right)^{\tau} \left(C_{N,t}^n\right)^{1-\tau}$$

$C_{N,t}^n$ represents the household's consumption of its country specific non-traded good and $C_{T,t}^n$ represents the country n household's consumption of a aggregate traded good comprised of traded goods from each individual country country,

$$C_{T,t}^n = \left(C_{T,US,t}^n\right)^{\frac{\tau}{3}} \left(C_{T,JP,t}^n\right)^{\frac{\tau}{3}} \left(C_{T,EU,t}^n\right)^{\frac{\tau}{3}}.$$

$C_{T,i,t}^n$ represents a final consumption bundle of intermediate traded goods produced by firms in country j and consumed in country n for $i \in \{US, JP, EU\}$. These final consumption bundles are a CES aggregate of differentiated intermediate traded goods,

$$C_{T,i,t}^n = \left[\int_0^1 \left(C_{T,i,j,t}^n\right)^{\varepsilon} dj\right]^{\frac{1}{\varepsilon}}, \tag{2}$$

j indexes firms in country i and $\varepsilon < 1$ determines the elasticity of substitution between the different varieties of country i's intermediate traded goods.

At the start of each period, each household in country n is endowed with one unit of the non-traded good, $Y_{N,t}^n = 1$.

2.2 Firms

Intermediate traded goods are produced at the start of each period by employing labor. In country n, firm j's output of its variety of intermediate traded good is

$$Y_{T,j,t}^n = A_t^n N_{j,t}^n$$

where $N_{j,t}^n$ is the quantity of labor demanded by firm j in country n and A_t^n is the aggregate productivity shock to the traded sector of country n.

These pricing assumptions capture key features of the international price system described in Gopinath (2015). Rather than having firms invoice their goods in the currency where a good is produced or where the good is purchased, I designate the Dollar as the global currency for international trade. Firms either invoice their exports in domestic currency or in Dollars.

Within each country, intermediate traded goods firms differ in their choice of invoicing currency. In country n, a fraction $X_\$^n$ of firms invoice their exports in Dollars. The remaining fraction $1 - X_\$^n$ of firms invoice their exports in domestic currency. Finally, domestic sales of intermediate traded goods are also invoiced in domestic currency.

Nominal prices in the first period are set prior to the realization of shocks and the nominal prices of goods are fixed in their currency of invoicing in the first period. As an example, consider a firm located in the U.S. that invoices it's exports in Dollars. Suppose this firm sets the nominal price of its exports as P Dollars. Then, regardless of any changes in the nominal exchange rate in the first period, households in Japan and the Eurozone pay P Dollars for this variety of intermediate traded good. If the Dollar depreciates relative to the Yen, then this good becomes relatively cheaper for Japanese households to consume.

I assume the law of one price holds for traded goods. The nominal price of any traded good in Yen is equal to the nominal price of the traded good in Dollars multiplied by the Yen - Dollar exchange rate,

$$\tilde{P}_{T,i,j,t}^{JP} = \tilde{E}_t^{JP,US} \tilde{P}_{T,i,j,t}^{US}. \tag{3}$$

$\tilde{P}_{T,i,j}^n$ is the nominal price of intermediate traded good j in units of country n currency. $\tilde{E}^{JP,US}$ is the Yen - Dollar nominal exchange rate given as units of Yen per Dollar.

I assume nominal prices adjust freely in the second period. Thus, monetary policy shocks in the model only affect real allocations in the first period, and they are interpreted as temporary shocks. The second period of the model exists solely for accounting purposes. It allows me to study the behavior of asset prices when they are exposed to monetary policy shocks that affect short term outcomes.

2.3 Financial Markets

Households trade a complete set of state contingent claims denominated in domestic currency. Since I do not introduce any frictions into financial markets, it does not matter which currency is used to denominate the state contingent claims.

Households receive wages for supplying labor in the production of intermediate traded goods and own an equal share of all intermediate traded goods firms located within their country. Letting variables with tilde's denote nominal prices, the country n household faces the following budget constraint

$$\mathbb{E}\left\{\sum_{t=1,2} Q_t^n \left[\tilde{P}_{N,t}^n C_{N,t}^n + \sum_{i\in\{US,JP,EU\}} \left(\int_0^1 \tilde{P}_{T,i,j,t}^n C_{T,i,j,t}^n dj\right)\right]\right\} = \tag{4}$$
$$\mathbb{E}\left\{\sum_{t=1,2} Q_t^n \left(\tilde{P}_{N,t}^n Y_{N,t}^n + \tilde{W}_t^n N_t^n + \tilde{\Gamma}_t^n\right)\right\} + \kappa^n.$$

$\tilde{W}_t^n$ is country n's nominal wage. $\tilde{\Gamma}_t^n$ is the household's share of nominal profits earned from owning country n intermediate traded goods firms. $\tilde{P}_{N,t}^n$ and $\tilde{P}_{T,i,j,t}^n$ are the nominal prices of the non-traded good and the jth variety of the intermediate traded good produced in country i. The n superscript above the prices denote that these prices are denominated in country n currency and the tildes denote that prices are nominal.

Q_t^n is the price (denoted in country n currency) of a state contingent claim that pays off a unit of country n currency.

I assume there exists a transfer, κ^n, which equalizes the marginal utility of initial wealth across households in different countries. This is the transfer that is required to decentralize the Social Planner's problem with unit Pareto weights, and it allows me to temporarily abstract from the wealth effects from introducing heterogeneity across countries.

2.4 Monetary Policy

Since prices of intermediate traded goods are fixed in the first period, central banks affect first period production through monetary policy. For simplicity, I assume that the central bank in each country picks the aggregate nominal price level in the economy. Since the final consumption bundle is a Cobb-Douglas aggregate of traded and non-traded goods, the nominal price level, $\tilde{P}_t^n$, in country n is

$$\tilde{P}_t^n = \frac{\left(\tilde{P}_{T,t}^n\right)^{\tau}\left(\tilde{P}_{N,t}^n\right)^{1-\tau}}{\tau^{\tau}(1-\tau)^{\tau-1}}.$$

$\tilde{P}_{T,t}^n$ is the appropriate nominal price index for the consumption of intermediate traded goods consumed in country n. The central bank of country n chooses $\tilde{P}_t^n$.

To develop some intuition for this specification of monetary policy, consider the following example: Suppose the nominal price of the traded consumption bundle, $\tilde{P}_{T,t}^n$ is fixed and the central bank wants to stimulate the economy. Then, the central bank achieves this policy goal by inflating the aggregate price level, $\tilde{P}_t^n$. Since the nominal price of the final traded good is fixed, the nominal price of the non-traded must rise. Hence, the central bank decreases the relative price of traded goods to non-traded goods, which encourages traded consumption and causes intermediate traded goods firms to increase production.

In this model, the nominal price of the final traded good is sticky but not fixed, because nominal exchange rate respond endogenously to monetary policy actions. However, the intuition for monetary policy is essentially the same. Central banks engage in expansionary monetary policy by increasing $\tilde{P}_t^n$. Intuitively, one can also think about an increase in the nominal price level as a currency devaluation. When $\tilde{P}_t^n$ rises, more units of country n currency are required to purchase a unit of final consumption. Naturally, as the value of a currency decreases, the relative cost of traded goods whose prices are fixed in that currency decreases as well and this stimulates production.

2.5 Solving the Model

This section describes first order conditions for the households' problem. All households within a country face the same optimization problem. I ignore the intermediate firm's pricing decision for now, because the firm's pricing decision does not have a first order impact on the spillover effects of U.S. monetary policy [2].

Households maximize utility (1) subject to their budget constraints (4). The first order conditions with respect to intermediate traded consumption of good j produced in country i are,

$$\frac{\tau}{3}\frac{C_t^n}{C_{T,i,t}^n}\left(\frac{C_{T,i,t}^n}{C_{T,i,j,t}^n}\right)^{1-\varepsilon} = \frac{\tilde{P}_{T,j,i,t}^n}{\tilde{P}_t^n}. \tag{5}$$

The first order condition with respect to non-traded consumption determines the price of the non-traded good

$$(1-\tau)\frac{C_t^n}{C_{N,t}^n} = \frac{\tilde{P}_{N,t}^n}{\tilde{P}_t^n} \tag{6}$$

Household labor supply is pinned down by the first order condition with respect to N_t^n,

$$C_t^\gamma N_t^n = \frac{\tilde{W}_t^n}{\tilde{P}_t^n}. \tag{7}$$

These first order conditions describe the demand side of the economy and hold in each period

[2] See Appendix A.1 for additional details for deriving the first order conditions as well as the solution to the firm's problem

regardless of the nominal rigidity in the supply side of the economy.

The market clearing condition for intermediate traded good j produced in country i is,

$$Y^i_{T,j,t} = A^i_t N^i_{j,t} = \sum_{n \in \{US,JP,EU\}} C^n_{T,i,j,t} \tag{8}$$

Households consume their endowment of non-traded goods,

$$C^n_{N,t} = Y^n_{N,t}. \tag{9}$$

I assume that each household splits its time proportionately across all domestic firms. This allows me to treat households within each country as a single representative household. The labor market clearing condition for each household in country n is,

$$N^n_t = \int_0^1 N^n_{j,t} dj = X^n_\$ N^n_{\$,t} + (1 - X^n_\$) N^n_{L,t}. \tag{10}$$

$N^n_{\$,t}$ denotes the labor demanded by a country n firm that invoices its exports in Dollars and $N^n_{L,t}$ denotes the labor demanded by a country n firm that invoices its exports in domestic currency. Since all firms in a country receive the same aggregate productivity shock, all firms that invoice in a particular currency will set the same prices, produce the same quantity of output and demand the same quantity of labor.

