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MONETARY POLICY SPILLOVERS THROUGH INVOICING CURRENCIES

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WEITING ZHANG

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ABSTRACT

United States monetary policy affects macro-financial outcomes globally. I introduce heterogeneity in invoicing currencies into an open economy New Keynesian model that also allows for differences in country size and household preferences. Within the model, cross-sectional variation in U.S. monetary policy spillover effects is fully captured by heterogeneity in countries' shares of dollar invoiced trade. Moreover, central banks of countries in which a larger share of exports are invoiced in dollars face a worse output-inflation trade-off, i.e., a steeper Phillips Curve. Using high frequency measures of monetary policy shocks, I find support for the model's predictions. Countries' shares of dollar invoiced trade explain cross-sectional heterogeneity in spillovers from U.S. monetary policy shocks onto foreign exchange rates, interest rates and industrial production. Constructing a new data set of monetary policy shocks emanating from the European Central Bank, the Bank of Japan and the Bank of England, I show currency invoicing explains variation in monetary policy spillovers from these other central banks as well. After controlling for currency invoicing in trade, the magnitude of U.S. monetary policy spillovers are not significantly different from those of other central banks.

CHAPTER 1

MONETARY POLICY SPILLOVERS THROUGH INVOICING CURRENCIES

1.1 Introduction

The actions of the Federal Reserve Bank of the United States are of fundamental concern for central bankers around the world. A growing literature finds monetary policy actions of the United States significantly impact macroeconomic conditions (Rey, 2013; Miranda-Agrippino and Rey, 2015) and asset prices (Brusa et al., 2015) globally. What features of the global economy allow the Federal Reserve to influence global macroeconomic conditions, and to what extent do monetary policy actions from other central banks also influence outcomes abroad? Recent evidence from Gopinath (2015) shows that over 80 percent of traded goods are invoiced in dollars and euros. This paper studies how patterns in currency invoicing generate international monetary policy spillovers, and its implications for monetary policy.

Building on Engel (2011), I develop an open economy New Keynesian model in which prices of traded goods are sticky in their currency of invoicing. Firms in each country invoice their exports in domestic currency or in a global trade currency issued by a "center" country. [1] I show central banks of countries in which firms invoice more of their exports in the global trade currency should face a worse output-inflation trade-off (i.e. a steeper Phillips curve), and I characterize international monetary policy transmission onto key elements of the New Keynesian framework: exchange rates, interest rates, and the level of output. Using high-frequency measures of monetary policy shocks, I test the model's predictions for nominal

1. Invoicing in domestic currency is typically labeled "producer currency pricing". Within the model, I take the firm's invoicing currency as given. A concern is that underlying factors expose a country to monetary policy shocks from the center country and also cause the country to invoice exports in the global trade currency. The international trade literature has identified some characteristics that influence the firm's invoicing currency choice (Devereux et al., 2004; Goldberg and Tille, 2008; Gopinath et al., 2010). Examples include the liquidity of the currency, industry structure and desired exchange rate pass-through. However, there is no consensus for why we observe the heterogeneity in invoicing currency use at the country level. In the empirical section of the paper, I control for alternative hypotheses for explaining heterogeneity in monetary policy spillovers beyond the role of currency invoicing itself.

exchange rates, nominal interest rates and output, and I find support for each one. Countries in which a larger share of imports and exports are invoiced in dollars are more exposed to U.S. monetary policy shocks. Furthermore, I provide evidence that monetary policy spillover effects emanate from other central banks in the world, and the large magnitude of U.S. monetary policy spillover effects can be explained by the dollar's dominance as a global trade currency.

I begin with the theoretical analysis, and characterize the effect of currency invoicing on monetary policy transmission across countries in a model where asset markets are complete. I allow countries to differ in size, households to differ in their preferences for varieties of traded goods and firms to differ in their invoicing currency of exports. Contractionary monetary policy from the center country increases the value of the global trade currency relative to all other currencies in the world. Hence, the relative price of traded goods invoiced in the global trade currency increases. Households consume an aggregate bundle of traded and non-traded goods. As the relative price of traded goods increases, foreign households decrease their traded good consumption as well as their aggregate consumption.

Within the model, variation in monetary policy spillover effects from the center country onto foreign consumption is fully captured by the share of each country's consumption invoiced in the global trade currency. In each country, the share of consumption invoiced in the global trade currency is a function of underlying household preferences and the fraction of traded goods invoiced in the global trade currency. When the center country engages in contractionary monetary policy, countries with a larger share of consumption invoiced in the global trade currency suffer a larger increase to their cost of consumption, because the currency appreciation affects a larger fraction their aggregate consumption bundle. As a result, these countries observe a larger decrease in their aggregate consumption in response to the center country's contractionary monetary policy.

The model shows central banks of countries in which a larger fraction of firms invoice their exports in the global trade currency face a worse output-inflation trade-off. A central bank's monetary policy affects the demand for all goods invoiced in its currency — domestically and abroad. When domestic firms invoice their exports in the global trade currency, the central bank loses control over foreign demand for these traded goods. An increase in the fraction of domestic firms invoicing in the global trade currency should diminish the effect of domestic monetary policy on domestic output. Hence, the central bank faces a steeper Phillips curve. In this sense, variation in the invoicing currencies of exports is important for characterizing the effectiveness of monetary policy across countries. After establishing this result, I derive additional predictions characterizing how heterogeneity in currency invoicing influences the transmission of monetary policy onto other components of the New Keynesian framework.

Within the model, heterogeneity in spillover effects to consumption drives the two main asset pricing predictions. In response to contractionary monetary policy shock from the center country, foreign countries with a larger share of consumption invoiced in the global trade currency appreciate, and their interest rates increase relative to countries with a smaller share of consumption invoiced in the global trade currency. In response to contractionary monetary policy from the center country, countries with a larger share of consumption invoiced in the global trade currency observe their marginal utility of consumption increase more. This increase in the marginal utility of consumption directly translates into a real exchange rate appreciation and an increase in real interest rates. Changes in nominal exchange rates and nominal interest rates mirror the changes in real exchange rates and real interest rates.

Monetary policy spillover effects are not unique to any country, and heterogeneity in currency invoicing explains cross-sectional variation in monetary policy spillover effects from each country. Within the model, the magnitude of monetary policy spillover effects onto exchange rates and interest rates are the same for all countries after controlling for shares of consumption invoiced in each currency. In other words, the model suggests that the Federal Reserve strongly influences global macro-financial conditions because of the dollar's preeminent position as an invoicing currency.

After showing the main insights of the paper in the complete asset markets model, I show the theoretical predictions of the model continue to hold in an incomplete markets extension. Although the complete asset markets model is an important benchmark, a well known empirical short-coming of the model is that it predicts a perfectly negative correlation between aggregate consumption and real exchange rates (Backus and Smith, 1993). The incomplete markets extension serves two purposes. First, it shows that the forces identified in the model carry over to a broader class of models with more elaborate frictions. Second, the addition of incomplete markets breaks the tight link between exchange rates, interest rates and aggregate consumption. As a result, the empirical section of the paper focuses on testing the predictions for exchanges rates, interest rates and production rather than aggregate consumption.

The predictions of the model are most effectively summarized by the result that countries in which firms invoice more of their exports in foreign currencies should face a steeper Phillips curve. However, empirical estimates of Phillips curves are strongly subject to specification error, and often give rise to conflicting results (Mavroeidis et al., 2014). Hence, I focus on testing the following predictions in which I can use high frequency measures of monetary policy shocks to identify the effects of monetary policy. In response to a contractionary U.S. monetary policy shock, countries with a larger share of dollar invoiced imports should observe (1) their nominal exchange rates depreciate less and (2) their nominal interest rates increase more. (3) Monetary policy spillover effects from the United States are no larger than the magnitude of monetary policy spillover effects from other central banks, after controlling for heterogeneity in currency invoicing. Finally, (4) countries that invoice a larger share of their exports in dollars observe their production decrease more in response to U.S. contractionary monetary policy.

In the empirical section of the paper, I use currency invoicing data from Gopinath (2015) to construct countries' shares of consumption invoiced in dollars, euros, yen and pounds. Using high frequency monetary policy shock data from Nakamura and Steinsson (2015), I show variation in dollar invoicing explains monetary policy spillovers from the Federal Reserve. Afterwards, I measure monetary policy shocks consistently for the Federal Reserve Bank, the European Central Bank, the Bank of Japan and the Bank of England, and test whether spillovers from the Federal Reserve stand out.

Figure 1.1 summarizes my main empirical results. I start by measuring responses in nominal exchange rates and nominal interest rates in a one-day window around U.S. monetary policy announcements. Using the sample of U.S. monetary policy shocks from Nakamura and Steinsson (2015), I estimate a panel regression of changes in each country's nominal exchange rates and nominal interest rates on country fixed effects, date fixed effects and an interaction term between country fixed effects and Federal Reserve monetary policy shocks. The coefficient on the interaction term captures each country's response to U.S. monetary policy shocks relative to the average country's response. Figure 1.1 plots the coefficients on the interaction term, against each country's share of dollar invoiced consumption. The left-hand plot in Figure 1.1 provides evidence that countries with a higher share of dollar invoiced consumption depreciate less in response to a contractionary U.S. monetary policy shock. The right-hand plot in Figure 1.1 provides evidence that nominal interest rates in countries with a higher share of dollar invoiced consumption increase more in response to contractionary U.S. monetary policy shocks.

In the paper, I show if a country experiences a one standard deviation increase in its share of dollar invoiced consumption, a 100 basis point contractionary monetary policy shock causes its nominal exchange rate to depreciate by 130 fewer basis points and causes its nominal interest rate to increase by an additional 53 basis points. Moreover, I provide evidence that currency invoicing explains monetary policy spillover effects from other central banks. Importantly, I fail to reject the null hypothesis that the magnitude of monetary policy spillover effects from the Federal Reserve are the same as those from other central banks after controlling for currency invoicing.

Finally, I construct monthly monetary policy shocks for the U.S., and provide evidence that industrial production in countries with a larger share of dollar invoiced exports is more responsive to U.S. monetary policy. Consistent with the literature, I find the strongest effects occur with a two to three year lag.

The rest of the paper is organized as follows. Section 1.2 reviews the related literature. Section 1.3 presents the model, and section 1.4 characterizes the equilibrium and derives the theoretical predictions of the model. Section 1.5 presents the data and empirical methodology. Section 1.6 presents empirical results and section 1.7 concludes.

1.2 Related Literature

This paper contributes to a large literature on the transmission of monetary policy shocks by characterizing how invoicing imports and exports in a global trade currency effects monetary policy transmission within and across borders. The existing literature has largely focused on models in which countries are symmetric (Clarida et al., 2002; Bacchetta and van Wincoop, 2005; Floden and Wilander, 2006; Engel, 2011) or in which 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 analyzes the macroeconomic consequences of introducing an asymmetry in currency invoicing across countries. Furthermore, the literature typically studies 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) who allow for "dominant currency invoicing" (invoicing in one particular country's currency) in a small open economy setting.

This paper also relates to a literature on exchange rate pass through by identifying and analyzing higher frequency effects of exchange rate movements. In general, this literature focuses on measuring long run consequences of exchange rate movements in macroeconomic variables (Gopinath and Rigobon, 2008; Burstein and Gopinath, 2014; Gopinath, 2015). By focusing on high-frequency monetary policy shocks, I identify causal relationships between monetary policy, exchange rate movements and changes in interest rates. Within this literature, my paper is most similar to Boz et al. (2017). Boz et al. (2017) also use currency invoicing data from Gopinath (2015) to understand heterogeneity in exchange rate pass through in the medium- to long-run. My results for nominal exchange rates complement lower frequency empirical evidence from Boz et al. (2017). Moreover, I contribute to this literature by analyzing the theoretical implications of the patterns in invoicing currencies for monetary policy, as well as by providing new empirical results showing spillover effects to asset prices and from multiple central banks.

This paper contributes to a growing literature measuring the consequences of monetary policy using high frequency measures of monetary policy shocks (Kuttner, 2001; Gurkaynak et al., 2005; Gertler and Karadi, 2015; Gorodnichenko and Weber, 2016; Leombroni et al., 2017; Ozdagli and Weber, 2017; Wiriadinata, 2017). The methodology in my paper is most similar to that of Nakamura and Steinsson (2015) in the sense that I also focus on measuring responses in high frequency outcomes. The literature focuses on measuring the effects of U.S. monetary policy shocks and estimating the reaction of U.S. macroeconomic and financial variables. A notable exception is Rey (2014), who extends the methodology in Gertler and Karadi (2015) to measure the effect of U.S. monetary policy shocks on macroeconomic variables in a sample of four foreign countries. Complementary work by Wiriadinata (2017) studies the effect of U.S. monetary policy shocks on exchange rates in credit constrained countries and shows that countries with larger amounts of dollar denominated debt are more exposed to U.S. monetary policy shocks. This paper focuses on a sample of advanced economies, which are unlikely to credit constrained. I extend the methodology used in this literature to analyze monetary policy spillovers across countries. Furthermore, I show monetary policy spillovers emanate from non-U.S. central banks as well. Finally, Shah (2017) uses high frequency asset pricing data to argue for an incomplete asset markets explanation of joint movements in exchange rates and long-term bond yields. [2]

2. A separate literature looks at returns on asset prices on monetary policy announcement days (Savor

Finally, this paper is related to a growing literature in international finance that studies the effects of heterogeneity across countries on exchange rates, currency returns and capital accumulation (Martin, 2012; Hassan, 2013; Maggiori, 2013; Richmond, 2015; Farhi and Gabaix, 2015; Hassan et al., 2016, 2017). This paper studies a different form of heterogeneity that influences how shocks transmit across countries, and drives variation in the properties of asset prices across countries.

1.3 The Model

I develop a static open economy New Keynesian model to capture key features of the distribution in currency invoicing. The model builds on canonical open economy New Keynesian models (Floden and Wilander, 2006; Engel, 2011) by allowing for heterogeneity in currency invoicing across countries. In each country, a fraction of firms invoice their exports in domestic currency, whereas the remainder of firms invoice their exports in a global trade currency.

I also allow for heterogeneity in country sizes and heterogeneity in household preferences for varieties of traded goods. These additional forms of heterogeneity have been shown to be important for explaining cross-sectional patterns in international trade and in asset prices (Martin, 2012; Hassan, 2013). I will later show that the impact of these additional forms of heterogeneity on the monetary policy transmission mechanism is fully captured by heterogeneity in currency invoicing. Hence, it is enough to only look at variation in currency invoicing of imports and exports to understand cross-sectional variation in monetary policy spillovers.

To develop intuition for the role of currency invoicing in transmitting monetary policy shocks, I first analyze a model in which financial markets are complete. However, the complete markets model has well known empirical short-comings. Hence, I later extend the complete markets model to allow for segmented markets where only a subset of households within each country have access to complete asset markets. The remaining households in

and Wilson, 2013; Lucca and Moench, 2015; Brusa et al., 2015; Mueller et al., 2017).

each country can only hold nominal bonds denominated in domestic currency. I show that the empirical predictions of the complete markets model continue to hold in an incomplete markets environment.

1.3.1 Households

Two time periods exist: $t = 1, 2$. A unit mass of households is partitioned into three countries. For expositional purposes, I label these countries the United States (US), Japan (JP) and Europe (EU). Let μ^n denote the mass of households residing in country n. Households in each country gain utility from consumption and disutility from providing labor services. In country n, a mass μ^n of firms also exists, 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. In this manner, all households within a country are identical.

Households in country n behave according to the following utility function,

$$U^n = \mathbb{E} \sum_{t=1,2} \beta^{t-1} \left\{ \frac{\left(C_t^n\right)^{1-\gamma}}{1-\gamma} - \frac{\left(N_t^n\right)^2}{2} \right\}. \tag{1.1}$$

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. This aggregate consumption bundle is comprised of traded and non-traded goods,

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

τ governs the share of the country n household's aggregate consumption that is comprised of traded goods. $C_{N,t}^n$ represents the household's consumption of its country specific non-traded good, and $C_{T,t}^n$ represents country n household's consumption of an aggregate traded good comprised of traded goods from each country:

$$C^n_{T,t} = \left(C^n_{T,US,t}\right)^{\alpha^n_{US}} \left(C^n_{T,JP,t}\right)^{\alpha^n_{JP}} \left(C^n_{T,EU,t}\right)^{\alpha^n_{EU}}.$$

$C^n_{T,m,t}$ represents a consumption bundle of intermediate traded goods produced by firms in country m and consumed in country n for $m \in \{US, JP, EU\}$. The parameters α^n_m determine what fraction of country n's traded consumption is comprised of intermediate traded goods produced in country m. These parameters can be thought of as capturing differences in trade costs or preferences across countries. I assume $\alpha^n_{US} + \alpha^n_{EU} + \alpha^n_{JP} = 1$. Each consumption bundle of intermediate traded goods is a CES aggregate of differentiated intermediate traded goods from within each country:

$$C^n_{T,m,t} = \left[\int_0^{\mu^m} \left(C^n_{T,m,j,t}\right)^{\varepsilon} dj\right]^{\frac{1}{\varepsilon}}. \tag{1.2}$$

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

At the start of each period, each household in country n is endowed with $Y^n_{N,t}$ units of the non-traded good, where $Y^n_{N,t}$ is log-normally distributed:

$$\log\left[Y^n_{N,t}\right] \sim N\left(-\frac{1}{2}\sigma^n, \sigma^n\right).$$

1.3.2 Firms

Intermediate traded goods are produced by employing labor. In country m, firm j's output of its variety of intermediate traded good is

$$Y_{T,m,j,t} = A^m_t \mu^m N_{m,j,t},$$

where $N_{m,j,t}$ is the quantity of labor firm j demands in country m from each household, and A_t^m is the aggregate productivity shock to the intermediate traded sector of country m:

$$\log\left[A_t^m\right] \sim N\left(-\frac{1}{2}\sigma_T^m, \sigma_T^m\right).$$

I assume the intermediate traded goods firms either invoice their exports (sales to foreign households) in domestic currency or in U.S. dollars. Within each country, firms only differ in their choice of invoicing currency. In country m, a fraction $X_\$^m$ of firms invoice their exports in dollars. The remaining fraction $1 - X_\$^m$ of firms invoice their exports in domestic currency. Domestic sales of intermediate traded goods are invoiced in domestic currency.

Nominal prices in the first period are set prior to the realization of productivity shocks, endowments of non-traded goods and monetary policy actions. Nominal prices of intermediate traded goods are fixed in their currency of invoicing in the first period, and I assume the law of one price holds for traded goods. Hence, the nominal price of any intermediate traded good in yen is equal to the nominal price of the traded good in dollars multiplied by the yen - dollar exchange rate:

$$\tilde{P}_{T,m,j,t}^{JP} = \tilde{E}_t^{JP,US}\tilde{P}_{T,m,j,t}^{US}. \tag{1.3}$$

$\tilde{P}_{T,m,j,t}^n$ 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. Throughout this paper, tildes present nominal prices.

These pricing assumptions capture key features of the international price system described in Gopinath (2015). The following example provides intuition for the consequences of these pricing assumptions. Consider a firm located in the United States that invoices its exports in dollars. Suppose this firm sets the nominal price of its exports as P dollars. Because nominal prices of intermediate traded goods are fixed in their currency of invoicing, then regardless of any changes in the nominal exchange rate between the dollar and the yen, households in Japan pay a price in yen equivalent to P dollars for the intermediate traded good. If the dollar depreciates relative to the yen, this good becomes relatively cheaper for Japanese households to consume.

I assume nominal prices adjust freely in the second period. Thus, monetary policy shocks in the model only affect real allocations in the short run, and they are interpreted as temporary shocks.

1.3.3 Monetary Policy

Prices of intermediate traded goods are fixed in the first period, central banks can use monetary policy to affect first-period allocations. I assume the monetary policy action of the central bank in each country is to choose the domestic aggregate nominal price level. Because the final consumption bundle is a Cobb-Douglas aggregate of traded and non-traded goods, Appendix A.1.1 shows the aggregate nominal price level, $\tilde{P}_t^n$, in country n can be written as

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

$\tilde{P}_{T,t}^n$ is the nominal price index for the consumption of intermediate traded goods for households in country n. I assume the central bank of country n chooses $\tilde{P}_t^n$. The nominal prices of traded goods, $\tilde{P}_{T,t}^n$, and non-traded goods, $\tilde{P}_{N,t}^n$ adjust once the central bank chooses the aggregate price level in the country.

This form of monetary policy provides a convenient shorthand for modeling some other forms of monetary policy. For example, it is equivalent to explicitly introducing money into the model, forcing households to purchase goods using cash holdings and allowing the central bank to control the money supply. Within models with money explicitly introduced, the central bank determines the aggregate nominal price level, $\tilde{P}^n$, by changing the money supply.

Intuitively, one can also think of an increase in the aggregate nominal price level as a currency devaluation. When the central bank increases $\tilde{P}_t^n$, more units of country n currency are required to purchase a unit of final consumption in country n. Hence, each unit of country n currency purchases fewer real consumption goods. As the real value of the currency decreases, the relative cost of traded goods whose prices are fixed in that currency decreases as well, which stimulates production.

1.3.4 Financial Markets

Households trade a complete set of state-contingent claims denominated in U.S. dollars. Because I do not introduce any frictions into financial markets, which currency is used to denominate the state-contingent claims is irrelevant. The state of world at date t is determined by the endowment of non-traded goods, $Y_{N,t}^n$, the productivity shocks to traded production, A_t^n, and monetary policy actions, $\tilde{P}_t^n$. In this sense, households can use state-contingent claims to insure against non-traded endowment shocks, productivity shocks and monetary policy actions.

However, frictions exist in goods markets such that consumption risk is not perfectly shared across countries. First, a fraction of each household's consumption cannot be traded across borders. Second, I assume households must use domestic currency to purchase domestic consumption. Hence, households cannot fully insure against non-traded endowment shocks and monetary policy actions.

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. The country n household faces the following budget constraint:

$$\mathbb{E}\left\{\sum_{t=1,2} Q_t \tilde{E}_t^{US,n}\left[\tilde{P}_{N,t}^n C_{N,t}^n + \sum_{i\in\{US,JP,EU\}}\left(\int_0^1 \tilde{P}_{T,i,j,t}^n C_{T,i,j,t}^n dj\right)\right]\right\} = \tag{1.4}$$

$$\mathbb{E}\left\{\sum_{t=1,2} Q_t \tilde{E}_t^{n,US}\left(\tilde{P}_{N,t}^n Y_{N,t}^n + \tilde{W}_t^n N_t^n + \tilde{\Gamma}_t^n\right)\right\} + \kappa^n.$$

$\tilde{W}_t^n$ 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 these prices are denominated in country n currency.

Q_t is the price of a state-contingent claim. I multiply Q_t by the nominal exchange rate $\tilde{E}_t^{US,n}$ to translate the domestic currency value of household wealth into dollars.

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

1.3.5 Solving the Model

This section describes first order conditions for the households' problem. All households within a country face the same optimization problem. I relegate the intermediate firm's pricing decision to the Appendix. [3]

Households maximize utility (1.1) subject to their budget constraints (1.4). The first order condition for households in country n with respect to their intermediate traded consumption of good j produced in country m is,

$$\alpha_m^n \tau \frac{C_t^n}{C_{T,m,t}^n} \left(\frac{C_{T,m,t}^n}{C_{T,m,j,t}^n} \right)^{1-\varepsilon} = \frac{\tilde{P}_{T,m,j,t}^n}{\tilde{P}_t^n}. \tag{1.5}$$

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

$$(1-\tau)\frac{C_t^n}{C_{N,t}^n} = \frac{\tilde{P}_{N,t}^n}{\tilde{P}_t^n} \tag{1.6}$$

3. See Appendix A.1.2 for additional details and the derivation of the first order conditions.

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

$$C_t^{\gamma} N_t^n = \frac{\tilde{W}_t^n}{\tilde{P}_t^n}. \tag{1.7}$$

These first order conditions describe the demand side of the economy and hold in each period regardless of the nominal rigidity in the supply side of the economy.

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

$$Y_{T,m,j,t} = A_t^m \mu^m N_{m,j,t} = \sum_{n \in \{US,JP,EU\}} \mu^n C_{T,m,j,t}^n \tag{1.8}$$

Recall that $N_{m,j,t}$ denotes the quantity of labor each firm j demands in country m from each household. Hence, $\mu^m N_{m,j,t}$ is the total quantity of labor firm j in country m demands. Households consume their endowment of non-traded goods:

$$Y_{N,t}^n = C_{N,t}^n. \tag{1.9}$$

Finally, the labor market clearing condition for households in country m is,

$$N_t^m = \int_0^{\mu^n} N_{m,j,t} dj. \tag{1.10}$$

All firms within a country and invoicing in dollars face the same optimization problem and demand the same quantity of labor. The same is true for firms invoicing in domestic currency within a country. Let $N_{m,\$,t}$ represent labor demand by firms in country m that invoice in dollars, and let $N_{m,h,t}$ represent labor demand by firms that invoice in domestic (home) currency, I can rewrite equation (1.10) as $N_t^m = \mu^m X_\$^m N_{m,\$,t} + \mu^m (1 - X_\$^m) N_{m,h,t}$.

For all pairs of countries n and m, the nominal exchange rate can be derived by taking the ratio of households' first order conditions with respect to aggregate consumption. Naturally, the nominal exchange rate between two countries is the ratio of the countries' marginal utilities of aggregate consumption divided by the nominal price level:

$$\frac{\left(C_t^n\right)^{-\gamma}}{\tilde{P}_t^n} = \frac{\left(C_t^m\right)^{-\gamma}}{\tilde{E}_t^{n,m}\tilde{P}_t^m}. \tag{1.11}$$

The nominal exchange rate $\tilde{E}^{n,m}$ is defined 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 $\left\{C_{T,m,j,t}^n, C_{N,t}^n, N_t^n\right\}$, a set of intermediate output, labor demand and nominal prices for each intermediate firm $\left\{Y_{T,m,j,t}^n, N_{m,j,t}, \tilde{P}_{T,m,j,t}^n\right\}$, a set of traded good prices and non-traded good prices $\left\{\tilde{P}_{T,t}^n, \tilde{P}_{N,t}^n\right\}$, a set of nominal wages for each country and a nominal exchange rate $\left\{\tilde{W}_t^n, \tilde{E}_t^{n,m}\right\}$, such that households maximize utility subject to their budget constraints, and the resource constraints are satisfied.

1.4 Theoretical Results

The model characterizes how heterogeneity in currency invoicing influences the monetary policy transmission across countries. I use the model to provide intuition and to derive empirical predictions. To study the model in closed form, I log-linearize the model around the deterministic solution. [4] Lowercase variables denote logs. I focus on the first period because nominal rigidites only affect allocations in the short-run. Hence, I drop the time t subscript whenever possible. All variables represent first-period prices and allocations unless otherwise noted.

Monetary policy shocks from the United States affect the demand for all dollar invoiced intermediate traded goods. Suppose the United States engages in contractionary monetary policy and decreases the log U.S. nominal price level, $\tilde{p}^{US}$. Mechanically, this action increases the nominal value of the dollar relative to all other currencies. Fewer dollars are needed to purchase a unit of the final consumption bundle in the United States. Hence, each dollar

4. See Appendix A.1.3 for additional details.

is more valuable. When the dollar appreciates with respect to foreign currency, the cost of dollar invoiced intermediate traded goods increases in terms of foreign currency. This increases the cost of the foreign household's traded consumption bundle. In response, foreign households decrease their consumption of traded and final consumption. The response of Japanese household consumption to U.S. contractionary policy is

$$-\frac{\partial c^{JP}}{\partial \tilde{p}^{US}} = -\frac{\gamma\tau^2(1+(\gamma-1)\tau)\nu_\alpha^{US}}{\nu} - \frac{(1-\tau)(1+(\gamma-1)\tau)}{\nu} \underbrace{\tau\left(\alpha_{US}^{JP} + X_\$^{EU}\alpha_{EU}^{JP}\right)}_{M_\$^{JP}} \tag{1.12}$$

$\nu_\alpha^{US} = \left(1-\alpha_{EU}^{EU}\right)\left(1-\alpha_{JP}^{JP}\right) - \left(1-X_\$^{JP}\right)\left(1-X_\$^{EU}\right)\alpha_{JP}^{EU}\alpha_{EU}^{JP}$ is a positive constant. ν is a positive constant, which I discuss below. $M_\$^{JP}$ is the equilibrium share of Japan's aggregate consumption bundle that is invoiced in dollars. It is comprised of the share α_{US}^{JP} of goods Japanese households import from the United States and the share $X_\$^{EU}\alpha_{EU}^{JP}$ of dollar invoiced goods Japanese households import from Europe multiplied by the share of traded goods in aggregate consumption, τ. The effect of contractionary U.S. monetary policy on consumption in Europe is analogously defined where $M_\$^{EU} = \tau\left(\alpha_{US}^{EU} + X_\$^{JP}\alpha_{JP}^{EU}\right)$.

The first line of equation (1.12) is a term that is common to the effect of U.S. monetary policy on Japanese and European consumption. It shows that, on average, contractionary U.S. monetary policy should decrease foreign consumption, and foreign consumption should decrease more when a larger share of global trade is invoiced in dollars. The coefficient in front of the $\alpha_{JP}^{EU}\alpha_{EU}^{JP}$ term captures how dollar invoicing increases the average effect of U.S. monetary policy on foreign consumption. If all firms invoiced their exports in domestic currency $\left(X_\$^{JP} = X_\$^{EU} = 0\right)$, U.S. monetary policy would only affect relative prices of traded goods when trading with the United States. The relative prices of trade goods between Europe and Japan would be unaffected. Dollar invoicing by Japanese and European firms allows U.S. monetary policy to distort the relative prices of traded goods between Japan and Europe.

The second line on the right-hand side shows countries with a larger share of dollar invoiced consumption see their consumption decrease more. Moreover, heterogeneity in the monetary policy spillover effect to consumption is fully captured by $M^n_\$$, even though α^n_m and $X^n_\$$ differ across countries. Households that consume more dollar invoiced intermediate traded goods observe a price increase over a larger share of their traded consumption bundle. Hence, their consumption of traded goods falls more.

ν is a positive constant that captures the degree of risk-sharing across countries. The expression for ν is relegated to Appendix A.1.4. Appendix A.1.4 also derives two properties of ν.

Lemma 1. *ν is positive and increasing in α^n_m for all $n \neq m$.*

A positive ν allows me to sign analytic expressions. The fact that ν increases with α^n_m for $n \neq m$ means increased risk sharing across countries dampens monetary policy spillover effects. α^n_m determines the share of country n household's traded consumption that is comprised of imports from country m. If $\alpha^n_m = 0$ for all $n \neq m$, countries only consume traded goods produced domestically. No country trades with any other. Positive α^n_m allow countries to share risk by shipping traded goods to households with high marginal utilities of consumption.

1.4.1 Monetary Policy

A central component for the implementation of monetary policy in the New Keynesian literature is the short-run trade-off between output and inflation. The previous section showed that patterns of currency invoicing impact how domestic monetary policy affects foreign demand. As a result, the share of firms that invoice their exports in dollars matters for determining the domestic central bank's trade-off between output and inflation.