Finally, I need to relate the level of consumption across countries. I assume that an initial wealth transfer, κ^n, equates the marginal utility of initial wealth across countries. Hence, for all pairs of countries n and m,

$$\frac{C^n_t}{\tilde{P}^n_t} = \frac{C^m_t}{\tilde{E}^{n,m}_t \tilde{P}^m_t}. \tag{11}$$

$\tilde{E}^{n,m}$ is the nominal exchange rate given as units of country n currency per unit of country m currency.

An equilibrium in this economy is a set of consumption and labor supply allocations for each household, $\left\{C^n_{T,i,j,t}, C^n_{N,t}, N^n_t\right\}$; a set of intermediate output, labor demand and nominal prices for each intermediate firm, $\left\{Y^n_{T,i,j,t}, N_{j,t}, \tilde{P}^n_{T,i,j,t}\right\}$; a set of traded goods prices and non-traded goods prices, $\left\{\tilde{P}^n_{T,t}, \tilde{P}^n_{N,t}\right\}$; a set of nominal wages for each country and a nominal exchange rate, $\left\{\tilde{W}^n_t, \tilde{E}^{n,m}_t\right\}$; such that households maximize utility subject to their budget constraints and the resource constraints are satisfied.

3 Theory Results

The static model provides intuition for how heterogeneity in import currency invoicing and export currency invoicing influence monetary policy transmission. To study the model in closed form, I log-linearize the model around a deterministic solution. See Appendix A.2 for additional details. I focus on the first period, because I assumed the nominal rigidities only affect real allocations in the first period. Hence, in this section, I drop the time t subscript. All variables represent first period variables unless otherwise noted.

Monetary policy shocks from the home country affect the consumption of all Dollar invoiced traded goods in the rest of the world. Contractionary monetary policy increases the nominal value of the Dollar relative to other currencies. Equation (12) shows the effect of a U.S. monetary policy on the Dollar exchange rate with country n,

$$-\frac{\partial \tilde{e}^{n,US}}{\partial \tilde{p}^{US}} = \frac{(1+(\gamma-1)\tau)(1+(\gamma\tau/3)+(\gamma-1)\tau)}{\nu} - \frac{\gamma(1+\gamma-1)\tau}{\nu} M_{\$}^{n} \tag{12}$$

ν is a constant that captures the fraction of the world's exports that are invoiced in each country's currency, which I discuss below. $M_{\$}^{n}$ is the share of country n's aggregate consumption bundle that is invoiced in Dollars. For Japan, $M_{\$}^{JP} = \big(\tau(1+X_{\$}^{EU})/3\big)$. For the Eurozone, $M_{\$}^{EU} = \big(\tau(1+X_{\$}^{JP})/3\big)$.

I assume households are risk adverse enough such that $\gamma\left((1-X_{\$}^{n})/3\right) > 1$. Under these parameter restrictions,

$$\nu = \left(1+\tau\left(\gamma(1-(X_{\$}^{JP}/3)-1)\right)\right)\left(1+\tau\left(\gamma(1-(X_{\$}^{EU}/3)-1)\right)\right) > 0.$$

This restriction on the parameter space is a sufficient condition for $\nu > 0$, and it happens to be easily satisfied in a number of quantitative models. For example, the condition holds under any calibration where the $\gamma > 3$.

The effect of U.S. monetary policy on foreign interest rates can be divided into two components. The first component on the right hand side of equation (12) is the effect of a U.S. monetary policy shock that is common to all foreign interest rates. Since the nominal exchange rate is given as units of foreign currency per Dollar, this first component shows more units of foreign currency are needed to purchase a Dollar. Hence, all foreign currencies depreciate with respect to the Dollar. Intuitively, this first component describes an "average" effect of U.S. monetary policy shocks on Dollar exchange rates. Contractionary monetary policy makes each

Dollar relatively more valuable, because fewer Dollars are now needed to purchase a unit of the final consumption bundle in the U.S.

The second component on the right hand side is country specific and shows how heterogeneity in currency invoicing leads to heterogeneity in monetary policy spillovers. When the U.S. issues a contractionary monetary policy shock (and decreases $\tilde{p}^{US}$), the foreign currency to Dollar exchange rate decreases more for countries with a more Dollar invoiced imports as a share of total consumption ($M_{\$}^{n}$). Since the nominal exchange rate is given as units of foreign currency per Dollar, this implies countries with higher shares of Dollar invoiced consumption appreciate with respect to countries with lower shares of Dollar invoiced imports. I will return to this prediction later, as the intuition for this result will become more clear after I discuss real exchange rates.

Contractionary monetary policy from the U.S. increases the real cost of all Dollar invoiced intermediate traded goods. The nominal price of all Dollar invoiced intermediate traded goods are fixed in Dollars. When the foreign currency depreciates with respect to the Dollar, the nominal cost of Dollar invoiced intermediate traded goods in terms of the foreign currency increases as well. Each unit of foreign currency still purchases the same quantity of the foreign final consumption bundle. Hence, the real cost of Dollar invoiced intermediate traded goods increases.

This increase in the real price of Dollar invoiced intermediate traded goods increases the real price of the aggregate traded consumption bundle in foreign countries. Foreign households to decrease their consumption of traded goods as well as total consumption,

$$-\frac{\partial c^{n}}{\partial \tilde{p}^{US}} = -\frac{\gamma\tau^{2}(1+(\gamma-1)\tau)\left(1+(X_{\$}^{JP}+X_{\$}^{EU}-X_{\$}^{JP}X_{\$}^{EU})/3\right)}{3(1-\tau)\nu} - \frac{(1+(\gamma-1)\tau)}{\nu}M_{\$}^{n} \quad (13)$$

Equation (13) shows that contractionary monetary policy from the U.S. decreases aggregate consumption abroad. However, countries with a larger share of Dollar invoiced consumption will see their consumption decrease more. Households that consume more Dollar invoiced intermediate traded goods will observe a price increase over a larger share of their aggregate consumption bundle. Hence, their consumption falls more. Given equation (13), I derive two immediate predictions for the effect of U.S. contractionary monetary policy on asset prices.

Prediction 1. *A contractionary monetary policy shock from the U.S. causes foreign currencies to depreciate in real value against the U.S. Dollar. Countries with more Dollar invoiced imports as a share of total consumption depreciate less than countries with fewer Dollar invoiced imports* *as a share of total consumption.*

$$-\frac{\partial e^{n,US}}{\partial \tilde{p}^{US}} = -\frac{\gamma\tau\left(1-\tau+(1+(\gamma-1)\tau)(X_{\$}^{JP}+X_{\$}^{EU})+\gamma\tau\left(1-(X_{\$}^{JP}X_{\$}^{EU}/3)\right)\right)}{\nu} + \frac{\gamma\tau(1+(\gamma-1)\tau)}{\nu}M_{\$}^{n} \tag{14}$$

The real exchange rate between two countries is just the ratio of their marginal utilities of total consumption. Equation (13) shows contractionary monetary policy shocks from the U.S. decreases aggregate consumption in foreign countries, which increases the marginal utility of consumption. However, countries with a larger share of Dollar invoiced consumption will decrease their aggregate consumption more. Hence, their marginal utility of consumption will increase relative to countries with a smaller share of Dollar invoiced consumption. Hence, countries with larger share of Dollar invoiced consumption appreciate relative to countries with smaller shares of Dollar invoiced consumption.

The first component of (14) shows that a contractionary monetary policy shock from the U.S. causes foreign currencies to depreciate against the Dollar. However, countries with a higher share of Dollar invoiced consumption depreciates less.

Prediction 2. *A contractionary monetary policy shock from the U.S. increases foreign real interest rates. Countries with more Dollar invoiced imports as a share of total consumption observe larger increases in real interest rates than countries with fewer Dollar invoiced imports as a share of total consumption.*

Real interest rates, R^n, in each country n are pinned down by consumption Euler equation for households in each country,

$$\tilde{R}^n = \frac{1}{\beta}\mathbb{E}\left[\frac{(C_1^n)^{-\gamma}}{(C_2^n)^{-\gamma}}\right]. \tag{15}$$

Monetary policy from the U.S. affects foreign real interest rates by changing households' marginal utility of consumption in the first period. Contractionary monetary policy in the U.S. decreases foreign consumption and makes foreign households feel poorer today relative to the future. This increases foreign real interest rates.

Real interest rates in countries a higher share of Dollar invoiced consumption increase more. Equation (13) shows consumption decreases more for households with a higher share of Dollar invoiced consumption. Hence, their marginal utility of consumption in the first period increases more, which increases the real interest rate in their country.

Up until now, I have primarily discussed the asset pricing implications of the model. However, the model is also useful for characterizing macroeconomic spillover effects from U.S. monetary policy. Heterogeneity in currency invoicing is essential for characterizing variation in the magnitude of these spillover effects across countries.

Prediction 3. *A contractionary monetary policy shock from the U.S. decreases foreign imports. Countries with more Dollar invoiced imports as a share of total consumption observe larger decreases in their imports than countries with fewer Dollar invoiced imports as a share of total consumption.*

$$-\frac{\partial\,(imports)^n}{\partial \tilde{p}^{US}} = -\frac{\gamma(1-(\tau/3))\tau(1+(\gamma-1)\tau)\left(1+(X_\$^{JP}+X_\$^{EU}-X_\$^{JP}X_\$^{EU})/3\right)}{2(1-\tau)\nu} - \frac{3(1-(\tau/3)(1+(\gamma-1)\tau))}{2\nu}\left(\frac{M_\$^n}{\tau}\right) \tag{16}$$

Prediction 3 is a direct result of the fact that U.S. contractionary policy increases the real price of Dollar invoiced intermediate traded goods. A country's imports is the sum of its consumption of intermediate traded goods produced in another country. Country n's imports are given by

$$(imports)^n = \sum_{m\neq n}\left(X_\$^m c_{T,m,\$}^n + (1-X_\$^m)c_{T,m,L}^n\right)$$

where m indexes countries in the world that are not country n. Households in Japan and the Eurozone shift away from consuming Dollar invoiced intermediate traded goods, which are all imports. Countries with larger shares of Dollar invoiced imports decrease their consumption of imported intermediate traded goods more, because a larger share of the intermediate traded goods become more expensive to consume.