Proposition 1. *Holding foreign monetary policy constant, the response of domestic traded production to domestic monetary policy is decreasing in the share of the country's dollar* *invoiced exports* $\left(X_{\$}^{n}\right)$. *Hence, central banks of countries where a larger share of firms invoice their exports in foreign currency face a steeper Phillips Curve.*

Proof. See Appendix A.1.7 □

In an open economy, the central bank policy affects demand from domestic households as well as foreign households. Suppose the central bank of Japan engages in contractionary monetary policy to decrease domestic production. Part of the contractionary effect comes from households decreasing consumption of Japanese goods in the rest of the world, because contractionary monetary policy increases the relative cost of yen invoiced traded goods.

The strength of the effect of Japanese monetary policy on foreign consumption of Japanese goods depends on the share of Japanese firms that invoice their exports in yen. In the limiting case, if no firms in Japan invoiced their exports in yen, then changes to relative value of the yen have no impact on the relative price of Japanese traded goods abroad. In this case, Japanese monetary policy only affects domestic demand. Foreign demand for Japanese produced goods would be tied to the relative value of the U.S. dollar. Hence, the effect of Japanese monetary policy on foreign demand decreases with the share of firms that invoice exports in dollars.

In the real world, data from Gopinath (2015) show that a significant number of countries invoice the majority of their exports in foreign currencies, e.g., the U.S. dollar. Proposition 1 suggests the central banks of these countries incur a greater cost of inflation for each change in domestic output. In this sense, central banks in countries where a large fraction of firms invoice their exports in foreign currency should be less effective at implementing monetary policy.

Prior literature has shown that empirical estimates of Phillips curves are strongly subject to specification and sampling uncertainty. As a result, empirical studies of the New Keynesian Phillips curve often give rise to conflicting results (Mavroeidis et al., 2014). However, the model yields a number of other predictions for key variables in the New Keynesian framework that are easier to measure. In the following sections, I characterize how heterogeneity in currency invoicing affects monetary policy transmission into these components of the open economy New Keynesian framework: the real interest rate, the nominal interest rate, the real exchange rate, the nominal exchange rate and the level of output.

1.4.2 Exchange Rates and Interest Rates

A country's nominal dollar exchange rate is comprised of its real dollar exchange rate and the differences in nominal price levels between countries,

$$\tilde{e}^{n,US} = \underbrace{-\gamma\left(c^{n} - c^{US}\right)}_{\text{real exchange rate}} - \left(\tilde{p}^{n} - \tilde{p}^{US}\right).$$

U.S. monetary policy affects three components of this equation: the nominal price level in the United States, the consumption in the United States and the consumption in country n. However, heterogeneity in the transmission of U.S. monetary policy shocks only comes from the heterogeneous impact of U.S. monetary policy on consumption in country n within the real exchange rate.

Prediction 1. *Holding foreign monetary policy constant, U.S. contractionary monetary policy should cause foreign currencies to depreciate against the U.S. dollar. Countries with higher $M_{\$}^{n}$ depreciate less than countries with lower $M_{\$}^{n}$.*

Equation (1.13) shows contractionary U.S. monetary policy causes all other currencies to depreciate against the dollar:

$$-\frac{\partial \tilde{e}^{n,US}}{\partial \tilde{p}^{US}} = \frac{(1-\tau)(1+(\gamma-1)\tau)(1+\left(\gamma\left(2-\alpha_{JP}^{JP}-\alpha_{EU}^{EU}\right)-1\right)\tau)}{\nu} - \frac{\gamma(1-\tau)(1+(\gamma-1)\,\tau)}{\nu}M_{\$}^{n}. \tag{1.13}$$

The first line of equation (1.13) describes the common component of U.S. monetary policy spillover onto foreign nominal exchange rates. Because the nominal exchange rate is given as units of foreign currency per dollar, this equation shows that more units of foreign currency are needed to purchase a dollar. Hence, foreign currencies depreciate against the dollar.

This average effect has two components. As mentioned above, one component is mechanical: contractionary monetary policy decreases the number of dollars used to purchase a unit of final consumption in the U.S, which increases the value of each dollar. The second component to this effect transmits itself through the real exchange rate. Contractionary U.S. monetary policy decreases household consumption in the United States, which increases the U.S. household's marginal utility of consumption. A unit of the U.S. final consumption bundle becomes more valuable in real terms, which also increases the real value of the dollar.

The second line on the right-hand side is country specific and shows heterogeneity in import currency invoicing fully captures the variation in monetary policy spillovers. Countries with higher shares of dollar invoiced consumption depreciate less with respect to countries with lower shares of dollar invoiced consumption. Equation (1.12) shows contractionary U.S. monetary policy decreases aggregate consumption more in foreign countries with a larger share of dollar invoiced imports. Hence, their marginal utility of consumption increases relative to countries with a smaller share of dollar invoiced consumption. Because the real exchange rate between two countries is the ratio of their marginal utilities of consumption, countries with larger shares of dollar invoiced consumption appreciate, in real terms, relative to countries with smaller shares of dollar invoiced consumption.

Prediction 2. *Holding foreign monetary policy constant, contractionary monetary policy from the United States should increase foreign nominal interest rates. Countries with higher* $M_{\$}^n$ *observe larger increases in nominal interest rates than countries with lower* $M_{\$}^n$*.*

The nominal interest rate, $\tilde{R}^n$, in country n is pinned down by the following consumption Euler equation:

$$\frac{1}{\tilde{R}^n} = \beta \mathbb{E}\left[\left(\frac{C_2^n}{C_1^n}\right)^{-\gamma} \frac{\tilde{P}_1^n}{\tilde{P}_2^n}\right]. \tag{1.14}$$

Holding foreign monetary policy fixed, the U.S. monetary policy action affects foreign real interest rates by changing the foreign household's marginal utility of consumption in the first period, C_1^n. Foreign consumption in the long-run , C_2^n, is unaffected because nominal prices are flexible in the second period.

Contractionary policy from the United States increases the foreign marginal utility of consumption today. Hence, both the real and nominal interest rate in the foreign country increase. Nominal interest rates in countries with a higher share of dollar invoiced consumption increase more, because their consumption decreases more.

1.4.3 Policy Spillovers from Other Central Banks

Although I have focused on discussing monetary policy spillovers from the United States in the model, monetary policy spillovers should clearly emanate from all countries.

Prediction 3. *Controlling for the share of consumption that is invoiced in each country's currency, the magnitude of spillover effects from Japanese monetary policy and the European monetary policy are the same as the magnitude of the spillover effects from U.S monetary policy.*

The magnitude of monetary policy spillover effects only differs according to the share of international trade that is invoiced in each currency. Equation (1.15) shows the effect of a Japanese contractionary monetary policy shock on yen exchange rates:

$$-\frac{\partial e^{n,JP}}{\partial \tilde{p}^{JP}} = \frac{(1-\tau)(1+(\gamma-1)\tau)(1+\left(\gamma\nu_\alpha^{JP}-1\right)\tau)}{\nu} - \frac{\gamma(1-\tau)(1+(\gamma-1)\tau)}{\nu}M_{¥}^n, \quad (1.15)$$

where $\nu_\alpha^{JP} = 2 - \alpha_{US}^{US} - \alpha_{EU}^{EU} - X_\$^{JP}\alpha_{JP}^{US} - X_\$^{EU}\alpha_{EU}^{US}$ and $M_{¥}^n = \tau\alpha_{JP}^n\left(1 - X_\$^{JP}\right)$ is the share of country n's total consumption that is invoiced in yen. It is the product of the share of country n imports produced in Japan (α_{JP}^n), the share of Japanese traded goods invoiced in yen ($1 - X_\$^{JP}$), and the share of traded goods in aggregate consumption (τ).

Comparing the second lines from equations (1.13) and (1.15) shows the heterogeneity in monetary policy spillovers from the United States and Japan are exactly the same after controlling for currency invoicing. Monetary policy spillovers from Japan naturally increase in magnitude with the share of a country's yen invoiced consumption. Symmetry in monetary policy spillover effects in exchange rates exists for consumption and interest rates as well. I formally derive these results in Appendix A.1.5.

1.4.4 Production

In this section, I characterize the role of currency invoicing in determining monetary policy spillovers to traded production. Aggregate output in the traded sector of country m is the weighted sum of its production invoiced in dollars and its production invoiced in domestic currency,

$$y_T^m = \mu^m X_\$^m y_{T,m,\$} + \mu^m \left(1 - X_\$^m\right) y_{T,m,h}.$$

$y_{T,m,h}$ represents the production in a firm that invoices its exports in domestic currency. As we have shown earlier, contractionary U.S. monetary policy decreases the production of traded goods. As the dollar appreciates, households' traded consumption becomes more expensive, and households demand fewer traded goods.

The magnitude of the effect of contractionary U.S. policy on production in country m is a weighted average of the effect of U.S. monetary policy on the consumption of country m intermediate traded goods in each country:

$$\frac{\partial y_{T,m}}{\partial \tilde{p}^{US}} = \sum_{n \in \{US,JP,EU\}} \frac{\mu^n \alpha_m^n}{\mu^{US} \alpha^U S_m + \mu^{JP} \alpha_m^{JP} + \mu^{EU} \alpha_m^{EU}} \left(\frac{\partial c_{T,m}^n}{\partial \tilde{p}^{US}} \right).$$

The weights are a function of the size of each country (μ^n), and how much each country prefers different varieties of traded goods, (α_m^n). The demand function for country m intermediate traded goods, $c_{T,m}^n$, further depends heavily on the preference parameters (α_m^n), and the elasticity of substitution between different varieties of traded goods (ε). Hence, analytic expressions of the demand function can be difficult to analyze in closed form.

To characterize this spillover effect, I simplify the model and consider a world in which countries are more symmetric. Let $\mu^n = 1/3$, $\alpha^n_n = \alpha$ for all countries n and $\alpha^n_m = (1-\alpha)/2$ for $n \neq m$. Hence, all countries are the same size, and the share of domestically produced traded goods in each household's final consumption bundle is the same across all countries. The parameter α determines household demand for foreign traded goods. Higher α forces households to consume fewer foreign traded goods. However, each household consumes an equal share of traded goods from each foreign country.

These assumptions force the demand functions of all firms to become symmetric along all dimensions except currency invoicing. In this special case, the behavior of U.S. monetary policy spillover effects onto foreign traded production mirrors Predictions 1 through 3.

Prediction 4. *Suppose countries are symmetric. Holding foreign monetary policy constant, contractionary monetary policy shock from the U.S. should decrease foreign traded production. Countries with higher $X^n_\$$'s should observe larger decreases in traded production more than countries with smaller $X^n_\$$'s.*

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

$$-\frac{\partial y^n_T}{\partial \tilde{p}^{US}} = -\delta_y - \frac{(1-\alpha)(1-\tau)(1+(\gamma-1)\tau)\left(1+(3/4)\left(\gamma(1-\alpha)-1-\alpha\right)\tau\right)}{\nu} X^n_\$, \quad (1.16)$$

where δ_y is a constant relegated to Appendix A.1.6.

Equation (1.16) shows the impact of U.S. monetary policy on foreign traded production increases in proportion to the country's share of dollar invoiced exports. Each firm that invoices its exports in dollars observes a greater drop in demand for its intermediate traded good compared to firms that invoice their exports in local currency. Hence, the aggregate effect depends on the total mass of firms in each country that invoice in dollars. As households demand more foreign produced traded goods (α decreases), the magnitude of these spillover effects increase.

1.4.5 Incomplete Asset Markets

Although the complete asset markets model is an important benchmark, it has some well known empirical shortcomings. One key shortcoming is that it predicts a perfect negative correlation between appreciations in the real exchange rate and aggregate consumption (Backus and Smith, 1993). Hence, it predicts changes in asset prices across countries are also perfectly negatively correlated with changes in consumption. As a result, many authors have argued for an incomplete asset market model in which the effect of monetary shocks on equilibrium exchange rates improves the fit of the model to the data (Alvarez et al., 2002).

I extend the model in section 1.3 and characterize the effect of currency invoicing on monetary policy spillovers when markets are segmented. [5] Within each country, only a fraction ϕ of households (labeled "active") trade a complete set of state-contingent securities. The remaining $1 - \phi$ of households (labeled "inactive") are excluded from trading in financial markets. Instead, inactive households cede the claims to their firm profits and their endowments of non-traded goods to active households. In return, inactive households receive a nominal bond that makes a fixed nominal payment $\tilde{B}_t^n$ in each period.

Exchange rates and interest rates are determined by the marginal utility of consumption of active households only. Equations (A.14), (A.15) and (A.16) provide the incomplete markets counterparts to equations (1.13), (1.12) and (1.16). These equations show that in the incomplete markets model, U.S. monetary policy shocks still transmit more to countries with a larger share of dollar invoiced consumption. In particular, a contractionary U.S. monetary policy shock decreases the consumption of active households more in countries with a higher share of dollar invoiced consumption relative to countries with a lower share of dollar invoiced consumption. Hence, Proposition 1 and Predictions 1 through 4 hold in the incomplete markets model. [6]

The introduction of incomplete asset markets does however break the tight link between

5. See Appendix A.1.8 for the formal setup.

6. See Appendix A.1.8 for a formal proof.

changes in aggregate consumption and movements in asset prices across countries. When the United States engages in contractionary monetary policy, a consequence of the decrease in demand for intermediate traded goods is that labor demand and wages decrease for inactive households in Japan and Europe. However, labor income decreases more for inactive households in Japan, which is the country with fewer dollar invoiced imports. Hence, the relative change in inactive household consumption is exactly opposite of the relative change in active household consumption. Contractionary monetary policy from the U.S. decreases inactive household consumption more in countries with fewer dollar invoiced imports as a share of per capita consumption.

Equation (A.18) in Appendix A.1.8 shows that even though the consumption of active households in Europe decrease relative to the consumption of active households in Japan, aggregate consumption in Europe can increase relative to aggregate consumption in Japan under certain parameter combinations. [7] Thus, the incomplete markets model extension to the model in section 1.3 achieves two goals. First, the incomplete markets model reinforces the insights from the model with complete financial markets. Second, incomplete markets can improve the quantitative implications of the model by breaking the perfectly negative correlations between exchange rates and aggregate consumption across countries.

1.5 Empirical Analysis and Data

The model in section 1.3 predicts monetary policy from any country affects exchange rates, interest rates and production, globally, when nominal prices are sticky and traded goods are invoiced in that country's currency. Heterogeneity in currency invoicing of imports and exports characterizes the strength of these monetary policy spillover effects. Rather than test the implications of the model for New Keynesian Phillips curves or aggregate consumption directly, I investigate Predictions 1 through 4. To re-iterate, empirical estimates of New

7. For example, $\phi \in [1/2, 2/3]$ and $\gamma > \frac{\phi}{\varepsilon\tau(1-(3/2)\phi}$.

Keynesian Phillips curves are subject to a number of concerns, which often lead to conflicting results. Furthermore, the previous section showed that only the consumption of the marginal investor is relevant for explaining changes in interest rates and exchanges rates. However, it is often hard to identify the consumption of the marginal investor, and changes in the consumption of the marginal investor are not equivalent to changes in aggregate consumption.

Hence, the model yields four testable implications. In response to contractionary U.S. monetary policy, countries with higher shares of dollar invoiced imports (1) should observe their currencies appreciate and (2) should observe their nominal interest rates increase relative to countries with lower shares of dollar invoiced imports. (3) Controlling for heterogeneity in currency invoicing, the magnitude of monetary policy spillover effects from any one central bank foreign onto exchange rates and interest rates should be the same. Finally, (4) in response to contractionary U.S. monetary policy, countries with a larger share of dollar invoiced exports should observe their traded production decrease more.

1.5.1 Monetary Policy Shock Data

For the majority of the analysis, I use high frequency measurements of Federal Reserve monetary policy shocks from Nakamura and Steinsson (2015), which are available from the authors' websites. I use their time series for U.S. "policy news shocks" from 1995 to 2014 as my independent variables. The authors measure changes in five interest rate futures of differing maturities in a 30 minute window around FOMC announcements. The U.S. "policy news shock" is the first principle component of the change in these five interest rate futures. These shocks are re-scaled such that a 1% shock increases the 1-year U.S. Treasury yield by 1%.

High frequency measurements of monetary policy shocks provide an estimate of the unexpected component of U.S. monetary policy. The identifying assumption is that all other sources of macroeconomic news and investor expectations are already incorporated into prices 30 minutes prior to the FOMC meeting. Hence, any changes in futures prices in a narrow minute window around FOMC meetings only capture the unexpected news from the FOMC meeting itself. Nakamura and Steinsson (2015) use a composite measure of monetary policy shocks from five interest rate futures to capture the possible effects of forward guidance along with Federal Reserve actions that target shorter maturity yields.

Unfortunately, no consistent measure of monetary policy shocks across the other large central banks exists. Hence, I construct a new data set of monetary policy shocks across four central banks in a consistent manner. The central banks in my sample are the Federal Reserve Bank, the European Central Bank, the Bank of England and the Bank of Japan. I gather the list of scheduled monetary policy announcement days for each central bank in my sample, and I measure changes in three month interest rate futures denominated in each central bank's currency on each monetary policy announcement day. Table A.1 lists the central banks in my sample as well as their corresponding interest rate futures. By choosing interest rate futures with the same maturity, I consistently define monetary policy shocks across central banks: A monetary policy shock is an unexpected policy action that moves the three month interest rate future denominated in the domestic currency. I only measure changes in one futures contract, because interest rate futures of other maturities are not available for all central banks in the sample.

Furthermore, I only daily changes interest rate futures data from Bloomberg, because I do not have access to tick-level data. Figure 1.2 plots U.S. monetary policy shocks derived from daily changes in three-month Eurodollar futures against corresponding shocks from Nakamura and Steinsson (2015). I only plot observations of monetary policy shocks on monetary policy announcement days in my sample. The slope of the regression line is one, and the correlation between the two measures is 0.74. Hence, these two measures of monetary policy are highly correlated. However, monetary policy shocks from three-month interest rate futures do appear to contain more background noise, which should decrease the statistical power in the analysis with multiple central banks.

In my analysis, I use the set of monetary policy announcement dates between January

1999 and December 2014 for which I observe monetary policy shocks. Following Nakamura and Steinsson (2015), I drop observations from the height of the financial crisis between June 30, 2008 and July 01, 2009. 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.

1.5.2 Other Data

I use currency invoicing data come from Gopinath (2015) to generate empirical counterparts to M_f^n and X_f^n from section 1.3. The data are available from the author's website, and describe the share of each country's imports and exports that are invoiced in various currencies. In both the complete markets model in Section 1.3 and the incomplete markets extension in Section 1.4.5, the relevant variables are the share of consumption invoiced in dollars, $M_{\$}^n$, and the share of exports invoiced in dollars, $X_{\$}^n$. I use annual import and consumption data from the Penn World Tables to estimate the average value of each country's imports invoiced in various currencies as a share of private consumption.

The data only describe cross-sectional variation in the currency invoicing of imports and exports, because the currency invoicing data are reported at the country - currency level and averaged over the years 1999 to 2014. However, Gopinath (2015) notes these invoicing shares are fairly stable over time. [8] Across all countries in my sample the mean of each country's dollar invoiced share of consumption, $M_{\$}^n$, is 0.349 and its standard deviation is 0.186. The mean of each country's share of dollar invoiced exports, $X_{\$}^n$, is 0.409 and its standard deviation is 0.235.

My high-frequency dependent variables are changes in nominal exchange rates and nominal interest rates on monetary policy announcement days. I gather all available dollar based forward contracts and the corresponding spot exchange rate data from Thomson Reuters Datastream.

8. See Appendix A.3.2 for additional details about the construction of M_f^k.

I construct nominal interest rates for each country applying covered interest rate parity. If covered interest rate parity holds, the nominal interest rates of the United States and a foreign country, n, are related as follows:

$$\left(1+\tilde{r}_{t,t+n}^{USA}\right)^n = \left(1+\tilde{r}_{t,t+n}^{n}\right)\frac{F_{t,t+n}^{USA,n}}{E_t^{USA,n}}. \tag{1.17}$$

$\tilde{r}_{t,t+n}^{f}$ 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. [9] I use forward data to construct nominal interest rates to address concerns that nominal interest rates derived from nominal bond yields would reflect differences in country specific risk premia. These effects would be outside the scope of the theoretical model presented in Section 1.3.

I use lower-frequency measures of industrial production to test the model's implications for traded production. I gather monthly indices on countries' industrial production from the OECD. For the exact series labels, see Appendix A.3.4. One important difference between the OECD data and the financial data is that I observe industrial production for each country within the Eurozone. Hence, I use variation in invoicing shares across Eurozone countries when using these data.

Table A.2 lists the countries in my sample along with their data availability. These countries are Australia, Canada, Denmark, Iceland, Israel, Japan, Norway, South Korea, Sweden, Switzerland, the United Kingdom and the United States. I include the Eurozone when studying changes in exchange rates and interest rates. I include all Eurozone countries when studying changes in industrial production . I focus on a sample of advanced economies

9. For additional details see Appendix A.3.3.

for which I observe currency invoicing data. [10] I drop observations at the country-date level of countries engaged in a hard or soft currency peg with the central bank that issues the monetary policy shock. [11] Tables A.3 and A.4 provide summary statistics for monetary policy shocks and country - central bank level characteristics.

1.6 Empirical Strategy and Results

First, I test the predictions of the model with regards to exchange rates and interest rates, using U.S. monetary policy shocks as well as monetary policy shocks from other central banks. Afterwards, I follow procedures in Gertler and Karadi (2015) to translate daily measures of U.S. monetary policy from Nakamura and Steinsson (2015) into monthly measures, and I test the model's predictions with regards to traded production.

1.6.1 High Frequency Outcomes

To test the effect of U.S. monetary policy shocks on nominal interest rates and nominal exchange rates, equation (1.13) suggests I run the following regression,

$$\Delta y_t^n = \delta_t + \beta_M M_{\$}^n + \gamma_M \left(\Delta i_{\$,t} \times M_{\$}^n \right) + \epsilon_t^n. \tag{1.18}$$

Δy_t^n is the change in country n's outcome variable on date t, which is either the country's nominal exchange rate or the country's nominal interest rate. δ_t is a date t fixed effect that captures the first line of equation (1.13). It is the average response of the dependent variable to the monetary policy on date t. $\Delta i_{\$,t}$ is the monetary policy shock from the Federal Reserve on date t. $M_{\$}^n$ is the value of country n's dollar invoiced imports normalized by consumption. The coefficient of interest in equation (1.18) is γ_M. γ_M corresponds to

10. Countries in the sample are designated as advanced economies by the IMF's 2015 Economic Outlook

11. I use data from Shambaugh (2004) to address the concerns about exchange rate pegs. Shambaugh (2004) indicates which pairs of currencies are pegged in each month. See Appendix A.3.6 for details.

the coefficient in front of $M_{\$}^{n}$ in equation (1.13) and captures how heterogeneity in dollar invoicing in imports affects the magnitude of the spillover effect. I cluster my standard errors by date.

Table 1.1 presents regression results from estimating equation (1.18), using changes in nominal exchange rates as the outcome variable. Column (1) provides a benchmark estimate: a point estimate of -6.981 implies that if a country experiences a one standard deviation increase in $M_{\$}^{n}$, its currency depreciates by 130 fewer basis in response to a 100 basis point contractionary U.S. monetary policy shock. In response to a 100 basis point U.S. monetary policy contraction, the currencies in my sample depreciate by an average of 800 basis points. Hence, the effect of currency invoicing is economically large as well as statistically significant.

Column (2) of Table 1.1 splits $M_{\$}^{n}$ into the share of country n's imports invoiced in dollars (Dollar Import Share) and country n's imports normalized by consumption (Imports / Cons.). The result in the second column shows that both components of $M_{\$}^{n}$ are important for explaining variation in monetary policy spillover effects. These results further support the theoretical mechanism by showing that both components of $M_{\$}^{n}$ are needed to explain heterogeneity in monetary policy spillovers. Countries are more affected by U.S. monetary policy shocks if imports make up a larger share of their consumption and if a larger share of the imports they consume are invoiced in dollars.

The major concern with the regression results is that another underlying characteristic of countries is driving co-movement in the outcome variables, and this underlying characteristic is also correlated with firms' decisions to invoice in dollars. Throughout this section, I test the currency invoicing transmission channel against possible alternative transmission channels that are not directly related to the currency invoicing of imports and exports.

Columns (3) - (5) in Table 1.1 show the benchmark result is robust to controls for the distance between countries, the share of each country's imports that originates from the United States and a country's dollar denominated net debt position. [12] The concern is that

12. Wiriadinata (2017) shows that a country's dollar denominated net debt position characterizes exchange

countries close to the United States are more exposed to U.S. monetary policy shocks, and firms in these countries also choose to invoice in dollars. However, proximity to the United States is the true monetary policy transmission mechanism. By itself, distance significantly affects the magnitude of monetary policy spillovers from the United States. Countries that are further from the U.S. depreciate more against the dollar in response to contractionary U.S. monetary policy shocks (not shown). However, when I control for both distance and currency invoicing, only the currency invoicing variable significantly explains cross-sectional variation in monetary policy transmission from the United States. The same is true regarding the share of trade each country conducts with the United States, and each country's dollar denominated net debt asset position.

Table 1.2 provides the corresponding regression results using changes in one-year nominal interest rates as the outcome variable. A benchmark point estimate of 2.844 implies that if a country experiences a one standard deviation increase in $M_{\$}^{n}$, its nominal interest rate will increase by an additional 53 basis points in response to a 100 basis point contractionary U.S. monetary policy shock. This effect is large relative to a one percent increase in U.S. nominal interest rates and statistically significant. Column (2) further supports the theoretical mechanism by showing that monetary policy transmission is explained by the combination of the share of each country's imports that are invoiced in dollars as well as each country's import to consumption ratio. Finally, columns (3) - (5) show that dollar invoicing in imports significantly explains cross-sectional variation in U.S. monetary policy spillovers even after controlling for additional measures of trade costs and net foreign assets. In a later section, I provide additional robustness tests for the empirical results in Tables 1.1 and 1.2.

Overall, the results in Tables 1.1 and 1.2 provide strong empirical support for Predictions 1 and 2 of the model. In response to contractionary U.S. monetary policy shocks, countries with a larger share of dollar invoiced imports see their currencies appreciate less and their

rate responses to U.S. monetary policy shocks among credit constrained countries. This paper focuses on advanced countries, which are unlikely to be credit constrained.

interest rates increase more relative to countries with a smaller share of dollar invoiced imports. Dollar invoicing in imports is important in explaining cross-sectional variation in monetary policy spillover effects. Countries with a greater share of dollar invoiced imports are more exposed to U.S. monetary policy shocks.

1.6.2 Robustness and Alternative Specifications

Tables 1.3 and 1.4 provide additional tests of the transmission mechanism. In all specifications, the outcome variables are changes in nominal exchange rates or nominal interest rates on U.S. monetary policy announcement days. All regressions include date fixed effects and the interaction term between the monetary policy shock and $M_{\$}^{n}$. Standard errors are always clustered by date.

An important feature of currency invoicing data is that nominal prices of intermediate traded goods are fixed in the short run. However, not all goods prices are equally sticky (Burstein and Gopinath, 2014). For example, commodities such as crude oil are often invoiced in dollars, but their prices are highly flexible and change frequently. Hence, the theory should predict that countries that primarily import traded goods with flexible prices should not be affected by foreign monetary policy shocks.

I verify that my results are not being driven by imports of dollar invoiced traded goods with highly flexible prices. Using the Rauch (1999) classification of traded goods, Burstein and Gopinath (2014) show the nominal prices of goods traded on an organized exchange or are priced off of a reference magazine are more flexible than the nominal prices of differentiated products (i.e. clothing). I use disaggregate Comtrade data and to calculate the share of each country's imports categorized as differentiated products (Diff. Share) based off of the Rauch (1999) classification. [13] The "Diff. Share" variable estimates the degree of price stickiness of a country's imports in the sense that the nominal prices of imports in countries that import

13. See Appendix A.3.9 for details about the Rauch (1999) classifications as well as my treatment of the data

more differentiated products should be more rigid.

Table 1.3 estimates equation (1.18), controlling for the share of differentiated products in each country's imports. I find suggestive evidence that countries with more differentiated products as a share of imports are more affected by U.S. monetary policy shocks. In particular, column (4) of Table 1.3 shows that the triple interaction term between the degree of import price stickiness (Diff. Share), the share of dollar invoiced consumption ($M^n_\$$) and the monetary policy shock, suggests the interaction between the share of imports that are differentiated products (Diff. Share) and the share of dollar invoiced consumption ($M^n_\$$) captures more of the variation in monetary policy spillovers to nominal interest rates than $M^n_\$$ alone. This result suggests price stickiness is important for the transmission of monetary policy shocks. The results in the previous section are are not being driven by imports of dollar invoiced commodities with flexible prices. Instead, they are driven by imports of differentiated products with rigid prices.

Table 1.4 estimates equation 1.18 using alternative cuts of the data or alternative measures of dollar invoicing. Looking across the top rows of Panels A and B, the regression results are all quantitatively and qualitatively similar to the results in Tables 1.1 and 1.2.

Recent papers suggest deviations from covered interest rate parity were large during and after the Great Recession (Du et al., 2016), which may introduce measurement error into my construction of nominal interest rates. Column 1 in Table 1.4 shows the results of estimating equation (1.18) using observations of monetary policy shocks prior to the height of the Great Recession (July, 2008). Another concern about the countries in my sample is that a few highly risky countries drive the empirical results. In another attempt to mitigate the effects of U.S. monetary policy on country specific risk premia, I collect monthly short term debt ratings from Fitch, and, in Column 2, I drop countries whose debt was ever rated below BBB-. Column 3 in Table 1.4 normalizes the value of each country's dollar invoiced imports by GDP, rather than consumption. The point estimates are larger in column 3 because GDP is a larger denominator than private consumption. However, the direction of the spillover effects remains the same. Finally, column 4 in Table 1.4 uses a longer window around each monetary policy shock. I measure changes in nominal exchange rates and nominal interest rates from one day prior to the monetary policy announcement to three days after the monetary policy announcement. Hence, I find empirical support for Predictions 1 and 2 across all alternative specifications.

1.6.3 Foreign Monetary Policy Reactions

Throughout this paper, I have interpreted movements in foreign interest rates and exchange rates as being determined by financial markets. However, one concern is that my empirical results are instead driven by the actions of foreign central banks reacting to U.S. monetary policy. Specifically, if central banks in countries with higher shares of dollar invoiced consumption increase their policy rates more in response to U.S. monetary policy contraction, then the patterns in the data would be the result of foreign monetary policy reactions.

I find no evidence, in the data, that my results are driven by foreign monetary policy reactions. I gather data on central bank policy rates of foreign central banks in each of the countries in my sample from Global Financial Data [14]. I measure changes in foreign central bank policy rates in the 30 days and the 60 days after each Federal Reserve monetary policy announcement. Table 1.5 estimates equation (1.18) using these 30 day and 60 day changes in foreign central bank policy rates as the dependent variable. In both regressions, the coefficient on the interaction term between the Federal Reserve monetary policy shock and the share of dollar invoiced consumption is statistically insignificant. Hence, I fail to find evidence that countries with higher shares of dollar invoiced consumption systematically respond more to U.S. monetary policy.