Prediction 4. *A contractionary monetary policy shock from the U.S. decreases foreign production. Countries with a larger share of Dollar invoiced exports decrease production more than countries a smaller share of Dollar invoiced exports.*

Prediction 4 provides a production side counterpart to the previous results: Firms decrease their production of Dollar invoiced intermediate traded goods, because demand for these goods decreases. Aggregate output in the traded sector of country n is the weighted sum of its production invoiced in Dollars and its production invoiced in domestic currency,

$$y_T^n = X_\$^n y_{T,n,\$} + (1 - X_\$^n)\, y_{T,n,L}.$$

The effect of a contractionary U.S. policy shock on aggregate production in the traded sector of foreign country n is,

$$-\frac{\partial y_T^n}{\partial \tilde{p}^{US}} = -\delta_y - \frac{(2 + (\gamma - 2)\tau)(1 + (\gamma - 1)\tau)}{3\nu} X_\$^n. \tag{17}$$

δ_y is a positive constant relegated in Appendix A.3.

There are two important features of equation (17): First, given a contractionary U.S. monetary policy shock, the model predicts foreign aggregate production decreases in proportion to the country's share of Dollar invoiced exports. Unlike previous predictions, heterogeneity in the effect of U.S. monetary policy production in country n is characterized by what fraction of country n's output is exported in Dollars. Each firm that invoices its exports in Dollars observes a drop in demand for its intermediate traded good, and decreases its output. Hence, the aggregate effect should depend on the fraction of each country's firms that invoices in Dollars.

The second important implication of equation (17) is that contractionary policy from the U.S. creates a contraction in all countries in the world. Moreover, countries where firms have chosen to invoice their exports in Dollars will experience a stronger contraction.

3.1 Policy Spillovers from Other Central Banks

The model makes a strong prediction for the magnitude of monetary policy spillovers from any central bank in the world.

Prediction 5. *Controlling for the share of each country's consumption that is invoiced in each currency, the magnitude of spillover effects from Japanese monetary policy and the Eurozone monetary policy are the same as the magnitude of the spillover effects from U.S monetary policy.*

Even though the model is set up such that U.S. Dollar is the only currency that can be used by all countries to invoice their trade

The magnitude of monetary policy spillover effects only differ according to the share of international trade that is invoiced in each currency. Equation (18) shows the effect of a Japanese contractionary monetary policy shock on Yen exchange rates,

$$-\frac{\partial e^{n,JP}}{\partial \tilde{p}^{JP}} = -\frac{\gamma\tau\left(1-\tau+\left(1-\left(X_{\$}^{JP}X_{\$}^{EU}/3\right)\right)\right)}{\nu} + \frac{\gamma\tau(1+(\gamma-1)\tau)}{\nu}M_{¥}^{n}. \tag{18}$$

Comparing equation (14) and (18), it is clear that, on average, Yen exchange rates depreciate less in response to Japanese monetary policy shocks. However, the second term in equation (18) shows that variation in monetary policy spillover effects from Japan depends only on the share of each country Yen invoiced consumption. This pattern holds for other forms of monetary policy spillovers as well, which I derive in Appendix A.4.

3.2 Monetary Policy Independence

The predictions of the model have an important implication for monetary policy independence: Countries that invoice their trade in foreign currency incur greater costs when implementing monetary policy. Up until this point, I have not talked about what central banks in this world actually want to do. In this section, I propose that the Japanese central bank wants to use its monetary policy to recover its level of consumption in a flexible price economy. Nominal price rigidities are inefficient, and a common benchmark in the New Keynesian literature is to analyze what policies a country can implement to recover the efficient allocation from the flexible price world.

Proposition 1. *Suppose the policy goal of the Japanese central bank is to choose $\tilde{P}^{JP}$, conditional on the actions of the other central banks and the realization of productivity shocks, to recover its domestic consumption allocation in a flexible price economy. Then, the magnitude of the Japanese central bank's response to U.S. monetary policy is increasing in share of Japan's Dollar invoiced exports ($X_{\$}^{JP}$).*

Proof. See Appendix A.5 □

Proposition1 shows that as the share of firms in the world that invoice their exports in Yen decreases, Japan needs to increase the magnitude its monetary policy response to counter U.S. monetary policy shocks. As the share of Japanese firms that invoice their exports in Dollars decreases, the Japanese central bank has less influence over production domestically. Each increase in the Japanese nominal price level influences a smaller fraction of firms. In order to recover a certain level of consumption, the Japanese central bank needs the firms it does influence to increase production more.

Naturally, there exist similar propositions for the case where the Japnese central bank wants to maintain a certain level of production. Predicitons 1 through 5 show that the influence a country has in determining global macroeconomic conditions is proportional to the share of traded goods that are invoiced in each currency. Countries that invoice their imports in foreign currency are more affected by foreign monetary policy shocks, and central banks of countries that invoice their exports in foreign currency have less power to influence domestic macroeconomic conditions.

4 Data

The model describes how domestic monetary policy shocks affect exchange rates, consumption, production and interest rates internationally. In this section, I test predictions 1 - 5 of the model using monetary policy shock data for the United States as well as three other central banks. These additional central banks are the European Central Bank, the Bank of England and the Bank of Japan.

Currency invoicing data from Gopinath (2015) show that countries vary greatly in the fraction of their imports and exports that are denominated in each currency. However, over 80% of traded goods in the world are invoiced in Dollars and Euros. I use these data to study cross-sectional heterogeneity in monetary policy spillovers.

In the following sections, I describe four groups of data: (1) My measures of monetary policy shocks for the Federal Reserve as well as other central banks, (2) The currency invoicing data provided Gopinath (2015), (3) my measurements of outcome variables and (4) the data I use to test alternative hypotheses.

4.1 Monetary Policy Shock Data

For the bulk of my analysis, I use measurements of Federal Reserve monetary policy shocks from Nakamura and Steinsson (2015). These data are available from the authors' websites and contain two measures Federal Reserve monetary policy shocks. I use the data containing changes in federal funds futures in a 30 minute window around FOMC announcements. Federal funds futures capture market expectations about the federal funds rate and are commonly used in the analysis of effects of monetary policy shocks (Gurkaynak et al., 2005; Gertler and Karadi, 2015; Gorodnichenko and Weber, 2016). The data are available from February 1995 through March 2014.

High frequency measurements of monetary policy shocks provide the cleanest measurement of unexpected FRB monetary policy. The identifying assumption is that macroeconomic news and investor expectations that can drive movements in federal funds futures are already incorporated into prices thirty minutes prior to the FOMC meeting. Any changes in federal funds futures in a thirty minute window around FOMC meetings ideally only capture the unexpected news from the FOMC meeting itself.

Unfortunately, doesn't exist a consistent measure of monetary policy shocks across the other large central banks. In order to test for monetary policy spillovers from the other central banks in my sample, I construct a new data set of monetary policy shocks using three month interest rate futures denominated in each central bank's currency. Table 1 summarizes the central banks in my full sample as well as their corresponding interest rate futures.

Table 1: Sample of Central Banks

Central Bank	Bank Code	3 Month Interest Rate Future
Federal Reserve Bank	FRB	Eurodollar
European Central Bank	ECB	Euribor
Bank of Japan	BOJ	Tibor
Bank of England	BOE	Short Stirling

I download daily data for each interest rate future from Bloomberg. My measure of monetary policy shocks are daily changes in each interest rate future on days of monetary policy announcements from the corresponding central bank. I download dates for the central banks' monetary policy announcements from the central banks' official websites.

By choosing interest rate futures with the same maturity, I define a consistent measure of monetary policy shocks across central banks: A monetary policy shock is an unexpected policy action that moves the expected three month interest rate denominated in domestic currency.

The major concern regarding measures of monetary policy shocks is that non-monetary policy related news might be captured by the monetary policy measure. Unfortunately, I do not have access to tick-level data for each of the interest rate futures. Hence, my measures of monetary policy shocks ought to contain additional noise. Nakamura and Steinsson (2015) shows that daily changes in federal funds futures are highly correlated with changes in federal funds futures in a 30-minute window around FOMC meetings. However, using daily measurements of federal funds futures does introduce noise into the analysis. Hence, I conduct my analysis in two stages. First, I use the higher frequency data from Nakamura and Steinsson (2015) for the U.S. to establish the spillovers from monetary policy in the U.S. only. Afterwards I perform the same tests using my noisier measures of monetary policy shocks for the larger sample of central banks to provide evidence that these spillover effects seem to be more general.

4.2 Currency Invoicing Data

The data come from Gopinath (2015) are available from the author's website and they describe the share of each country's imports and exports that are invoiced in various currencies. The data are reported at the country - currency level and averaged over the years 1999 to 2014. Gopinath (2015) notes that these invoicing shares are fairly stable over time.

My main empirical challenge in using the currency invoicing data is constructing measures of currency invoicing for the Eurozone. I only observe nominal interest rates and nominal exchange rates for the Eurozone as a whole, but the currency invoicing data are presented at the country level. I use UN Comtrade data to estimate the share of intra-Eurozone trade conducted by each Eurozone member. I assume all trade conducted between Eurozone countries are invoiced in Euros in order to estimate invoicing currency shares for the Eurozone's imports and exports [3].

4.3 Exchange Rates, Interest Rates, Imports and Production Data

I measure changes in nominal exchange rates and nominal interest rates on days of monetary policy announcement days using data from Thomson Reuters Datastream. I gather all available Dollar based forward contracts and the corresponding spot exchange rate data from Datastream, and I construct nominal interest rates for each country using covered interest rate parity.

Given covered interest rate parity holds, the nominal interest rates of the United States and a foreign country, n, are related as follows,

$$\left(1+\tilde{r}_{t,t+n}^{USA}\right)^n = \left(1+\tilde{r}_{t,t+n}^{n}\right)\frac{F_{t,t+n}^{USA,n}}{E_t^{USA,n}}. \tag{19}$$

$\tilde{r}_{t,t+n}^{f}$ is the (annualized) nominal interest rate in country f of maturity n years. $F_{t,t+n}^{USA,f}$ is a forward exchange rate contract of maturity n years in units of Dollars per unit of foreign currency, and $\tilde{E}_t^{USA,f}$ is the spot exchange rate in units of Dollars per unit of foreign currency. I use U.S. government bond yields from FRED as my time series of U.S. nominal interest rates.

I use forward data to construct nominal interest rates to address concerns that nominal interest rates derived from bond yields reflect differences in country specific risk premia. Changes

[3] See Appendix C.2 for additional details.

in nominal bond yields may reflect the response of country specific risk premia to monetary policy shocks. These effects are outside the scope of the theoretical model presented in section 2.

For each monetary policy announcement date t, I measure the change in the nominal exchange rate and nominal interest rate between the close on date $t-1$ and the close on date $t+1$ as my dependent variables.

I gather monthly indices on countries' imports and industrial production from the OECD. For the exact series labels, see Appendix C.4. The primary difference between the OECD data and the financial data is that I observe imports and industrial production for each country within the Eurozone. Hence, I am able to use variation in invoicing shares within Eurozone countries when using these data.

4.4 Additional Data

I use data from Shambaugh (2004) to address the concerns regarding exchange rate pegs. The Shambaugh (2004) data indicates which pairs of currencies are pegged in any given month, and I drop observations where countries engage in a hard or soft peg with the currency of the central bank issuing the monetary policy announcement. See Appendix C.6 for additional details.

I use data from Mayer and Zignago (2011) to control for geographical distance between countries and central banks. I use Germany as the geographical location of the European Central Bank.

I use bilateral trade data from the OECD to control for alternate hypotheses that a country simply responds more to U.S. monetary policy shocks because the country conducts more trade with the U.S. Using the data, I generate the share of each country's imports that originate from each monetary union in my sample.

I combine data from Rauch (1999) and UN Comtrade data to estimate the degree of price stickiness of imports. Rauch (1999) categorizes traded goods into three groups based on how prices of these products are be set: (1) goods traded on an organized exchange, (2) reference prices and (3) differentiated products. Gopinath and Rigobon (2008) show nominal prices of differentiated products are most sticky, while goods traded on an organized exchange are least sticky. UN Comtrade divides each country's imports into four-digit SITC codes, which I use to merge with the Rauch (1999) data to estimate the fraction of each country's imports that are differentiated products. See Appendix C.9 for additional details.

5 Empirical Strategy and Results

For the bulk of the empirical analysis, I use the monetary policy shocks from Nakamura and Steinsson (2015), because the authors have access to tick level data and are better able to identify monetary policy shocks. I first test the predictions of the model with regards to exchange rates and interest rates. I observe changes in exchange rates and interest rates at the daily frequency. Hence, I can more easily identify the impact of the high frequency measures of monetary policy shocks on these outcome variables. Afterwards, I follow procedures in Gertler and Karadi (2015) to translate daily measures of monetary policy into monthly measures, and I test the model predictions with regards to imports and industrial production.

As a final step, I use my data set to test the empirical prediction that U.S. monetary policy spillovers are no larger than those from other central banks after controlling for invoicing currencies.

5.1 Sample Selection

Table (2) lists the countries in my sample. I focus on a sample of 20 advanced economies for which I am able to construct nominal interest rate data using forward contracts, and for which I observe currency invoicing data. Each country in the sample is designated as an advanced economy by the IMF's 2015 Economic Outlook.

My sample consists of dates monetary policy announcements between January 1999 and December 2014. Following Nakamura and Steinsson (2015), I drop observations between June 30, 2007 and July 01, 2008. The concern that the monetary policy shock data pick up non-monetary policy related news is especially problematic during the Great Recession. Throughout this period, federal governments often proposed new fiscal policies on or around monetary policy announcement days. When conducting tests using the full sample of four central banks, I also drop observations of days when more than once central bank issued a monetary policy announcement.

Table 3 provides summary statistics for the variables in my data set.

5.2 Empirical Strategy: High Frequency Outcomes

To investigate the effect of monetary policy shocks on nominal interest rates and nominal exchange rates, equation (14) from the model suggests I run regressions of the following form,

$$\Delta y_t^n = \delta_t + \beta_M M_k^n + \gamma_M \left(\Delta i_{k,t} \times M_k^n\right) + \epsilon_t^n. \tag{20}$$

Δy_t^n is the change in country n's outcome variable on date t. This is either the country's nominal exchange rate or the country's nominal interest rate. δ_t is a time t fixed effect. $\Delta i_{k,t}$ is the monetary policy shock from central bank k on date t. M_k^n is the value of country n's imports invoiced in currency k normalized by consumption. To construct an empirical counterpart to M_k^n, I divide each country's annual imports by annual consumption, and calculate the mean from 1999 to 2014. I take the product between each country's average import share of consumption and each country's share of imports invoiced in Dollars, Euros, Yen and Pounds from Gopinath (2015).

The coefficient of interest in equation (20) is γ_M. The time fixed effect δ_t captures the average spillover effect of the monetary policy shock on date t. γ_M captures how heterogeneity in currency invoicing in imports affects the magnitude of the spillover effect. A positive and significant γ_M coefficient provides suggests that the outcome variable Δy_t^n increases more in countries with more currency k invoiced imports as a share of consumption, whenever central bank k issues a contractionary monetary policy shock.

5.3 Empirical Results: High Frequency Outcomes with U.S. Shocks

Table 4 presents regression results from estimating equation (20) with changes in nominal exchange rates at the outcome variable. Column (1) provides a benchmark estimate. Since exchange rate are given as units of foreign currency per Dollar, a negative coefficient means the foreign currency appreciates. A point estimate of -4.841 means that if a country experiences a one standard deviation increase in $M_{\$}^n$, then its currency to depreciates by 72 fewer basis in response to a one percent contractionary monetary policy shock from the FRB [4]. This effect is economically significant as well as statistically significant.

Columns (2) through (3) in table 4 test the benchmark result against alternative explanations for spillover effects. For country n, distance is the population weighted distance between country n and the U.S and import share is the value of country n's imports that originate from the

[4] Across all countries in my sample, the standard deviation of $M_{\$}^n$ is 0.149.

U.S normalized by consumption. Columns (2) and (3) suggest that my benchmark results for U.S. monetary policy spillovers to exchange rates cannot be explained distance or the share of a country's imports with the U.S. alone.

Columns (4) and (5) shows that once I control for price stickiness of each country's imports, the coefficient on the interaction between U.S. monetary policy shocks and $M_{\$}^{n}$ is no longer statistically significant. In particular, the standard errors increase dramatically, and I lose the statistical power to explain variation in the impact of U.S. monetary policy shocks reactions on Dollar nominal exchange rates.

Table 5 presents regression results from estimating equation (20) with changes in one year nominal interest rates at the outcome variable. Column (1) provides the benchmark result. A point estimate of 2.118 means that if a country experiences a one standard deviation increase in $M_{\$}^{n}$, then its nominal interest rate will increase by an additional 32 basis points in response to a one percent contractionary monetary policy shock from the FRB. Again, this effect is economically as well as statistically significant. Furthermore, columns (2) through (3) show that this benchmark result cannot be explained by distance or the share of a country's imports with the U.S. alone.

The results in columns (4) and (5) in table 5 further support the model's predictions. Columns (4) shows that variation in the share of each country's imports that are differentiated goods does not explain the benchmark result alone. However, when I include the triple interaction term between $\Delta i_{US,t}$, $M_{\$}^{n}$ and the share of differentiated imports, this triple interaction terms absorbs all the explanatory power. The model requires that prices of traded goods are sticky, and prices of differentiated products are sticky. The prices of traded goods in countries with more differentiated products as a fraction of imports should be stickier. Hence, monetary policy shocks from the U.S. should affect these countries more.

Recent papers suggest that deviations from covered interest rate parity have remained large after the Great Recession (Du et al., 2016). Since my construction of nominal interest rates relies on covered interest rate parity, these deviations from CIP may add noise to my results. Table 6 reproduces the results in Table 4 using observations of monetary policy shocks prior to the height of the Great Recession (July, 2008). Table 7 reproduces the results in Table 5 using observations of monetary policy shocks prior to the height of the Great Recession. The coefficient estimates in Tables 6 and 7 are quantitatively and qualitatively similar to the results when using the full sample of monetary policy shocks.

Taken together, the regression results from this section provide strong empirical evidence that variation in import currency invoicing is important for explaining monetary policy spillovers from the Federal Reserve.