14. See Appendix A.3.10 for additional details

1.6.4 Is the Federal Reserve Special?

I generate a sample of monetary policy shocks consistently measured across four central banks — the Federal Reserve Bank of the United States, the European Central Bank, the Bank of Japan and the Bank of England and test whether monetary policy spillover effects emanate from other central banks. Similar to the Federal Reserve, the additional three central banks manage interest rates in economies with freely floating currencies and hold regularly scheduled meetings to decide policies. Prediction 3 suggests cross-sectional heterogeneity in monetary policy spillover effects from any central bank is captured by variation in the each country's share of consumption invoiced in that central bank's currency, M_f^n. Using the sample of monetary policy shocks from all central banks, I estimate equation (1.18). Afterwards, I augment equation (1.18) with an indicator variable $D_{FRB,t}$, which equals 1 if the monetary policy shock on date t was issued by the Federal Reserve:

$$\Delta y_t^n = \delta_t + \beta_M M_f^n + \gamma_M \left(\Delta i_{f,t} \times M_f^n\right) + \gamma_{M,FRB} \left(\Delta i_{f,t} \times M_f^n \times D_{FRB,t}\right) + \epsilon_t^n. \quad (1.19)$$

Prediction 3 suggests the coefficient on the triple interaction between the monetary policy shock, the import currency variable, and the Federal Reserve indicator is zero, $\gamma_{M,FRB} = 0$.

Table 1.6 presents regression results from estimating equations (1.18) and (1.19) using the pooled sample of monetary policy shocks from all central banks. Columns (1) and (3) provide an estimate of the average effect of import currency invoicing on cross-sectional variation in monetary policy spillovers. The regression results show currency invoicing of imports explains variation in monetary policy spillovers across all central banks. When the European Central Bank issues a contractionary monetary policy shock, countries with a larger share of Euro invoiced consumption see their Euro exchange rates depreciate less and their nominal interest rates increase relative to countries with a smaller share of Euro invoiced imports. Furthermore, the magnitude of these coefficients remains large and quantitatively similar to the results using Nakamura and Steinsson (2015) shocks. If a country experiences a one standard deviation increase in M_f^n, a contractionary monetary policy shock from central bank f causes its exchange rate to depreciate by 97 fewer basis points and its nominal interest rates to increase by an additional 33 basis points.

Columns (2) and (4) in Table 1.6 provide a direct test of prediction 3 and do not find evidence that monetary policy spillover effects are larger for U.S. monetary policy shocks. In both regressions, I fail to reject the null hypothesis that $\gamma_{M,FRB} = 0$. However, the standard errors around the point estimates of γ_M and $\gamma_{M,FRB}$ are both large, which suggests the lack of statistical power to make the more precise statement that $\gamma_{M,FRB}$ is zero. Nevertheless, taken together, the results in Table 1.6 support Prediction 3.

1.6.5 Industrial Production

In this section, I test for monetary policy spillover effects from U.S. monetary policy to foreign industrial production. I use the measure of industrial production from the OECD, and I follow procedures in Gertler and Karadi (2015) to translate daily U.S.monetary policy shocks from Nakamura and Steinsson (2015) into monthly shocks. [15] In the end, I obtain a series of average monthly monetary policy shocks from the Federal Reserve, and a panel of monthly (log) changes in industrial production across 29 countries.

I modify equation (1.18) to account for the fact that I am using lower-frequency data in which the reactions to monetary policy shocks may not be realized immediately. Equation (1.16) from the model suggests I run regressions of the following form,

$$\Delta y_{t+\tau}^n = \alpha^n + \delta_t + \beta_X X_\$^n + \gamma_X \left(\Delta i_{\$,t-1} \times X_\$^n \right) + \epsilon_t^n. \tag{1.20}$$

The outcome variable $\Delta y_{t,t+\tau}^n$ is the (log) change in country n's industrial production index from month t to month $t + \tau$. $X_\$^n$ is the share of country n's exports that are invoiced in dollars. Finally, I introduce a country fixed effect α^n to control for trends.

15. See Appendix A.3.1 for a detailed description of the procedure.

The method for generating monthly monetary policy shocks essentially assigns to each month a weighted average of daily shocks that occur between 30 days prior to the first day of the month and the last day of the month. This procedure introduces some correlation between monetary policy shocks of subsequent months. Hence, I estimate equation (1.20) twice. First, I estimate equation (1.20) as written. Afterwards, I control for one lag of the monetary policy shock variable and using non-overlapping observations. I cluster standard errors at the monthly level in both specifications.

The coefficient of interest in equation (1.20) is γ_X. Prediction 4 suggests that whenever the United States engages in contractionary monetary policy, industrial production decreases more in countries with a larger share of dollar invoiced exports, $\gamma_X < 0$.

I estimate regression (1.20) for all time horizons, τ, up to 36 months, and I plot γ_X at each horizon in Figure 1.3. In general, I find empirical support for Prediction 4. Figure 1.3 shows that countries with a higher share of dollar invoiced exports do observe a larger decrease in their industrial production, in the medium run, relative to countries with a smaller share of dollar invoiced exports. The magnitude of these monetary policy spillover effects appear to increase with the time horizon τ, which corresponds with previous studies that show U.S. monetary policy shocks affect aggregate macroeconomic outcomes with a lag.

Table (1.7) shows more detailed regression results every six months. A point estimate of -0.495 at 30 months implies that a country that experiences a one standard deviation increase in $X^n_\$$ observes its industrial production decrease by an additional 12 basis points in response to a 100 basis point contractionary U.S. monetary policy shock. Figure (1.4) and Table (1.8) provide corresponding results using non-overlapping observations and controlling for an additional lag in the monetary policy shock variable, Δi_{t-2}. These results are qualitatively and quantitatively similar to the previous results when I do not control for lags. However, the standard errors around the point estimates are slightly larger, because estimate the regression using only half the data.

Taken together, the empirical findings support Prediction 4. When the United States issues a contractionary monetary policy shock, countries that invoice a larger share of their exports in dollars observe a larger decrease in industrial production. Furthermore, the timing of these effects are consistent with Gertler and Karadi (2015), who also find the strongest effects of monetary policy shocks between two to three years.

1.7 Conclusion

This paper analyzed the implications of heterogeneity in currency invoicing on monetary policy transmission. I present a model of currency invoicing that captures key features of the international price system: the vast majority of imports and exports in the world are invoiced in very few currencies, and goods prices tend to be sticky in their currency of invoicing in the short run. As a result, the central banks of countries where a larger fraction of firms invoice their exports in foreign currency should face a worse trade-off between output and inflation. Furthermore, I derive testable predictions characterizing how heterogeneity in currency invoicing affects monetary policy transmission to other key components of the New Keynesian framework across countries.

The empirical part of the paper provides support for each of the theoretical predictions of the model. I show heterogeneity in the import invoicing currencies explains the heterogeneity in monetary policy transmission from the Federal Reserve to foreign nominal exchange rate, nominal interest rates and industrial production across a sample of advanced economies. Additionally, I provide evidence that monetary policy spillovers emanate from other central banks in the world. Monetary policy spillover effects appear larger for the Federal Reserve because of the prevalence of the dollar as a global trade currency.

The focus of this paper has been on characterizing monetary policy spillovers through trade channels within a group of advanced economies. This leaves a number of avenues for future research: First, it would be useful to begin characterizing how other forms of heterogeneity influence monetary policy transmission across a larger set of countries. A notable contribution towards this goal is Wiriadinata (2017), which shows how a country's new dollar denominated debt position is important for monetary policy transmission across credit constrained countries. Second, the paper leaves out an interesting discussion of risk premia. In particular countries that invoice their exports in a global trade currency should be more exposed to monetary policy risk from abroad. Finally, the empirical section of the paper leaves open the larger task of measuring and characterizing the effects of monetary policy transmission from other central banks. This paper provides evidence that monetary policy actions from other central banks are an important source of shocks. A first step would be to measure tick-level futures data for other interest rate futures.

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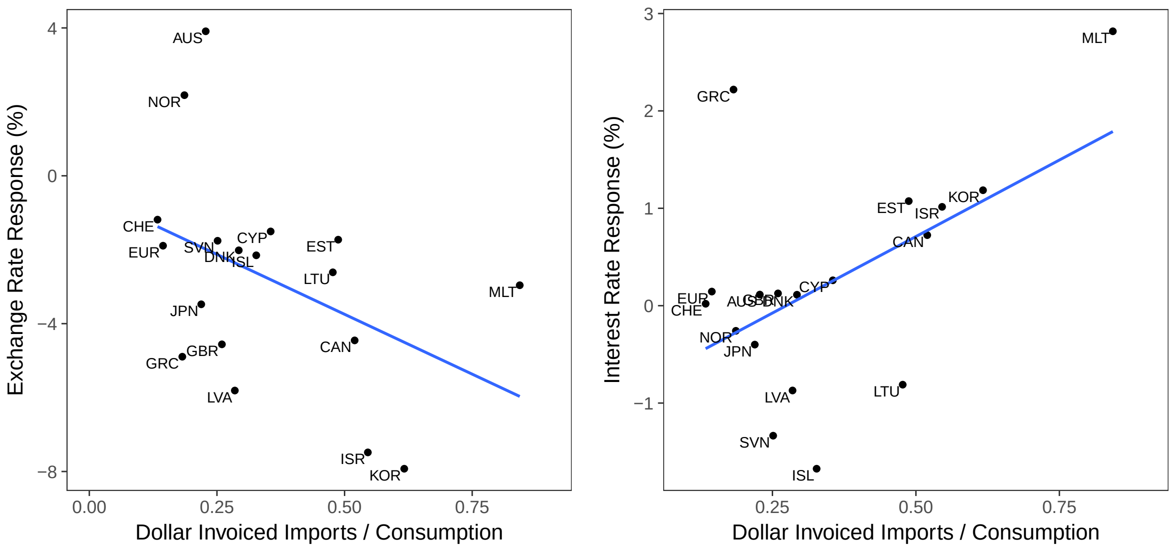
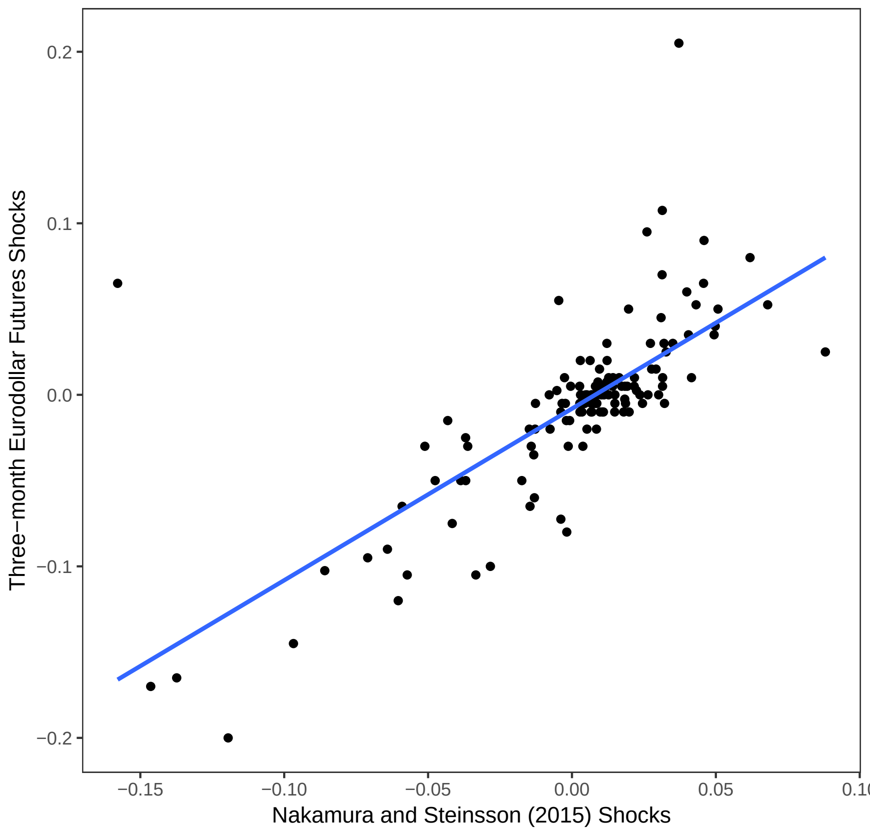
Figure 1.1: Average Responses to U.S. Monetary Policy Shocks



Notes: I estimate the following 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. $\beta = -6.476$, $R^2 = 0.13$. 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. $\beta = 3.142$, $R^2 = 0.23$. The sample consists of monetary policy announcement days between Jan. 1999 through Mar. 2014, excluding the height of the financial crisis (Jul. 2008 - Jun. 2009).

Figure 1.2: U.S. Monetary Policy Shock Comparison



Notes: The figure plots U.S. monetary policy shocks derived from changes in three-month Eurodollar futures on U.S. monetary policy announcement days against those from Nakamura and Steinsson (2015). The slope of the regression line is 1.000 and the intercept is -0.008. The correlation between the two measures of monetary policy shocks is 0.74.

Table 1.1: Nominal Exchange Rate Response: Nakamura and Steinsson (2015) Shocks

	Dependent variable: Nominal Exchange Rates				
	(1)	(2)	(3)	(4)	(5)
$M^n_\$ \times \Delta i_{f,t}$	-6.981^{***}		-6.669^{***}	-6.368^{***}	-12.340^{***}
	(2.193)		(2.146)	(1.589)	(3.424)
(Imports / Cons.) $\times \Delta i_{f,t}$		-2.144^{**}			
		(0.881)			
(Dollar Import Share) $\times \Delta i_{f,t}$		-8.846^{***}			
		(3.177)			
Distance $\times \Delta i_{f,t}$			0.667	0.664	0.949
			(0.411)	(0.413)	(0.910)
US Import Share $\times \Delta i_{f,t}$				−2.603	−1.096
				(10.859)	(10.037)
$(\text{NetDebt}_{\$,t-1}/Y) \times \Delta i_{f,t}$					−0.045
					(0.037)
Observations	1,675	1,675	1,675	1,675	1,501
Adjusted R^2	0.638	0.639	0.638	0.638	0.620

Notes: This table presents regression results from estimating equation (1.18). The dependent variable is changes in nominal exchange rates. $M^n_\$$ is the value country n's dollar invoiced imports normalized by consumption. (Imports / Cons.) is country n's total imports as share of its consumption and (Dollar Import Share) represents the share of country n's imports that is invoiced in dollars. $M^n_\$ =$ (Dollar Import Share) $\times$ (Imports / Cons.). Distance is the log of the populaiton weighted distance between country n and the United States. US Import Share is the value of each country's imports from the U.S. normalized by consumption. $(\text{NetDebt}_{\$,t-1}/Y)$ is the country's dollar denominated net debt position. Standard errors in parentheses are clustered by date. *p<0.1; **p<0.05; ***p<0.01

Table 1.2: Nominal Interest Rate Response: Nakamura and Steinsson (2015) Shocks

	Dependent variable: Nominal Interest Rates (1Y)				
	(1)	(2)	(3)	(4)	(5)
$M^n_{\$} \times \Delta i_{f,t}$	2.844***		2.916***	2.761***	1.915***
	(0.824)		(0.846)	(0.904)	(0.686)
(Imports / Cons.) $\times \Delta i_{f,t}$		1.002***			
		(0.380)			
(Dollar Import Share) $\times \Delta i_{f,t}$		1.969***			
		(0.653)			
Distance $\times \Delta i_{f,t}$			0.241*	0.376	0.473
			(0.145)	(0.234)	(0.289)
US Import Share $\times \Delta i_{f,t}$				1.151	2.604
				(1.304)	(1.755)
$(NetDebt_{\$,t-1}/Y) \times \Delta i_{f,t}$					0.007
					(0.005)
Observations	1,366	1,366	1,366	1,366	1,280
Adjusted R^2	0.156	0.153	0.157	0.158	0.175

Notes: This table presents regression results from estimating equation (1.18). The dependent variable is changes in one-year nominal interest rates. $M^n_{\$}$ is the value country n's dollar invoiced imports normalized by consumption. (Imports / Cons.) is country n's total imports as share of its consumption and (Dollar Import Share) represents the share of country n's imports that is invoiced in dollars. $M^n_{\$}$ = (Dollar Import Share) × (Imports / Cons.). Distance is the log of the populaiton weighted distance between country n and the United States. US Import Share is the value of each country's imports from the U.S. normalized by consumption. $(\text{NetDebt}_{\$,t-1}/Y)$ is the country's dollar denominated net debt position. Standard errors in parentheses are clustered by date. *p<0.1; **p<0.05; ***p<0.01

Table 1.3: Nakamura and Steinsson (2015) Shocks, Controlling for Product Pricing

	Nominal Exchange Rate		*Nominal Interest Rate (1Y)*	
	(1)	(2)	(3)	(4)
$M^n_\$ \times \Delta i_{f,t}$	-5.251^{*}	-3.679	2.663^{***}	-0.110
	(3.022)	(11.414)	(0.800)	(1.284)
Diff. Share $\times \Delta i_{f,t}$	-5.101		0.616	
	(3.533)		(0.388)	
Diff. Share $\times M^n_\$ \times \Delta i_{f,t}$		-3.775		3.626^{**}
		(11.252)		(1.742)
Observations	1,675	1,675	1,366	1,366
Adjusted R^2	0.639	0.638	0.157	0.159

Notes: Table 1.3 estimates equation (1.18) controlling for how products are priced according to Rauch (1999). The outcome variable in columns (1) and (2) is the nominal exchange rate. The outcome variable in columns (3) and (4) is the one year nominal interest rate. Diff. Share is the share of each country's imports that are differentiated products (not traded on an organized exchange or reference priced). Standard errors in parentheses are clustered by date. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 1.4: Nakamura and Steinsson (2015) Shocks, Alternative Specifications

	(1)	(2)	(3)	(4)
Panel A:	*Nominal Exchange Rates*			
$M_{\$}^{n} \times \Delta i_{\$,t}$	-6.652^{***}	-4.978^{***}	-9.741^{***}	-5.850^{**}
	(2.120)	(1.859)	(2.648)	(2.396)
Observations	1,201	1,236	1,675	1,675
Adjusted R^2	0.601	0.644	0.638	0.620
Panel B:	*Nominal Interest Rates (1Y)*			
$M_{\$}^{n} \times \Delta i_{\$,t}$	2.877^{***}	3.296^{***}	4.383^{***}	2.712^{***}
	(0.816)	(0.916)	(1.356)	(0.561)
Observations	892	1,068	1,366	1,294
Adjusted R^2	0.249	0.315	0.155	0.040

Notes: This table estimates equation (1.18) using various alternative specifications. The dependent variable in Panel A is the change in nominal exchange rate and the dependent variable in Panel B is the change in the one year nominal interest rate. Column (1) only uses observations monetary policy shocks prior to the height of the financial crisis, June 2007. Column (2) restricts the sample of countries to those that maintained a Fitch sovereign bond credit rating above BBB- throughout the entirety of the sample. Column (3) normalizes $M_{\$}^{n}$ by GDP rather than consumption. Column (4) measures changes outcome variables from one day prior to the monetary policy announcement day to three days after the announcement day. Standard errors are clustered by date. *p<0.1; **p<0.05; ***p<0.01

Table 1.5: Foreign Monetary Policy Rate Responses

	30 Day Response	60 Day Response
	(1)	(2)
$M_{\$}^{n} \times \Delta i_{f,t}$	-0.020	-0.036
	(0.067)	(0.064)
Observations	1,142	1,133
Adjusted R^2	0.015	0.047

Notes: This table estimates equation (1.18) using responses in foreign central bank monetary policy rates to Federal Reserve monetary policy shocks as the dependent variable. I measure changes in foreign central bank policy rates in the 30 days and the 60 days after Federal Reserve monetary policy announcements. Standard errors are clustered by date. *p<0.1; **p<0.05; ***p<0.01

Table 1.6: Pooled Regressions: Multiple Central Banks

	Nominal Exchange Rate		*Nominal Interest Rate (1Y)*	
	(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

Notes: Table 1.6 presents regression results from estimating equation (1.18) using data from multiple central banks. $\Delta i_{f,t}$ is the measurement of the monetary policy shock from central bank f on date t. M_f^n is the value country n's imports invoiced in country f currency and normalized by consumption. Nominal exchange rates are denominated in the currency of the central bank that issues the monetary policy shock. Standard errors in parentheses are clustered by date. *p<0.1; **p<0.05; ***p<0.01

Figure 1.3: Relative Change in Industrial Production

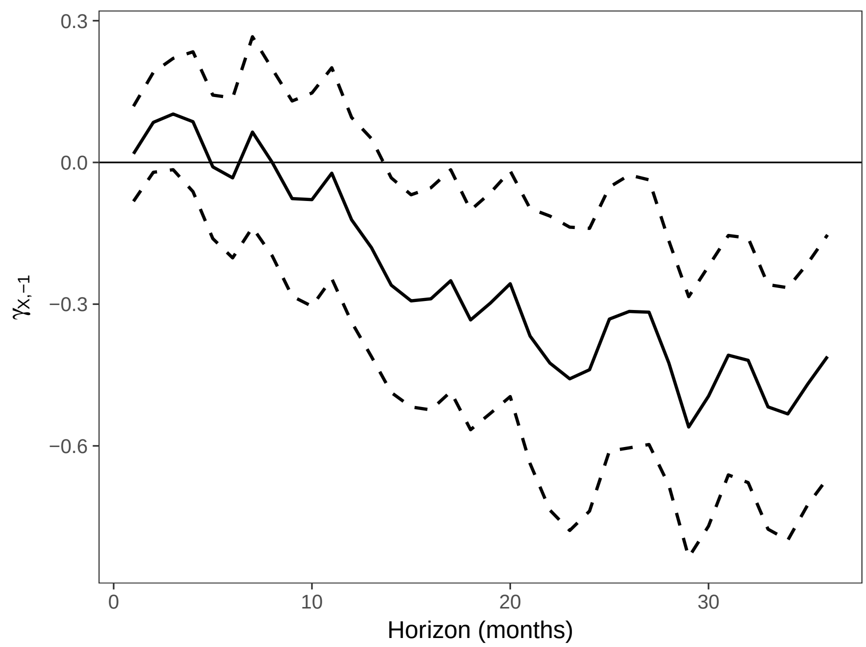


Table 1.7: Relative Change in Industrial Prodcution

τ (months)	6	12	18	24	30	36
$X^n_{\$} \times \Delta i_{US,t}$	-0.033	-0.121	-0.333^{**}	-0.439^{***}	-0.495^{***}	-0.411^{***}
	(0.103)	(0.132)	(0.141)	(0.182)	(0.167)	(0.157)
Date Fixed Effects	Y	Y	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	3,358	3,231	3,105	2,974	2,842	2,719
Adj. R-sqr	0.285	0.554	0.649	0.681	0.722	0.746

Notes: $X^n_{\$}$ 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

Figure 1.4: Relative Change in Industrial Production Controlling for Lags

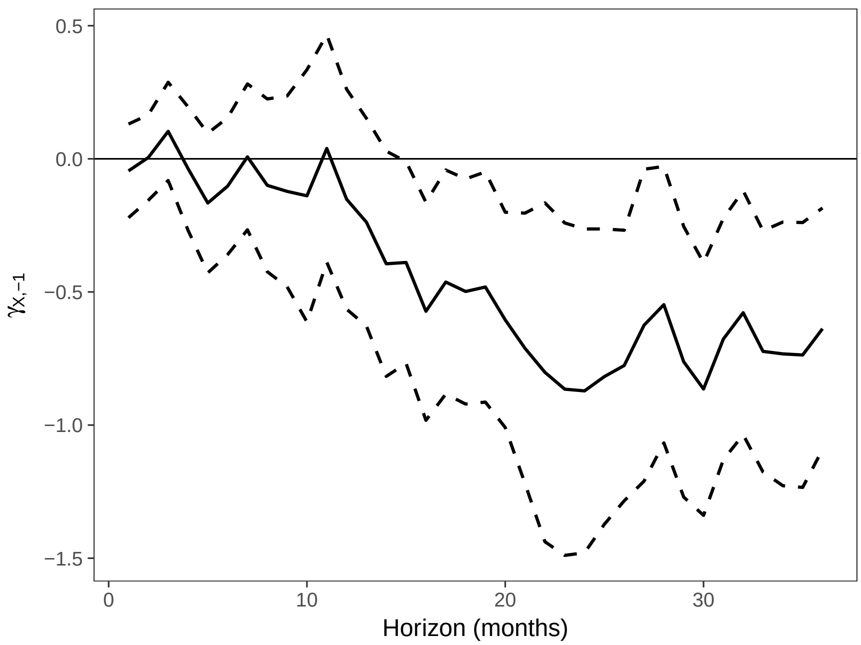


Table 1.8: Relative Change in Industrial Production Controlling for Lags

τ (months)	6	12	18	24	30	36
$X_{\$}^{n} \times \Delta i_{US,t}$	-0.103	-0.152	-0.498^{*}	-0.872^{**}	-0.865^{***}	-0.638^{**}
	(0.156)	(0.251)	(0.257)	(0.370)	(0.288)	(0.276)
Date Fixed Effects	Y	Y	Y	Y	Y	Y
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	1,680	1,616	1,553	1,488	1,422	1,360
Adj. R-sqr	0.267	0.547	0.648	0.682	0.726	0.744

Notes: $X_{\$}^{n}$ 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

APPENDIX A

APPENDIX

A.1 Appendix to the Theory Section

A.1.1 Deriving the Nominal Price Indices

In this section, I derive expressions for country n price indices for intermediate traded goods produced in country m, $\tilde{P}^n_{T,m}$, for aggregate consumption of traded goods, $\tilde{P}^n_T$, and for the aggregate consumption bundle of traded and non-traded goods, $\tilde{P}^n$.

In country n, the cost of a unit of traded consumption from country m is

$$\tilde{P}^n_{T,m} = \arg\min \int_0^{\mu^m} \tilde{P}^n_{T,m,j} C^n_{T,m,j} dj \text{ s.t. } \left[\int_0^{\mu^m} \left(C^n_{T,m,j} \right)^{\varepsilon} dj \right]^{\frac{1}{\varepsilon}} = 1$$

All country m intermediate traded goods invoiced in dollars have the same nominal price in country n, and all country m intermediate traded goods invoiced in domestic currency have the same nominal price in country n. Hence, I can re-write the optimization problem as,

$$\begin{aligned} \tilde{P}^n_{T,m} = \arg\min \mu^m X^m_{\$} \tilde{P}^n_{T,m,\$} C^n_{T,m,\$} + \mu^m \left(1 - X^m_{\$}\right) \tilde{P}^n_{T,m,h} C^n_{T,m,h} \\ \text{s.t. } \left[\mu^n X^m_{\$} \left(C^n_{T,m,\$} \right)^{\varepsilon} + \mu^n \left(1 - X^m_{\$}\right) \left(C^n_{T,m,h} \right)^{\varepsilon} \right]^{\frac{1}{\varepsilon}} = 1 \end{aligned}$$

I take first order conditions with respect to $C^n_{T,m,\$}$ and $C^n_{T,m,h}$ and take the ratio to solve for $C^n_{T,m,h}$,

$$C^n_{T,m,h} = C^n_{T,m,\$} \left(\frac{\tilde{P}^n_{T,m,\$}}{\tilde{P}^n_{T,m,h}} \right)^{\frac{1}{1-\varepsilon}}.$$

I solve for $C^n_{T,m,\$}$ by plugging this equation back into the constraint,

$$C^n_{T,m,j} = \left(\mu^m X^m_\$ + \mu^m \left(1 - X^m_\$\right) \left(\frac{\tilde{P}^n_{T,m,\$}}{\tilde{P}^n_{T,m,h}} \right)^{\frac{1}{1-\varepsilon}} \right)^{-\frac{1}{\varepsilon}}$$

$$= \left(\tilde{P}^n_{T,m,\$}\right)^{-\frac{1}{1-\varepsilon}} \left(\mu^m X^m_\$ \left(\tilde{P}^n_{T,m,\$}\right)^{\frac{\varepsilon}{\varepsilon-1}} + \mu^m \left(1 - X^m_\$\right) \left(\tilde{P}^n_{T,m,h}\right)^{\frac{\varepsilon}{\varepsilon-1}} \right)^{-\frac{1}{\varepsilon}}.$$

I use this equation to solve for $C^n_{T,m,h}$, plug $C^n_{T,m,\$}$ and $C^n_{T,m,h}$ into the objective and derive the following expression for $\tilde{P}^n_{T,m}$,

$$\tilde{P}^n_{T,m} = \left(\mu^m X^m_\$ \left(\tilde{P}^n_{T,m,\$}\right)^{\frac{\varepsilon}{\varepsilon-1}} + \mu^m \left(1 - X^m_\$\right) \left(\tilde{P}^n_{T,m,h}\right)^{\frac{\varepsilon}{\varepsilon-1}} \right)^{\frac{\varepsilon-1}{\varepsilon}}. \qquad \text{(A.1)}$$

In country n, the cost of a unit of the final traded consumption comprised of intermediate traded goods from each country is,

$$\tilde{P}^n_T = \arg\min \sum_{m=\{US,JP,EU\}} \tilde{P}^n_{T,m} C^n_{T,m} \text{ s.t. } \left(C^n_{T,US}\right)^{\alpha^n_{US}} \left(C^n_{T,JP}\right)^{\alpha^n_{JP}} \left(C^n_{T,EU}\right)^{\alpha^n_{EU}} = 1$$

First order conditions imply,

$$C^n_{T,JP} = \frac{\alpha^n_{JP}}{\alpha^n_{US}} \frac{\tilde{P}^n_{T,US}}{\tilde{P}^n_{T,JP}} C^n_{T,US} \text{ and } C^n_{T,EU} = \frac{\alpha^n_{EU}}{\alpha^n_{US}} \frac{\tilde{P}^n_{T,US}}{\tilde{P}^n_{T,EU}} C^n_{T,US}.$$

Plugging these values into the constraint, using the identity $\sum_{m=US,JP,EU} \alpha^n_m = 1$ and solving for $C^n_{T,US}$ yields,

$$\tilde{P}^n_{T,US} C^n_{T,US} = \frac{\alpha^n_{US}}{\left(\alpha^n_{US}\right)^{\alpha^n_{US}} \left(\alpha^n_{JP}\right)^{\alpha^n_{JP}} \left(\alpha^n_{EU}\right)^{\alpha^n_{EU}}} \left(\tilde{P}^n_{T,US}\right)^{\alpha^n_{US}} \left(\tilde{P}^n_{T,JP}\right)^{\alpha^n_{JP}} \left(\tilde{P}^n_{T,EU}\right)^{\alpha^n_{EU}}.$$

Plugging this equation into the objective yields,

$$\tilde{P}^n_T = \frac{\left(\tilde{P}^n_{T,US}\right)^{\alpha^n_{US}} \left(\tilde{P}^n_{T,JP}\right)^{\alpha^n_{JP}} \left(\tilde{P}^n_{T,EU}\right)^{\alpha^n_{EU}}}{\left(\alpha^n_{US}\right)^{\alpha^n_{US}} \left(\alpha^n_{JP}\right)^{\alpha^n_{JP}} \left(\alpha^n_{EU}\right)^{\alpha^n_{EU}}}. \tag{A.2}$$

In country n, the cost of a unit of the aggregate consumption bundle comprised of final traded goods and non-traded goods is,

$$\tilde{P}^n = \arg\min \tilde{P}^n_T C^n_T + \tilde{P}^n_N \text{ s.t. } \left(C^n_T\right)^{\tau} \left(C^n_N\right)^{1-\tau} = 1$$

Repeating the same steps as above yields the following expression for the aggregate nominal price level in country n,

$$\tilde{P}^n = \frac{\left(\tilde{P}^n_T\right)^{\tau} \left(\tilde{P}^n_N\right)^{1-\tau}}{(\tau)^{\tau} (1-\tau)^{1-\tau}}. \tag{A.3}$$

A.1.2 Deriving the Conditions of Optimality

In this subsection, I provide additional details about solving the model in Section 1.3. Households maximize utility (1.1) subject to their budget constraints (1.4). 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 1.4 equalizes $\Psi^n = \Psi^m$ for all n, m. For a household in country n, the first order condition with respect to the consumption of intermediate traded good j produced in country m, $C^n_{T,m,j,t}$, yields,

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

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

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

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

$$N_t^n = \Psi^n Q_t^n \tilde{W}_t^n.$$

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

$$(C_t^n)^{-\gamma} = \Psi^n Q_t^n \tilde{P}_t^n \tag{A.4}$$

I derive equations (1.5) - (1.7) by taking the ratio between the households's first order conditions with respect to intermeditate traded consumption, non-traded consumption and labor supply with the household's first order condition with respect to aggregate consumption.