5.4 Empirical Strategy: Low Frequency Outcomes

I follow the procedure in Gertler and Karadi (2015) to translate the daily U.S. monetary policy shock measures into monthly measures in order to estimate the effect of U.S. monetary policy shocks on lower frequency macroeconomic outcomes. See Appendix C.1 for a detailed description of the procedure. In the end, I obtain a series of average monthly monetary policy shocks from the Federal Reserve.

To investigate the effect of monetary policy shocks on imports, equation (16) from the model suggests I run regressions of the following form,

$$\Delta y^n_{t+\tau} = \alpha^n + \delta_t + \beta_M M^n_k + \gamma_{M,-1}\left(\Delta i_{k,t-1} \times M^n_k\right) + \sum_{l=2}^{12} \gamma_{M,-l}\left(\Delta i_{k,t-l} \times M^n_k\right) + \epsilon^n_t. \tag{21}$$

Δy^n_t is the (log) change in country n's imports from month t to month $t+\tau$. α^n is a country fixed effects and δ_t is a time t fixed effect. $\Delta i_{k,t-l}$ is the monetary policy shock from central bank k in month $t-l$.

I include lags of the monthly monetary policy shock variable, because each months' monetary policy shock is essentially an average of the daily monetary policy shocks over the previous 30 days. Hence, monetary policy shocks from consecutive months are correlated by construction. I control for 12 lags of monthly monetary policy shocks following Gertler and Karadi (2015).

The coefficient of interest in equation (21) is $\gamma_{M,-1}$. $\gamma_{M,-1}$ captures how heterogeneity in currency invoicing in imports affects the magnitude of the spillover effect. A negative and significant $\gamma_{M,-1}$ provides evidence that imports decrease more in countries with more currency k invoiced imports as a share of consumption, whenever central bank k issues a contractionary monetary policy shock.

To investigate the effect of monetary policy shocks on industrial production, equation (17) from the model suggests I run regressions of the following form,

$$\Delta y^n_{t+\tau} = \alpha^n + \delta_t + \beta_X X^n_k + \gamma_{X,-1}\left(\Delta i_{k,t-1} \times X^n_k\right) + \sum_{l=2}^{12} \gamma_{X,-l}\left(\Delta i_{k,t-l} \times X^n_k\right) + \epsilon^n_t. \tag{22}$$

Δy^n_t is the (log) change in country n's industrial production from month t to month $t+\tau$.

Unlike equations (20) and (21), I interact the monetary policy shock with each country's share of Dollar invoiced exports.

The coefficient of interest in equation (22) is $\gamma_{X,-1}$. $\gamma_{X,-1}$ captures how heterogeneity in currency invoicing in exports affects the magnitude of the spillover effect. A negative and significant $\gamma_{X,-1}$ provides evidence that industrial production decreases more in countries with a larger share of currency k invoiced exports, whenever central bank k issues a contractionary monetary policy shock.

5.5 Empirical Results: Low Frequency Outcomes with U.S. Shocks

Table (8) shows regression results for equation (21) for horizons of 24 months, 30 months and 36 months. A point estimate of -0.667 at 30 months means: A country that experiences a one standard deviation increase in the share of its Dollar invoiced imports observes its imports decrease by an additional 15 basis points in response to a one percent contractionary U.S. monetary policy shock. Table (9) shows regression results for equation (22) for horizons of 24 months, 30 months and 36 months. A point estimate of -0.375 at 30 months means: A country that experiences a one standard deviation increase in the share of its Dollar invoiced exports observes its imports decrease by an additional 8 basis points in response to a one percent contractionary U.S. monetary policy shock.

I find empirical evidence supporting Predictions 3 and 4. These effects are economically significant. These point estimates capture variation in monetary policy spillover effects that affect a country's total imports and total industrial production. Furthermore, the timing of these effects are consistent with Gertler and Karadi (2015), which also finds the strongest effects of monetary policy shocks between two to three years.

5.6 Empirical Results: Multiple Central Banks

Are the empirical results being driven by U.S. monetary policy shocks alone? I generate a sample of monetary policy shocks from four central banks: the Federal Reserve Bank of the United States, the European Central Bank, the Bank of Japan and the Bank of England. For each central bank, I measure monetary policy shocks as changes in their three month interest rate futures on monetary policy announcement days. Finally, I toss out observations on days where more than one central bank issued a monetary policy announcement.

Table 10 presents regression results from estimating equation (20) using changes in nominal exchange rates and changes in nominal interest rates as the dependent variables. Columns (1) and (3) show that import currency invoicing is significant for explaining variation in monetary policy spillovers to nominal rates and interest rates across my sample of central banks. When the ECB issues a contractionary monetary policy shock, countries that invoice a larger share of their consumption in Euros see their Euro exchange rates depreciate less and their nominal interest rates increase more. The same is true for the Bank of England or the Bank of Japan.

Columns (2) and (4) in Table 10 provide a direct test of whether monetary policy spillovers from the U.S. are larger than those from other central banks. I do not find evidence to support this claim. Controlling for the share of trade invoiced in each currency, I cannot reject the null hypothesis that the magnitude of monetary policy spillovers from the U.S. is the same as the magnitude of monetary policy spillover effects from the other central banks in my sample. The coefficients on the triple interaction terms in these regressions are not statistically significant and the magnitude of the point estimates are smaller. These results are consistent with Prediction 5 and the results from the previous sections.

6 Conclusion

This paper analyzed the implications of foreign currency invoicing on monetary policy transmission. I present a model of foreign currency invoicing that captures two main features of the international price system: (1) The vast majority of imports and exports in the world are invoiced in Dollars or Euros, and (2) Goods prices tend to be sticky in their currency of invoicing in the short run. I show that these two features help characterize cross-sectional heterogeneity in international monetary policy spillovers. Countries that have a larger share of Dollar invoiced imports are impacted more by monetary policy shocks from the FRB. Because of this, countries that invoice a larger share of their exports in foreign currency incur greater costs to implement monetary policy.

The empirical part of the paper provides support for the theoretical predictions of the model. I show that heterogeneity in the import currency invoicing help explain the heterogeneity in monetary policy transmission to foreign nominal exchange rate, interest rates, imports and industrial production across a sample of advanced economics and central banks.

References

Bacchetta, P. and E. van Wincoop (2005). A theory of the currency denomination of international trade. *Journal of International Economics 67*(2), 295–319.

Boz, E., G. Gopinath, and M. Plagborg-Moller (2017). Global trade and the dollar. Technical report.

Brusa, F., P. Savor, and M. Wilson (2015, November). One central bank to rule them all. Technical report, Oxford University. mimeo.

Burstein, A. and G. Gopinath (2014). International prices and exchange rates. In G. Gopinath, E. Helpman, and K. Rogoff (Eds.), *Handbook of International Economics*, Volume 4, pp. 391–451. Elsevier.

Casas, C., F. J. Diez, G. Gopinath, and P.-O. Gourinchas (2017). Dominant currency pricing. Technical report.

Clarida, R., J. Gali, and M. Gertler (2002). A simple framework for international monetary policy analysis. *Journal of Monetary Economics 49*, 879–904.

Du, W., A. Tepper, and A. Verdelhan (2016, December). Deviations from covered interest rate parity. Technical report, Federal Reserve Board.

Engel, C. (2011, October). Currency misalignments and optimal monetary policy: A reexamination. *American Economic Review 101*, 2796–2822.

Farhi, E. and I. Werning (2013, October). Dilemma not trilemma? capital controls and exchange rates with volatile capital flows. Technical report, Massachusetts Institute of Technology. mimeo.

Floden, M. and F. Wilander (2006). State dependent pricing, invoicing currency, and exchange rate pass-through. *Journal of International Economics* (70), 178–196.

Gali, J. and T. Monacelli (2005). Monetary policy and exchange rate volatility in a small open economy. *Review of Economic Studies 72*, 707–734.

Gali, J. and T. Monacelli (2008). Optimal monetary and fiscal policy in a currency union. *Journal of International Economics 76*, 116–132.

Gertler, M. and P. Karadi (2015, January). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics 7*(1), 44–76.

Gopinath, G. (2015, November). The international price system. Technical report, Harvard University. mimeo.

Gopinath, G. and R. Rigobon (2008). Sticky borders. *Quarterly Journal of Economics 123*(2), 531–575.

Gorodnichenko, Y. and M. Weber (2016). Are sticky prices costly? evidence from the stock market. *American Economic Review 106*(1), 165–199.

Gurkaynak, R., B. Sack, and E. Swanson (2005). Do actions speak louder than words? the response of asset pprice to monetary policy actions and statements. *International Journal of Central Banking 1*(1), 55–93.

Kuttner, K. (2001). Monetary policy surprises and interest rates: Evidence from the fed funds futures market. *Journal of Monetary Economics 47*(3), 523–544.

Lucca, D. and E. Moench (2015). The pre-fomc announcement drift. *Journal of Finance 70*, 329–371.

Mayer, T. and S. Zignago (2011, December). Notes on cepii's distances measures: The geodist database. Working papers, CEPII.

Nakamura, E. and J. Steinsson (2015, October). High frequency identification of monetary non-neutrality. Technical report, Columbia University. mimeo.

Rauch, J. E. (1999). Networks versus markets in international trade. *Journal of International Economics 48*(1), 7–35.

Rey, H. (2013). Dilemma not trilemma: The global financial cycle and monetary policy independence. *Federal Reserve Bank of Kansas City Economic Policy Symposium*.

Rey, H. (2014). International channels of transmission of monetary policy and the mundellian trilemma. *IMF Economic Review*. Mundell Fleming Lecture 2014.

Savor, P. and M. Wilson (2013). How much do investors care about macroeconomic risk? evidence from scheduled economic announcements. *Journal of Financial and Quantitative Analysis 48*, 343–375.