I derive equation (1.11) by taking the ratio between the first order condition with respect to aggregate consumption for country n and country m, given by equation (A.4). I can cancel out the Lagrange multipliers, because $\Psi^h = \Psi^f$. Since I do not introduce and frictions into financial markets, $Q_t^n = \tilde{E}_t^{n,m} Q_t^m$. I simplify and recover equation (1.11).

In the remainder of this subsection, I solve the firm's problem. These equations are not shown in the main text. In both periods, the intermediate traded good firm maximizes profits by choosing the price of its variety of intermediary traded good. Firm j in country m faces the following demand function in country n,

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

In the second period, nominal prices are flexible and the firm j in country m chooses the nominal price of their traded good in each country and in each state of the world to maximize discounted profits,

$$\max_{\tilde{P}_{T,m,j,t}^n} \sum_{n\in\{US,JP,EU\}} \mu^n \left\{ \tilde{P}_{T,m,j,2}^n C_{T,m,j,2}^n - \tilde{W}_2^m \left(\frac{C_{T,m,j,2}^n}{A_2^m}\right)\right\} \tag{A.6}$$

I plug equation (A.5) into the equation (A.6), take first order conditions with respect to $\tilde{P}^n_{T,m,j,t}$, and I solve for $\tilde{P}^n_{T,m,j,t}$ This yields the typical result where the firm sets it's nominal price as a constant markup over marginal cost in domestic currency,

$$\tilde{P}^m_{T,m,j,2} = \frac{1}{\varepsilon}\frac{\tilde{W}^n_2}{A^n_2} \text{ and } \tilde{P}^n_{T,m,j,2} = \tilde{E}^{n,m}_2 \tilde{P}^n_{T,m,j,2}$$

In the first period, firms set prices before the realization of shocks to maximize expected discounted first period profits. Furthermore, firms that invoice their exports in a foreign currency need to set a domestic currency price as well as a foreign currency price.

If the firm only invoices in domestic currency (producer currency pricing), then it faces the following problem,

$$\max_{\tilde{P}^m_{T,m,j,1}} \mathbb{E}\left[Q^m_1 \sum_{n\in\{US,JP,EU\}} \mu^n \left\{\tilde{P}^m_{T,m,j,1} C^n_{T,m,j,1} - \tilde{W}^m_1 \left(\frac{C^n_{T,m,j,1}}{A^m_1}\right)\right\}\right].$$

Demand in each country each country is given by,

$$C^n_{T,m,j,1} = \left(\tilde{E}^{n,m}_1 \tilde{P}^m_{T,m,j,1}\right)^{\frac{1}{\varepsilon 1}} \left(\frac{\alpha^n_m}{\tau}\right)^{\frac{1}{\varepsilon-1}} \left(\frac{C^n_1}{\tilde{P}^n_1}\right)^{\frac{1}{\varepsilon-1}} \left(C^n_{T,m,1}\right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

I plug in the demand function into the firm's problem, take the first order condition with respect to $\tilde{P}^m_{T,m,j,1}$ and solve for the price,

$$\tilde{P}^m_{T,m,j,1} = \frac{\mathbb{E}\left[Q^m_1 \left(\tilde{W}^m_1 Y_{T,m,j,1}\right)/A^m_1\right]}{\mathbb{E}\left[Q^m_1 Y_{T,m,j,1}\right]}$$

where $Y_{T,m,j,1} = \sum_{n\in\{US,JP,EU\}} \mu^n C^n_{T,m,j,1}$ is the total output by firm j located in country m.

If the firm invoices in dollars, then the firm chooses a domestic currency price, $\tilde{P}^m_{T,m,j,1}$, as well as a dollar price, $\tilde{P}^{US}_{T,m,j,1}$, in order to maximize expected discounted first

$$\max_{\tilde{P}^{m}_{T,m,j,1},\tilde{P}^{US}_{T,m,j,1}} \mathbb{E}\left\{Q^m_1\left[\mu^m \tilde{P}^m_{T,m,j,1} C^m_{T,m,j,1} + \sum_{n\neq m} \mu^n \tilde{E}^{m,US}_1 \tilde{P}^{US}_{T,m,j,1} C^m_{T,m,j,1} - \tilde{W}^m_1 \left(\frac{\sum_n \mu^n C^n_{T,m,j,1}}{A^m_1}\right)\right]\right\}.$$

I plug in the demand function into the firm's problem, take the first order conditions and solve for the optimal prices,

$$\tilde{P}^m_{T,m,j,1} = \frac{\mathbb{E}\left[Q^m_1\left(\tilde{W}^m_1 C^m_{T,m,j,1}\right)/A^m_1\right]}{\mathbb{E}\left[Q^m_1 C^m_{T,m,j,1}\right]}$$

and

$$\tilde{P}^m_{T,m,j,1} = \frac{\mathbb{E}\left[Q^m_1\left(\tilde{W}^m_1 \sum_{n\neq m} \mu^n C^n_{T,m,j,1}\right)/A^m_1\right]}{\mathbb{E}\left[Q^{US}_1 \sum_{n\neq m} \mu^n C^n_{T,m,j,1}\right]}$$

where $Q^{US}_1 = Q^m_1 \tilde{E}^{m,US}_1$.

A.1.3 Log-Linear Approximation of the Equilibrium

I log-linearize the model around the following deterministic steady state:

$$A^n_t = \sqrt{(\varepsilon\mu^n)^{-1} \sum_m \mu^m \alpha^m_n}$$

$$C^n_{T,m,j,t} = \frac{\alpha^n_m}{\mu^m},\ C^n_{N,t} = Y^n_{N,t} = \prod_m \left[(\mu^m)^{-\frac{\alpha^n_m(1-\varepsilon)\tau}{\varepsilon(1-\tau)}} (\alpha^n_m)^{-\alpha^n_m \frac{\tau}{1-\tau}}\right]$$

$$Y_{T,m,j,t} = \frac{1}{\mu^m}\sum_n \mu^n \alpha^n_m,\ N_{m,j,t} = Y_{T,m,j,t}/A^m_t,\ N^n_t = \mu^n N_{n,j,t}$$

$$\tilde{P}^n_{T,m,j,t} = 1,\ \tilde{W}^n_t = \varepsilon A^n_t,\ \tilde{P}^n_{N,t} = (1-\tau)(\tau)^{-1+\frac{1}{(\gamma-1)(1-\tau)}} \prod_m \left[(\mu^m)^{-\frac{\alpha^n_m(1-\varepsilon)\tau}{\varepsilon(1-\tau)}} (\alpha^n_m)^{-\alpha^n_m \frac{\tau}{1-\tau}}\right]$$

$$\tilde{P}^n_t = (\tau)^\gamma \gamma - 1,\ \tilde{E}^{n,m}_t = 1$$

for all countries n and m and time periods t.

A.1.4 Properties of Constant ν

$$\nu = (1-\tau)^3 + \gamma\tau(1-\tau)\left(\gamma\tau\Xi_1 + (1-\tau)\left(\left(1 - X_\$^{EU}\right)\alpha_{EU}^{US} + \left(1 - X_\$^{JP}\right)\alpha_{JP}^{US} + \alpha_{US}^{JP} + \alpha_{EU}^{JP} + \alpha_{US}^{EU} + \alpha_{JP}^{EU}\right)\right) \tag{A.7}$$

where,

$$\begin{aligned}\Xi_1 = &\left(1 - X_\$^{JP}\right)\alpha_{JP}^{US}\left(\left(1 - X_\$^{EU}\right)\alpha_{EU}^{JP} + \alpha_{US}^{EU} + \alpha_{JP}^{EU}\right) + \\ &\left(1 - X_\$^{EU}\right)\alpha_{EU}^{US}\left(\alpha_{US}^{JP} + \alpha_{EU}^{JP} + \left(1 - X_\$^{JP}\right)\alpha_{JP}^{EU}\right) + \\ &\alpha_{US}^{JP}\left(\alpha_{US}^{EU} + \alpha_{JP}^{EU}\right) + \alpha_{EU}^{JP}\left(\alpha_{US}^{EU} + \alpha_{JP}^{EU}\left(X_\$^{JP} + X_\$^{EU} - X_\$^{JP}X_\$^{EU}\right)\right)\end{aligned}$$

I prove two propositions characterizing the constant ν.

Remark. The constant $\nu > 0$.

Proof. This is straightforward to show, because $\gamma > 0$, $\tau \in (0,1)$, $X_\$^n \in (0,1)$ and $\alpha_m^n > 0$ for all n, m. Plugging these assumptions into equation (A.7) shows that $\nu > 0$. □

Remark. ν is increasing in α_m^n for $n \neq m$.

Proof. This is straightforward to check. Equation A.7 displays ν as the product and sum of positive constants and each α_m^n where $n \neq m$. Hence, all derivatives of ν with respect to α_m^n are positive. □

A.1.5 Proof of Prediction 3

The effect of contractionary Japanese monetary policy on aggregate consumption in the U.S. and Europe is

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

The first line of the previous equation corresponds with the first line of equation (1.12). The second line of the previous equation exactly mirrors the second line of equation (1.12) with $M_{¥}^{n}$ taking the place of $M_{\$}^{n}$.

Since nominal interest rates are determined by the consumption Euler equation given by equation (1.14), the effect of of contractionary Japanese monetary policy on nominal interst rates in the U.S. and Europe is

$$-\frac{\partial \tilde{r}^n}{\partial \tilde{p}^{JP}} = -\gamma\left(-\frac{\partial c^n}{\partial \tilde{p}^{JP}}\right).$$

Hence, the effect of Japanese monetary policy on foreign nominal interest rates is symmetric to the effect of U.S. monetary policy due to the symmetry in the monetary policy spillovers to consumption.

The corresponding expressions for European monetary policy shocks simply involve replacing the JP superscripts in the expressions above with EU superscripts.

A.1.6 Constant δ_y

When $\mu^n = 1/3$, $\alpha_n^n = \alpha$ for all countries n and $\alpha_m^n = (1-\alpha)/2$ for $n \neq m$

$$\delta_y = \frac{\tau(1-\alpha)\left((1+3\alpha)(1-\tau)+\gamma\left(1-3\alpha(1-\tau)+\tau\right)\right)\left(1+\left((3/2)\alpha\gamma-1\right)\tau\right)}{16\nu}.$$

A.1.7 Proof of Proposition 1

If $\tau^n = \tau$ is constant across all countries n, then it is straightforward to show that the derivative $\frac{\partial y_T^n}{\partial \tilde{p}^n}$ for $n = JP, EU$ is decreases with the share of country n's dollar invoiced exports, $X_\$^n$. For $n = JP$,

$$\frac{\partial^2 y_T^{JP}}{\partial \tilde{p}^{JP} \partial X_\$^{JP}} = -\frac{(1+(\gamma-1)\tau)\left(1+\left(\gamma\left(\left(1-X_\$^{EU}\right)\alpha_{EU}^{US}+1-\alpha_{EU}^{EU}\right)-1\right)\tau\right)}{(1-\tau)\left(\sum_m \mu^m \alpha_{JP}^m\right)(\Xi_4)^2} \times \left(\Xi_2 + \left(\mu^{US}\alpha_{JP}^{US}+\mu^{EU}\alpha_{JP}^{EU}\right)\Xi_3\right) < 0,$$

where Ξ_2 and Ξ_3 are positive constants. Ξ_4 is a constant that is not displayed here.

$$\begin{aligned}\Xi_2 =& \alpha_{JP}^{US}\alpha_{JP}^{EU}(\gamma-1)(1-\tau)(1-\mu^{JP})\left(1+\left(\gamma(1-\alpha_{JP}^{JP})-1\right)\tau\right)+\mu^{JP}\alpha_{JP}^{JP}\gamma\tau^2 \\ &\times\left((1-\tau)(1-X_\$^{EU})\left(\alpha_{US}^{JP}\alpha_{JP}^{US}+\alpha_{EU}^{JP}\alpha_{JP}^{EU}\right)+(1-\alpha_{JP}^{JP})\left(\gamma\tau\left(\alpha_{JP}^{US}\alpha_{US}^{EU}+\alpha_{JP}^{EU}\right.\right.\right. \\ &+\left.\left.\left.\left(1-\alpha_{US}^{US}-\alpha_{EU}^{US}X_\$^{EU}\right)\right)\alpha_{JP}^{US}(1-\tau)X_\$^{EU}\right)\right).\end{aligned}$$

$$\begin{aligned}\Xi_3 =& \left(1+\left(\gamma(1-\alpha_{JP}^{JP})-1\right)\tau\right)\left(\left(1+(1-\alpha_{JP}^{US})\tau\right)\left(1+\left(\alpha_{US}^{EU}\gamma-1\right)\tau\right)\right. \\ &+\left.\alpha_{EU}^{US}\gamma(1-\tau)\tau(1-X^{EU})\$)+\left(\alpha_{JP}^{EU}\tau\left(1+\left(\gamma(1-\alpha_{US}^{US}-\alpha_{EU}^{US}X_\$^{EU})-1\right)\tau\right)\right)\right).\end{aligned}$$

The analogous expressions for $n = EU$ are similar except the superscripts and subscripts for EU and JP are reversed.

Domestic expansionary monetary policy increases aggregate traded production, $\frac{\partial y_T^n}{\partial \tilde{p}^n}$. Hence, an increase in the share of country n's dollar invoiced exports decreases the magnitude of the effect of domestic monetary policy on domestic aggregate production.

A.1.8 Model Extension with Incomplete Asset Markets

In this section, I extend the model in the paper to include incomplete asset markets. Within each country, only a fixed proportion ϕ of households (labelled "active") trade a complete set of state-contigent securities. The remaining $1-\phi$ of households (labelled "inactive") are excluded from trading in financial markets. Instead, inactive households cede the claims to their firm profits and their endowments of non-traded goods to active households. In return, inactive households receive a nominal bond that makes a fixed nominal payment $\tilde{B}_t^n$ in each period.

Active households maximize expected utility (1.1) subject to the following modified budget constraint

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

The active household's budget constraint differs from equation (1.4) in two ways: Active households pay $((1-\phi)/\phi)\,\tilde{B}_t^n$ units of currency to inactive households in each period, and active households receive $1/\phi$ shares of claims to the non-traded endowment and the profits of the firms in each period.

Although the budget constraint has changed from the model Section 1.3, the first order conditions for active households are unaffected. Equations (1.5), (1.6) and (1.7) still determine the active household's allocation of intermediate traded goods, non-traded goods and labor supply. The wealth transfer κ^n equates the marginal utility of wealth across active households such that equation (1.11) continues to hold.