Shambaugh, J. (2004). The effect of fixed exchange rates on monetary policy. *Quarterly Journal of Economics 119*(1), 301–352.

Appendix

A Appendix to the Theory Section

A.1 Deriving the Conditions of Optimality

In this subsection, I provide additional details about solving the model in Section 2. Households maximize utility (1) subject to their budget constraints (4). Let Ψ^n denote the Lagrange multiplier on the budget constraint for households in country n. By assumption, the wealth transfer, κ^n, in equation 4 equalizes $\Psi^h = \Psi^f$. For a household in country n, the first order condition with respect to the consumption of intermediate traded good j produced in country m, $C^n_{T,j,t}$, yields,

$$\frac{\tau}{3}\left(\frac{(C^n_t)^{1-\gamma}}{C^n_{T,m,t}}\right)\left(\frac{C^n_{T,m,t}}{C^n_{T,m,j,t}}\right)^{1-\varepsilon} = \Psi^n Q^n_t \tilde{P}^n_{T,m,j,t}.$$

The first order condition with respect to the consumption of non-traded goods is,

$$(1-\tau)\frac{(C^n_t)^{1-\gamma}}{C^n_{N,t}} = \Psi^n Q^n_t \tilde{P}^n_{N,t}.$$

The first order condition with respect to labor supplied by the household is,

$$N^n_t = \Psi^n Q^n_t \tilde{W}^n_t.$$

Finally, I take a first order condition with respect to aggregate consumption,

$$(C^n_t)^{-\gamma} = \Psi^n Q^n_t \tilde{P}^n_t \tag{23}$$

I derive equations (5) - (7) by taking the ratio between each of the households's first order conditions and the households's first order condition with respect to aggregate consumption.

I derive equation (11) by taking the ratio between the first order condition with respect to aggregate consumption for country h and country f, given by equation (23). I can cancel out the Lagrange multipliers, because $\Psi^h = \Psi^f$. Since I do not introduce and frictions into financial markets, $Q^h_t = \tilde{E}^{h,f}_t Q^f_t$ by no arbitrage arguments. I simplify and recover equation (11).

In the remainder of this subsection, I derive first order conditions for the firm's optimal pricing problem. These equations are not shown in the main text. None the less, they are necessary for deriving the equilibrium.

In the second period, the intermediate traded firm maximizes profits by choosing the price of its variety of intermediary traded good. For the firm j in country n I formally write this problem as,

$$\max_p pY^n_{T,n,j,2} - \tilde{W}^n_2 \left(\frac{Y^n_{T,n,j,2}}{A^n_2} \right) \tag{24}$$

where p is the nominal price of the firm's good denominated in producer currency (the currency of country n). I derive the firm's demand curve by inverting equation (5),

$$Y^n_{T,j,t} = \sum_{m \in \{h,f\}} p^{\frac{1}{\varepsilon-1}} \left(\frac{2}{\tau} \right)^{\frac{1}{\varepsilon-1}} \left(\frac{\tilde{E}^{n,m} C^m_t}{\tilde{P}^m_t} \right)^{\frac{1}{\varepsilon-1}} \left(C^m_{T,n,t} \right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{25}$$

I plug equation (25) into the equation (24) and take first order conditions with respect to p. I solve for p and to derive the nominal price of intermediary traded good for firm j located in country n. This yields the usual result where the firm sets it's nominal price as a constant markup over marginal cost,

$$\tilde{P}^n_{T,n,j,2} = \frac{1}{\varepsilon} \frac{\tilde{W}^n_2}{A^n_2}$$

Since firms are allows to adjust their prices, their invoicing currency does not matter. The price of their exported good is just adjusted by the exchange rate.

In the first period, firms set prices before the realization of shocks. Furthermore, firms need to set a domestic price and an export price. **To be completed.**

A.2 Log-Linear Approximation of the Equilibrium

I log-linearize the model around a symmetric deterministic steady state where $C^n_{T,m,j,t} = 1, C^n_{N,t} = 1, \tilde{E}^{n,m}_t, Y_{T,n,j,t} = 3, Y^n_{N,t} = 1, N^n_t = N^n_{j,t} = \sqrt{\varepsilon\tau}, \tilde{W}^n_t = \sqrt{\varepsilon\tau}, \tilde{P}^n_{T,m,j,t} = \frac{\tau}{3}, \tilde{P}^n_{N,t} = 1-\tau$ and $\tilde{P}^n_t = 1$.

A.3 Constant δ_y

$$\delta_y = \frac{\delta_{y,N}}{3\,(1-\tau)\,\nu}$$

where

$$\delta_{y,N} = \frac{1}{3}\gamma\tau\left((\gamma-1)\tau+1\right)\left(X_{\$}^{JP}+X_{\$}^{EU}-\frac{X_{\$}^{JP}X_{\$}^{EU}}{3}\right)+$$
$$\frac{2}{3}(1-\tau)\tau\left((\gamma-1)\tau+1\right)\left(X_{\$}^{JP}+X_{\$}^{EU}-\frac{\gamma X_{\$}^{JP}X_{\$}^{EU}}{3}\right)+\tau\left((\gamma-1)\tau+1\right)^2$$

A.4 Proof of Prediction 5

To be completed.

A.5 Proof of Proposition 1

Under flexible prices, equilibrium consumption in country n is given by

$$c^n = \frac{2\tau}{(2+(\gamma-1)\tau)}\bar{a} + \frac{(\gamma-1)(1-\tau)\tau}{(1+(\gamma-1)\tau)\left(2+(\gamma-1)\tau\right)}\bar{y}_N + \frac{(1-\tau)}{1+(\gamma-1)\tau}y_N^{JP}. \tag{26}$$

Under fixed prices, consumption in Japan is a function of the productivity shocks as well as the monetary policy actions in each country. I equate the expression for Japanese consumption under flexible prices with the expression under fixed prices. The Japanese central bank can recover the consumption allocation in equation (26) by choosing the appropriate level of domestic inflation, $\tilde{p}^{JP}$. I solve for this $\tilde{p}^{JP}$,

$$\frac{\partial\tilde{p}^{JP}}{\partial\tilde{p}^{US}} = -\frac{(1-\tau)\left(1+X_{\$}^{EU}\right)+\gamma(1+\left(X_{\$}^{EU}/3\right))}{1+\tau\left(\gamma\left(1-(X_{\$}^{EU}/3)\right)-1\right)} -$$
$$\frac{2\gamma\tau(2(1+(\gamma-1)\tau)+(1-\tau)X_{\$}^{EU})}{(1+\tau(\gamma(1-X_{\$}^{JP})-1))(1+\tau\left(\gamma\left(1-(X_{\$}^{EU}/3)\right)\right)}X_{\$}^{JP}$$

The first line shows that if the U.S. engages in contractionary policy and decreases $\tilde{p}^{US}$, then Japan must inflate it's own nominal price level to recover the flexible price consumption allocation. Then, it is straight-forward to show that,

$$\frac{\partial^2\tilde{p}^{JP}}{\partial\tilde{p}^{US}\partial X_{\$}^{JP}} = -\frac{2\gamma\tau(2(1+(\gamma-1)\tau)+(1-\tau)X_{\$}^{EU})}{(1+\tau(\gamma(1-X_{\$}^{JP})-1))^2(1+\tau\left(\gamma\left(1-(X_{\$}^{EU}/3)\right)\right)} < 0.$$

Hence, the larger Japan's share of Dollar invoiced exports, the more Japan needs to inflate it's own domestic price level in order to recover the flexible price allocation.

Naturally, the Japanese central must also deflate its own nominal price level in response to expansionary monetary policy from the U.S., and the higher its share of Dollar invoiced exports, the more Japan needs to deflate. Hence, the overall magnitude of Japan's response to U.S. monetary policy is increasing in the share of Japan's Dollar invoiced exports.

A.6 Calvo Pricing and Price Stickiness

In this sub-section, I relax the assumption that prices are fixed in the first period. In order to simplify the algebra, I assume that all firms firms invoice in domestic currency (producer currency pricing). This assumption implies $X_{\$}^{US} = 1$ and $X_{\$}^{JP} = X_{\$}^{EU} = 0$.

Suppose a fraction $1-\theta$ of firms in the U.S. country are allowed to reset their prices after the realization of shocks in the first period. Solving the firm optimization problem, firms that are allowed to reset prices will set the nominal price their variety of intermediate traded good to a constant markup over marginal costs,

$$P_{T,h,\$}^{US*} = \frac{1}{\varepsilon}\frac{W^h}{A^h}.$$

I continue to assume that the nominal prices of all intermediate traded goods produced by Japanese firms and Eurozone firms are fixed prior to the realization of shocks in the first period.

The effect of home monetary policy on final consumption in the foreign country is now dampened by the fact that some firms are allowed to adjust the nominal price of their product,

$$\frac{\partial c^n}{\partial \tilde{p}^{US}} = \frac{\theta\tau}{2\left(1-\tau+(1-\theta)(1+((\gamma-1)\tau)/2)\right)}.$$

As the fraction of firms whose prices are fixed, θ, approaches zero, the spillover effects from the U.S. monetary policy disappears. If all firms in the U.S. could freely adjust their prices, then monetary policy in the U.S. will have no impact on their demand.