Inactive households also maximize expected utility (1.1) in each period. However, their problem simply involves choosing how to use their nominal bond payment and their labor income to purchase consumption. Inactive households face the following budget constraint in each period t,

$$\tilde{P}_{N,t}^n \hat{C}_{N,t}^n + \sum_{i\in\{US,JP,EU\}} \left(\int_0^1 \tilde{P}_{T,i,j,t}^n \hat{C}_{T,i,j,t}^n dj\right) \leq \tilde{B}_t^n + \tilde{W}_t^n \hat{N}_t^n$$

$\hat{C}^n_N$ and $\hat{C}^n_{T,m,j}$ denote the non-traded consumption and intermediate traded consumption of inactive households in country n. $\hat{N}^n$ denotes the labor supplied by inactive households in country n.

Since household utility (1.1) is a Cobb-Douglas aggregate of traded and non-traded goods, it is straightforward to write the inactive household's consumption of traded and non-traded goods as a function of market prices and their total income. The inactive household's consumption of intermediate good j produced in country m is

$$\hat{C}^n_{T,m,j} = \alpha^n_m \tau \left(\frac{\tilde{P}^n_{T,m}}{\tilde{P}^n_{T,m,j}} \right)^{\frac{1}{1-\varepsilon}} \left(\frac{\tilde{B}^n_t + \tilde{W}^n_t \hat{N}^n_t}{\tilde{P}^n_{T,m}} \right). \tag{A.8}$$

$\tilde{P}^n_{T,m}$ is the nominal price index in country n for the aggregate traded good produced in country m, which is derived in Appendix A.1.1. The inactive household's consumption of the non-traded good is

$$\hat{C}^n_{N,t} = (1-\tau) \left(\frac{\tilde{B}^n_t + \tilde{W}^n_t \hat{N}^n_t}{\tilde{P}^n_{N,t}} \right). \tag{A.9}$$

The inactive household's labor supply is determined by the first order condition with respect to $\tilde{N}^n_t$

$$\left(\hat{C}^n_t \right)^{\gamma} \hat{N}^n_t = \frac{\tilde{W}^n_t}{\tilde{P}^n_t} \tag{A.10}$$

The resource constraints in the economy need to account for the consumption and labor supply of both active and inactive households. The market clearing condition for non-traded goods is

$$Y^n_{N,t} = \phi C^n_{N,t} + (1-\phi) \hat{C}^n_{N,t}. \tag{A.11}$$

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

$$Y_{T,m,j,t} = A^m_t \mu^m \left(\phi N_{m,j,t} + (1-\phi) \hat{N}_{m,j,t} \right) = \sum_{n \in \{US,JP,EU\}} \mu^n \left(\phi C^n_{T,m,j,t} + (1-\phi) \hat{C}^n_{N,t} \right). \tag{A.12}$$

Finally, the labor market clearing conditions for active and inactive households in country

m are,

$$N_t^m = \int_0^{\mu} N_{m,j,t} dj \text{ and } \hat{N}_t^m = \int_0^{\mu} \hat{N}_{m,j,t} dj \tag{A.13}$$

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

I log-linearize the model around the same deterministic steady state described in Appendix A.1.3. The addition of market segmentation significantly complicates the analytic expressions in the model. Hence, I make the simplifying assumptions in order to derive expressions analogous to the results from Section 1.4. I assume households consume an equal share of traded goods from all countries, $\alpha_m^n = \alpha = 1/3$ and countries are all the same size, $\mu^n = 1/3$, for all countries n and m. Furthermore, I assume all firms in the Europe invoice in Euros, $X_{\$}^{EU} = 0$.

I derive the effects of a contractionary U.S. monetary policy shock on nominal exchange rates, consumption and production and show that Predictions 1 through 4 hold in the incomplete markets model. First, I define the constant $\hat{\nu}$

$$\hat{\nu} = \frac{(1-\tau)(1+(\gamma-1)\tau)\hat{\Xi}_1\hat{\Xi}_2}{3\hat{\Xi}_3\hat{\Xi}_4},$$

where

$$\hat{\Xi}_1 = \phi(1-\tau) + \gamma\tau(1+\varepsilon(1-\tau)(2-\phi)) + \varepsilon\gamma^2\tau^2(2\phi-1)$$

$$\hat{\Xi}_2 = 2\gamma\tau(1+\varepsilon(1-\tau)) + \gamma\tau\hat{\Xi}_4(1-X_{\$}^{JP}) + 3\phi(1-\tau) + \varepsilon\gamma\tau(\phi(1-\tau)+2\gamma\tau(2\phi-1))$$

$$\hat{\Xi}_3 = \phi(1-\tau) + \gamma(1-(1-\tau)\phi) + \gamma\varepsilon\tau(1+(\gamma-1)\tau)(2\phi-1)$$

$$\hat{\Xi}_4 = 1 + \varepsilon\left(4(1-\tau)(1-\phi) + \gamma\tau(2\phi-1)\right)$$

It is straightforward to show that ν is positive whenever $\phi > 1/2$. Hence, I assume $\phi > 1/2$ for the remainder of this section.

Equation (A.14) provides the incomplete markets analog to equation (1.13) in Section (1.4),

$$-\frac{\partial \tilde{e}^{n,US}}{\partial \tilde{p}^{US}} = \hat{\delta}_e - \frac{\gamma(1-\tau)(1+(\gamma-1)\,\tau)}{\hat{\nu}} M_{\$}^{n}. \tag{A.14}$$

$\hat{\delta}_e$ is constant that is common across countries, $M_{\$}^{JP} = \alpha\tau$ and $M_{\$}^{EU} = \left(\alpha + X_{\$}^{JP}\alpha\right)\tau$. Equation (A.15) provides the incomplete markets analog to equation (1.12) in Section (1.4),

$$-\frac{\partial c^n}{\partial \tilde{p}^{US}} = \hat{\delta}_c - \frac{(1-\tau)(1+(\gamma-1)\tau)}{\hat{\nu}} M_{\$}^{n}. \tag{A.15}$$

Active household consumption in Europe decreases relative to active household consumption in Japan, because Europe has a larger share dollar invoiced consumption than Japan. Equation (A.16) provides the incomplete markets analog to equation (1.16)

$$\begin{aligned} -\frac{\partial y_T^n}{\partial \tilde{p}^{US}} &= \hat{\delta}_y \\ &- \frac{\alpha(1-\tau)(1+(\gamma-1)\tau)\left(\gamma\tau(\gamma\varepsilon\tau-1)(2\phi-1) + 2\phi(1+(\gamma(1+\varepsilon(1-\tau))-1)\tau)\right)}{\hat{\nu}\hat{\Xi}_4} X_{\$}^{JP}. \end{aligned} \tag{A.16}$$

Traded production in Japan decreases more than traded production in Europe, because Japan has a higher share of dollar invoiced exports. Finally, equation (A.17) shows the effect of a contractionary Japanese monetary policy shock on an active household's consumption in the U.S. and Europe,

$$-\frac{\partial c^n}{\partial \tilde{p}^{JP}} = \hat{\delta}_c^{JP} - \frac{(1-\tau)(1+(\gamma-1)\tau)}{\hat{\nu}} M_{¥}^n. \tag{A.17}$$

In the incomplete markets extension, monetary policy shocks from Japan have the same magnitude at those from the U.S. after controlling for the share of consumption invoiced in each currency.

Finally, I show that the incomplete markets model breaks the tight link between a country's aggregate consumption and changes in its exchange rates and interest rates. Aggregate consumption in country n (denoted by $\bar{C}^n$) is the weighted sum of active household consumption and inactive household consumption,

$$\bar{C}^n = \phi C^n + (1-\phi)\,\hat{C}^n$$

Equation (A.18) shows the effect of a contractionary U.S. monetary policy shock on the difference in aggregate consumption between Japan and Europe

$$-\frac{\partial}{\partial \tilde{p}^{US}}\left(\bar{c}^{JP} - \bar{c}^{EU}\right) = -\frac{(1-\tau)(1+(\gamma-1)\tau)\,(2\gamma\varepsilon\tau(1-2\phi)+\phi(\gamma\varepsilon\tau-1))\,\alpha\tau X_{\$}^{JP}}{\nu\hat{\Xi}_4}. \tag{A.18}$$

It is straightforward to find an example where the right-hand side of equation A.18 is negative. For example, this is true whenever $\phi \in [1/2, 2/3]$ and the coefficient of risk aversion is sufficiently large ($\gamma > \phi/(\varepsilon\tau(1-(3/2)\phi))$). Then, the decrease in Japanese aggregate consumption is greater than the decrease in European aggregate consumption even though European households consume more dollar invoiced traded goods as a share of total consumption.

A.2 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.

A.2.1 Summary Statistics

Table A.1: 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

Table A.2: Data Availability

Region	Alpha3	Exchange Rates	Interest Rates	Ind. Prod.
Australia	AUS	1999 - 2014	1999 - 2014	1999 - 2014
Canada	CAN	1999 - 2014	1999 - 2014	1999 - 2014
Denmark	DNK	1999 - 2014	1999 - 2014	1999 - 2014
Eurozone		1999 - 2014	1999 - 2014	
Iceland	ISL	1999 - 2014	2004 - 2014	1999 - 2014
Israel	ISR	1999 - 2014	2004 - 2014	1999 - 2014
Japan	JPN	1999 - 2014	1999 - 2014	1999 - 2014
Norway	NOR	1999 - 2014	1999 - 2014	1999 - 2014
South Korea	KOR	1999 - 2014	2002 - 2014	1999 - 2014
Sweden	SWE	1999 - 2014	1999 - 2014	1999 - 2014
Switzerland	CHE	1999 - 2014	1999 - 2014	1999 - 2014
United Kingdom	GBR	1999 - 2014	1999 - 2014	1999 - 2014
United States	USA	1999 - 2014	1999 - 2014	1999 - 2014
		Eurozone Countries		
Austria	AUT			1999 - 2014
Belgium	BEL			1999 - 2014
Cyprus	CYP	1999 - 2007	2004 - 2007	
Estonia	EST	1999 - 2010	2004 - 2010	1999 - 2014
Finland	FIN			1999 - 2014
France	FRA			1999 - 2014
Germany	DEU			1999 - 2014
Greece	GRC	1999 - 2000	1999 - 2000	1999 - 2014
Ireland	IRL			1999 - 2014
Italy	ITA			1999 - 2014
Latvia	LVA	1999 - 2013	2004 - 2013	2000 - 2014
Lithuania	LTU	2002 - 2014	2004 - 2014	1999 - 2014
Luxembourg	LUX			1999 - 2014
Malta	MLT	1999 - 2007	2004 - 2007	
Netherlands	NLD			1999 - 2014
New Zealand	NZL			1999 - 2014
Portugal	PRT			1999 - 2014
Slovakia	SVK			1999 - 2014
Slovenia	SVN	1999 - 2006	2004 - 2006	1999 - 2014
Spain	ESP			1999 - 2014

Table A.3: Summary Statistics with Nakamura and Steinsson (2015) Data

	Obs	Mean	Std Dev	Max	Min
Monetary Policy Shocks (bps)					
Federal Reserve Bank	115	0.331	3.609	9.863	-13.736
Country Characteristics					
Dollar Imports / Imports	19	0.444	0.206	0.808	0.125
Imports / Consumption	19	0.846	0.330	1.441	0.308
Dollar Imports / Consumption $\left(M_{\$}^{n}\right)$	19	0.349	0.186	0.843	0.134
Dollar Exports / Consumption $\left(X_{\$}^{n}\right)$	19	0.409	0.235	0.852	0.000

Notes: The table 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).

Table A.4: Summary Statistics with Multiple Central Banks

	Obs	Mean	Std Dev	Max	Min
Monetary Policy Shocks (bps)					
Federal Reserve Bank	108	-0.644	4.943	20.500	-20.000
European Central Bank	98	0.612	3.742	15.000	-8.500
Bank of Japan	200	-0.145	1.253	3.000	-11.000
Bank of England	66	-0.606	5.217	23.000	-19.000
Country Characteristics					
Currency f Imports / Imports	67	0.176	0.233	0.808	0.000
Imports / Consumption	67	0.846	0.308	1.441	0.308
Currency f Imports / Consumption $\left(M_{f}^{n}\right)$	67	0.144	0.198	0.843	0.000
Currency f Exports / Consumption $\left(X_{f}^{n}\right)$	67	0.159	0.227	0.852	0.000

Notes: The table 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).

A.3 Data Appendix

A.3.1 Monetary Policy Shocks

Table A.5 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 A.5: 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.

A.3.2 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

$$S^n_{M,c} = \left(\frac{V^{n,RoW}_{M,c}}{V^{n,RoW}_M}\right)\left(\frac{V^{n,RoW}_M}{V^n_M}\right) + \left(\frac{V^{n,EUR}_{M,c}}{V^{n,EUR}_M}\right)\left(\frac{V^{n,EUR}_M}{V^n_M}\right). \tag{A.19}$$

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, $\left(V_{M,c}^{n,EUR}/V_{M}^{n,EUR}\right)$ is the share of country n's imports from Eurozone countries that are invoiced in currency c and $\left(V_{M}^{n,EUR}/V_{M}^{n}\right)$ is the share of country n's total imports that come from Eurozone countries.

I use equation (A.19) to solve for the share of country n's imports from non-Eurozone countries that are invoiced in currency c, $\left(V_{M,c}^{n,RoW}/V_{M}^{n,RoW}\right)$. 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 A.3.5 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 A.3.7 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.

A.3.3 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.

A.3.4 Industrial Production Data

I use the OECD index for Industrial Production, which is part of their Key Economic Indicators (KEI) series. The data are available at the monthly level. The indicators are prepared by national statistical agencies. Measures of industrial production typically include output from manufacturing, mining, electricity, gas and water industries.

A.3.5 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. Unforturnately, these data only cover goods trade and I would ideally like to observe bilateral trade in both goods and services. These data are mostly drawn from the UN Comtrade database. Their documentation is located:

http://www.oecd.org/trade/bilateraltradeingoodsbyindustryandend-usecategory.htm

A.3.6 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.

A.3.7 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 Penn World Tables version 9. I use the following series: cgdpo for GDP, csh_x for the export share of GDP, and csh_m for the import share of GDP.

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. 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. These calculations are analogous to those for the currency invoicing data, described in Appendix A.3.2.

For each country, I calculate the share of its imports origination from each country, using bilateral trade data from the OECD. Next, I multiply these shares by the total value of goods and services imports in each country, from the Penn World Tables data, to estimate the value of each country's total imports from each country. Using these data, I calculate the total value of imports into the Eurozone originating from non-Eurozone countries. I normalize the Eurozone's imports by the total GDP of all countries within the Eurozone in each year. Finally, I average the annual data over all years in the sample period (1999 - 2014). I perform the analogous calculations for exports.

A.3.8 Trade Costs

I 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.

A.3.9 Price Stickiness Data

I download the Rauch (1999) classification of goods from the author's website:

http://econweb.ucsd.edu/ jrauch/rauch_classification.html

The classification distinguishes between traded goods that are traded on an organized exchange, reference priced or differentiated products. The classification is provided at the 4-digit SITC rev. 2 level.

I merge the Rauch classification with UN Comtrade data. From the UN Comtrade database, I download import and export data for each country in my sample for each year in my sample period (1999 - 2014) at the 4-digit SITC rev. 2 level. For each country, I calculate the value of each country's imports classified as differentiated products and normalize by the country's total imports. The "Diff. Share" variable is the average share of each country's imports classified as differentiated products, where I take the average across years in the sample (1999 - 2014). For the Eurozone, I first calculate the share of all Eurozone imports from outside of the Eurozone that are differentiated products for each year in the sample, and then I average across years.

A.3.10 Foreign Monetary Policy Rates

I use foreign central bank policy rates from Global Financial Data. The data are provided by the Central Bank Interest Rate series. The data are found under the ticker code "IDcccD", where "ccc" represents a three digit country code. The data are provided at the daily frequency. I observe central bank policy rate data for the following countries: Australia, Canada, Switzerland, Cyprs, Denmark, Estonia, the United Kingdom, Greece, Iceland, Israel, Japan, Korea, Lithuania, Latvia, Malta, Norway, Slovenia, Sweden and the Eurozone.