Similarly, the effect of home monetary policy on the real price level in foreign countries decreases as nominal prices become more flexible,

$$\frac{\partial e^{n,US}}{\partial \tilde{p}^{US}} = \frac{\gamma\tau(-1+X_{\$}^{h})\theta}{2\left(1-\tau\left(1+\gamma(1-(\theta/2))+\gamma\theta X_{\$}^{h}\right)\right)}.$$

Comparing this expression to equation (14) shows that the effect of having a larger fraction of Dollar invoiced imports is now dampened by a factor θ. Hence, as θ approaches zero, variation in the share of Dollar invoiced imports in the foreign country will no longer affect the strength of the spillover effects on the real price level.

Proposition 2. *As θ increases and nominal prices in the economy become more rigid, the spillover effects of home monetary policy on the real value of foreign currency, on real consumption in the foreign country, on real interest rates and on foreign production all increase.*

Proof. To be completed. □

B Appendix to the Empirical Section

This section of the Appendix provides summary statistics provides summary statistics for the data, empirical results and robustness checks for the main empirical results.

B.1 Region Names, Codes and Summary Statistics

Table 2: Region Names

Country Name	Alpha 3	OECD Country
Australia	AUS	TRUE
Canada	CAN	TRUE
Switzerland	CHE	TRUE
Cyprus	CYP	FALSE
Denmark	DNK	TRUE
Estonia	EST	TRUE
Europe	EUR	TRUE
United Kingdom	GBR	TRUE
Greece	GRC	TRUE
Iceland	ISL	TRUE
Israel	ISR	TRUE
Japan	JPN	TRUE
South Korea	KOR	TRUE
Lithuania	LTU	FALSE
Latvia	LVA	FALSE
Malta	MLT	FALSE
Norway	NOR	TRUE
Slovenia	SVN	TRUE
Sweden	SWE	TRUE
United States	USA	TRUE

Notes: This table lists the regions in my sample by name and alpha 3 code. This is list of countries for which I observe forward premia data at the one year maturity from Datastream as well as currency invoicing data from Gopinath (2015). I observe forward premia for the Euro, and hence, I observe data for the Eurozone as a whole. I include a

Table 3: Summary Statistics

	(1)	(2)	(3)	(4)	(5)
	Obs	Mean	Std Dev	Max	Min
Panel A:		*Monetary Policy Shocks (bps)*			
Federal Reserve Bank	111	-0.973	5.866	20.500	-32.000
European Central Bank	93	0.726	3.743	15.000	-8.500
Bank of Japan	184	-0.174	1.223	3.000	-11.000
Bank of England	62	-0.581	5.302	23.000	-19.000

Notes: The sample summarizes monetary policy shocks on regularly scheduled policy announcements days for each central bank between 1999 to 2014. I drop days where more than one central bank issued a monetary policy announcement, and I drop the height of the financial crisis (July 2008 - June 2009).

B.2 Regression Results: High Frequency Data

The following section presents regression results with high frequency outcome variables. The dependent variables are changes in U.S. Dollar exchange rates and changes in one year nominal interest rates on monetary policy announcement days.

Table 4: Nominal Exchange Rate Response: Nakamura and Steinsson (2015) Shocks

	Dependent variable: Nominal Exchange Rates				
	(1)	(2)	(3)	(4)	(5)
$M_{\$}^{n} \times \Delta i_{US,t}$	-4.841^{**}	-4.441^{*}	-4.304^{**}	-4.037	-2.928
	(2.373)	(2.277)	(1.815)	(3.234)	(10.806)
Distance $\times \Delta i_{US,t}$		0.716^{**}			
		(0.303)			
Import Share $\times \Delta i_{US,t}$			-5.743		
			(18.979)		
Diff. Share $\times \Delta i_{US,t}$				-2.524	
				(3.534)	
Diff. Share $\times M_{\$}^{n} \times \Delta i_{US,t}$					-2.221
					(10.495)
Observations	1,526	1,526	1,526	1,526	1,526
Adjusted R^2	0.649	0.650	0.649	0.649	0.648

Notes: This table presents regression results from estimating equation (20) with changes in the nominal exchange rates as the dependent variable. $M_{\$}^{n}$ is the value country n's imports normalized by consumption. Distance is the log of the populaiton weighted distance between country n and the U.S. Import Share is the value of each country's imports from the U.S. normalized by consumption. Diff. Share is the share of each country's imports classified as differentiated goods. Standard errors in parentheses are clustered by date. *p<0.1; **p<0.05; ***p<0.01

Table 5: Nominal Interest Rate Response: Nakamura and Steinsson (2015) Shocks

	Dependent variable: Nominal Interest Rates (1Y)				
	(1)	(2)	(3)	(4)	(5)
$M_{\$}^{n} \times \Delta i_{US,t}$	2.118***	2.176***	2.101***	1.928***	−0.666
	(0.622)	(0.640)	(0.697)	(0.608)	(1.291)
Distance $\times \Delta i_{US,t}$		0.177			
		(0.111)			
Import Share $\times \Delta i_{US,t}$			0.172		
			(1.124)		
Diff. Share $\times \Delta i_{US,t}$				0.678	
				(0.494)	
Diff.Share $\times M_{\$}^{n} \times \Delta i_{US,t}$					3.443**
					(1.662)
Observations	1,286	1,286	1,286	1,286	1,286
Adjusted R^2	0.153	0.154	0.152	0.155	0.158

Notes: This table presents regression results from estimating equation (20) with changes in one year nominal interest rates as the dependent variable. $M_{\$}^{n}$ is the value country n's imports normalized by consumption. Distance is the log of the populaiton weighted distance between country n and the U.S. Import Share is the value of each country's imports from the U.S. normalized by consumption. Diff. Share is the share of each country's imports classified as differentiated goods. Standard errors in parentheses are clustered by date. *p<0.1; **p<0.05; ***p<0.01

Table 6: Nominal Exchange Rate Response: Nakamura and Steinsson (2015) Shocks, Pre-Crisis

	Dependent variable: Nominal Exchange Rates				
	(1)	(2)	(3)	(4)	(5)
$M_{\$}^{n} \times \Delta i_{US,t}$	-4.756^{**}	-4.355^{**}	-4.240^{**}	-3.985	-2.796
	(2.312)	(2.220)	(1.781)	(3.140)	(10.551)
Distance $\times \Delta i_{US,t}$		0.724^{**}			
		(0.301)			
Import Share $\times \Delta i_{US,t}$			-5.508		
			(19.349)		
Diff. Share $\times \Delta i_{US,t}$				-2.439	
				(3.481)	
Diff. Share $\times M_{\$}^{n} \times \Delta i_{US,t}$					-2.282
					(10.297)
Observations	1,052	1,052	1,052	1,052	1,052
Adjusted R^2	0.618	0.619	0.617	0.618	0.617

Table 7: Nominal Interest Rate Response: Nakamura and Steinsson (2015) Shocks, Pre-Crisis

	Dependent variable: Nominal Interest Rates (1Y)				
	(1)	(2)	(3)	(4)	(5)
$M_{\$}^{n} \times \Delta i_{US,t}$	2.059^{***}	2.111^{***}	2.020^{***}	1.869^{***}	-0.726
	(0.625)	(0.646)	(0.707)	(0.606)	(1.286)
Distance $\times \Delta i_{US,t}$		0.152			
		(0.116)			
Import Share $\times \Delta i_{US,t}$			0.370		
			(1.151)		
Diff. Share $\times \Delta i_{US,t}$				0.677	
				(0.502)	
Diff. Share $\times M_{\$}^{n} \times \Delta i_{US,t}$					3.442^{**}
					(1.687)
Observations	812	812	812	812	812
Adjusted R^2	0.247	0.247	0.245	0.252	0.260

Notes: Tables 6 and 7 present regression results from estimating equation (20) with changes in nominal exchange rates and changes in one year nominal interest rates as the dependent variable. I only use data prior to July, 2008. $M_{\$}^{n}$ is the value country n's imports normalized by consumption. Distance is the log of the populaiton weighted distance between country n and the U.S. Import Share is the value of each country's imports from the U.S. normalized by consumption. Diff. Share is the share of each country's imports classified as differentiated goods. Standard errors in parentheses are clustered by date. *p<0.1; **p<0.05; ***p<0.01

B.3 Regression Results: Low Frequency Data

The following section presents regression results with low frequency outcome variables. The dependent variables are monthly changes in log imports and log industrial production.

Table 8: Imports

τ (months)	24	30	36
$\mu^n_\$ \times \Delta i_{US,t}$	-0.128	-0.667^{**}	-0.784^{**}
	(0.298)	(0.308)	(0.308)
Date Fixed Effects	Y	Y	Y
Country Fixed Effects	Y	Y	Y
Observations	3,472	3,304	3,136
Adj. R-sqr	0.801	0.806	0.799

Table 9: Industrial Production

τ (months)	24	30	36
$X^n_\$ \times \Delta i_{US,t}$	-0.299^{*}	-0.375^{**}	-0.359^{**}
	(0.166)	(0.168)	(0.165)
Date Fixed Effects	Y	Y	Y
Country Fixed Effects	Y	Y	Y
Observations	2,976	2,832	2,688
Adj. R-sqr	0.627	0.679	0.718

Notes: $\mu^n_\$$ is the share of country n's imports that are invoiced in Dollars and $X^n_\$$ is the share of country n's exports that invoiced in Dollars. Standard errors in parentheses are clustered by month. *p<0.1; **p<0.05; ***p<0.01

B.4 Evidence from Multiple Countries

In this subsection, I present evidence of monetary policy spillovers from multiple central banks. The dependent variables are changes in U.S. Dollar exchange rates and changes in one year nominal interest rates on monetary policy announcement days.

Table 10: Pooled Regression : Multiple Central Banks

	Nominal Exchange Rate		Nominal Interest Rate	
	(1)	(2)	(3)	(4)
$M_f^n \times \Delta i_{f,t}$	-4.881^{**}	-4.234	1.682^{***}	1.510^{**}
	(2.164)	(4.080)	(0.571)	(0.696)
$M_f^n \times \Delta i_{f,t} \times FRB$		-1.466		0.195
		(4.709)		(0.946)
Observations	6,460	6,460	5,075	5,075
Adjusted R^2	0.692	0.692	0.128	0.128

C Data Appendix

This section provides additional details on the data used.

C.1 Monetary Policy Shocks

Table 11 summarizes the scheduled monetary policy announcement dates in my sample. I list the initial date, the final date, the number of monetary policy announcement days per year and link to the data.

Table 11: Scheduled Monetary Policy Announcement Days

Central Bank	Data Availability	Announcements per Year	Source
FRB	1990 - 2015	For the relevant part of the sample (1999 - 2014) there have been eight meetings a year. However, during the Great Recession, we also observe "Intermeeting Press Releases" on: Aug 10, 2007; Aug 17, 2007; Jan 22, 2008; Oct 8, 2008 and May 9, 2010.	Link
ECB	1999 - 2015	For the most part, the ECB meets monthly. However, the number of meetings increased when the Euro was first created, and during the Eurozone Crisis.	Link
BOJ	1998 - 2015	Fourteen to twenty	Link
BOE	1997 - 2015	Twelve monthly meetings	Link

I gather daily measures of three month interest rate futures from Bloomberg. The series symbols for three month interest rate futures for the Dollar, Euro, Yen and Pound are "ED1 Comdty", "ER1 Comdty", "YE1 Comdty" and "L 1 Comdty", respectively. For each series, I pull the opening price (PX_OPEN) and the closing price (PX_CLOSE). My measure of monetary policy shock is the change between the openning price and closing price on days of monetary policy announcements.

C.2 Import and Export Invoicing Currencies

I use data on import and export invoicing currencies from Gopinath (2015). The data are available on her website:

http://scholar.harvard.edu/gopinath/publications/international-price-system

The data provide the average share of each countries imports and exports that are invoiced in each currency over the period 1999 - 2014.

I need to perform additional calculations for the Eurozone, because I only observe one nominal interest rate for the Eurozone as a whole but I obseve currency invoicing data for the countries of the Eurozone individually. Hence, I need to estimate the currency composition of the Eurozone's exports and the Eurozone's imports with respect to the rest of the world. I use bilateral goods trade data to estimate the share of each country's imports and exports with respect to other Eurozone countries, and I assume that all trade conducted within the Eurozone is done using Euros. These assumptions allow me to estimate each country's imports and exports with respect to non-Eurozone countries that are invoiced in each currency. Finally, I aggregate the country level data to calculate the invoicing shares of the Eurozone's imports and exports with respect to the rest of the world.

The details of my procedure for estimating currency invoicing shares for the Eurozone are as follows. For each country n in the Eurozone in year t, I observe the share of the country's imports invoiced in currency c. Denote this as $S^n_{M,c}$. I denote the total current Dollar value of country n's imports as V^n_M, and the total current Dollar value of country n's imports invoiced in currency c as $V^n_{M,c}$. Furthermore, denote the value of country n's imports from the Eurozone as $V^{n,EUR}_M$ and the value of country n's imports with the non-Eurozone countries as $V^{n,RoW}_M$. All values are denoted in current U.S. Dollars and these values are calculated annually. I have chosen to drop the time t notation to simplify the exposition.

I estimate the value of each country's imports from non-Eurozone countries that are invoiced in currency c is, $V^{n,RoW}_{M,c}$ as

$$S^n_{M,c} = \left(\frac{V^{n,RoW}_{M,c}}{V^{n,RoW}_M}\right)\left(\frac{V^{n,RoW}_M}{V^n_M}\right) + \left(\frac{V^{n,EUR}_{M,c}}{V^{n,EUR}_M}\right)\left(\frac{V^{n,EUR}_M}{V^n_M}\right). \tag{27}$$

Where $\left(V^{n,RoW}_{M,c}/V^{n,RoW}_M\right)$ is the share of country n's imports from non-Eurozone countries that are invoiced in currency c and $\left(V^{n,RoW}_M/V^n_M\right)$ is the share of country n's total imports that come from non-Eurozone countries. Analogously, $\left(V^{n,EUR}_{M,c}/V^{n,EUR}_M\right)$ is the share of country n's imports from Eurozone countries that are invoiced in currency c and $\left(V^{n,EUR}_M/V^n_M\right)$ is the share of country n's total imports that come from Eurozone countries.

I use equation (27) to solve for the share of country n's imports from non-Eurozone countries that are invoiced in currency c, $\left(V^{n,RoW}_{M,c}/V^{n,RoW}_M\right)$. I observe the left-hand side, and I assume that for all countries inside the Eurozone, all intra-Eurozone trade is conducted in Euros. I need to estimate the share of each country's total imports that originate from other Eurozone countries. To do so, I use bilateral bilateral **goods** trade data from the OECD Library. I use "Bilateral Trade in Goods by Industry and End-use (BTDIxE), ISIC Rev. 4" data. See Appendix C.5 for additional details.

For each Eurozone country and year, I calculate the share of that country's goods imports originating from other Eurozone countries. I do not have bilateral services trade data. Hence, I assume that the share of total imports originating from Eurozone countries is equal to the share of total goods imports originating from Eurozone countries.

These assumptions allow me to estimate $\left(V_{M,c}^{n,RoW}/V_{M}^{n,RoW}\right)$ for each country n. For a small number of observations this value is negative, which means I over-estimated the share of that country's total imports from the Eurozone that were invoiced in Euros. If $\left(V_{M,c}^{n,RoW}/V_{M}^{n,RoW}\right) < 0$, I set it to zero.

Next, I estimate the share of the Eurozone's imports invoiced in currency c by taking a weighted average of $\left(V_{M,c}^{n,RoW}/V_{M}^{n,RoW}\right)$ over the Eurozone countries,

$$\left(\frac{V_{M,c}^{EUR,RoW}}{V_{M}^{EUR,RoW}}\right) = \frac{\sum_n V_M^{n,RoW}\left(V_{M,c}^{n,RoW}/V_{M}^{n,RoW}\right)}{\sum_n V_M^{n,RoW}}.$$

where $V_M^{n,RoW}$ is still the value of country n's imports that originate from non-Eurozone countries. I estimate $V_M^{n,RoW}$ using bilateral goods import data by multiplying the share of country n's goods imports from non-Eurozone countries with the total value of country n's imports. I use import data from the OECD Library. See Appendix C.7 for more details.

Thus, I estimate the share of the Eurozone's imports from the rest of the world that are invoiced in currency c. I repeat the same calculations for exports.

C.3 Spot and Forward Rates

I use data for dollar-based spot and forward exchange rates from Datastream to construct nominal interest rates for each country. I use the World Markets PLC/ Reuters (WM/R) data provider within Datastream for my spot and forward exchange rate data. Identifiers for the forward rate data usually follow the form $USisomm$, where the U.S. Dollar is the base currency, "iso" is the other currency's ISO code, and "mm" is a two letter identifier for the maturity of the forward rate. The identifiers for the three month, six month, one year and two year forward rates are "3F", "6F", "1Y" and "2Y", respectively. The identifiers for the spot rate data are of the form *cccccc*\$, which is a six digit currency identifier followed by a Dollar sign.

C.4 OECD Data

C.5 Bilateral Trade Data

I use bilateral trade data to aggregate currency invoicing data, as well as other measure trade intensity, for the Eurozone countries. I use data from the "Bilateral Trade in Goods by Industry and End-use (BTDIxE), ISIC Rev. 4" database in the OECD Statistics Library. I use data from 1999 to 2014 for all countries within the Eurozone. Unfortunately, these data only cover goods trade and I would ideally like to observe bilateral trade in both goods and services.

C.6 Exchange Rate Peg Data

I use exchange rate peg data using classification mechanism from Shambaugh (2004). The data are available from Shambaugh's website and define whether or not countries have fixed exchange rates from 1960 to 2014. The data are available at the annual frequency. Among other variables, the data classify whether countries engage in hard exchange rate pegs or soft exchange rate pegs.

C.7 Imports, Exports and GDP

I construct measures of the import share of GDP and export share of GDP for each country in my sample. I use annual import, export, and GDP data from the OECD Statistics Library. I use data under the "Quarterly national accounts" heading labeled: "Gross domestic product", "GDP Exports" and "GDP Imports of goods and services". For most observations in my sample, I take the simple ratio between imports (exports) and GDP.

Calculating the import and export shares of GDP for the Eurozone requires extra effort. Again, for each country in the Eurozone, I estimate the share of the country's imports (exports) with non-Eurozone countries using bilateral goods trade data as a fraction of that country's total imports (exports). Implicitly, I assume that the pattern of each country's trade in goods and services matches that country's pattern of trade in goods alone.

For each country, I divide its goods imports from every other country by the country's total goods imports. Next, I multiply these shares by the total value of goods and services imports in each country to estimate the value of each country's total imports with respect to non-Eurozone countries. I sum the country level data to calculate the value of the Eurozone's imports from the rest of the world, and I divide this number by the GDP of all countries within the Eurozone. Finally, I average the annual data over all years in the sample period (1999 - 2014). I perform the analogous calculations for exports.

C.8 Alternate Measures of Trade Costs

I also use measures of trade costs from Mayer and Zignago (2011). The data are located in the GeoDist database on the CEPII website:

http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=6

I use the following variables from this database: *distw* and *contig*. I use Germany for the geographic region for the Euro. See the documentation in Mayer and Zignago (2011) for additional details.

C.9 Price Stickiness Data

To be completed.