ESSAYS IN INTERNATIONAL ECONOMICS

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This dissertation consists of two essays in international economics with a focus on the effects of exchange rate fluctuations on an economy through their impact on international capital flows and international trade.

The first chapter examines the effect of exchange rate risk in foreign investors' payoff on the informativeness of security prices and home bias in portfolio holdings. I present a model with dispersed private information where foreign investors' payoff differs from domestic investors' payoff because of exchange rate changes. The equilibrium asset price aggregates private information and acts as a public signal about future payoffs. I show that higher private information acquired by foreign investors about their exchange rate adjusted payoff has two opposing effects on the information obtained by domestic investors from the equilibrium price. First, foreign investors' private information increases information about asset payoff in domestic currency, which increases information about domestic investors' payoff in the price. On the other hand, foreign investors' private information increases information about exchange rate changes, which lowers the relative information about domestic investors' payoff in the price. This second effect is higher if exchange rate volatility is high. I find support for the model's implication by using firm-level data (2000-2016) and showing that foreign institutional ownership[1] of firms from higher exchange rate volatility countries is associated with lower price informativeness.

[1]the fraction of common stocks outstanding that is foreign-owned

The second chapter improves on current treatment of exchange rate variation in quantitative trade models. Exchange rate changes with heterogeneous passthrough to buyers are embedded in the structural gravity model. Quantification on two digit annual bilateral trade data reveals real effects of exchange rate changes on producers that are substantial for some country-sector-time period observations. Real national income effects are small but not always negligible. Effective exchange Rates with Gravitas (ERGs) are introduced as theory-consistent indexes to guide potential policy remedies.

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To my parents

Chapter 1

The impact of Exchange Rate Volatility on the Informativeness of Security Prices

1.1 Introduction

Foreign investors investing in a domestic asset face exchange rate risk in addition to the risk that affects domestic investors' future payoff [1]. I incorporate this observation into an endogenous information portfolio choice model with dispersed information to study how the presence of exchange rate risk in foreign investors' payoff affects the informativeness of security prices for domestic investors.

Higher informativeness of security prices is desirable because, at any point in time, security prices provide a signal for resource allocation. Security markets aggregate private information dispersed among investors (Hayek (1945), Arrow (1964)). Firm managers can make better production-investment decisions by incorporating this aggregate private information from security prices into their information set (Fama (1970)). Kacperczyk, Sundaresan and Wang (2020) studies

[1] Consider stock market investors who are trying to earn from stock investments to purchase a property in their country. As a result, they are concerned about the return in their domestic currency. The payoffs of these investors investing in a foreign country differ from those of a local investor in that foreign country due to exchange rate fluctuations.

the impact of foreign institutional investors on the informativeness of stock prices using firm-level international data and finds that firms with higher foreign institutional ownership have higher informativeness of stock prices. Moreover, this impact of foreign institutional ownership on the informativeness of stock prices is lower in emerging markets relative to developed countries. At the same time, we observe higher exchange rate volatility in emerging markets relative to developed countries. In the model presented in this paper, I show that higher exchange rate volatility reduces the impact of foreign institutional ownership on the informativeness of asset prices and find evidence in support of the negative effect of exchange rate volatility on the informativeness of stock prices using firm-level international data. This provides an explanation for the lower impact of foreign institutional ownership in emerging countries relative to developed countries found in Kacperczyk et al. (2020).

The equilibrium price in my model acts as a public signal about the future payoff of an asset by aggregating private information on future asset payoff. Higher informativeness of security prices, as measured in Kacperczyk et al. (2020), is the same as higher informativeness of the equilibrium asset price for domestic investors in the model. An increase in the mass of informed domestic investors confers a positive externality on other domestic investors by increasing the informativeness of this public signal for domestic investors. An increase in the mass of informed foreign investors confers on domestic investors the same positive externality, but also a negative externality via their learning about future exchange rate fluctuations. This negative effect increases with exchange rate volatility. I find evidence of this negative effect in firm-level data. Firms with foreign institutional ownership from high exchange rate volatility countries have lower informativeness of equity prices relative to firms with foreign institutional ownership from low exchange rate volatility countries.

I also study the impact of exchange rate risk in foreign investors' payoffs on portfolio home bias in the model. In a world with frictionless markets and homogeneous investors, the standard international capital asset pricing model (ICAPM) predicts that domestic asset weight in investors' portfolio should equal the domestic country's market capitalization relative to world market capitalization. However, in practice, investors hold a higher proportion of domestic equity than the ICAPM prediction, according to data on international equity holdings. This pattern in the data is commonly referred to as equity home bias (French and Poterba (1991), Coeurdacier and Rey (2013)). I show in the model that exchange rate risk affects home bias in portfolio holdings in two ways. First, by making foreign payoff more risky because of added exchange rate risk (Fidora, Fratzscher and Thimann (2007)). Second by the changing informativeness of the equilibrium price for domestic investors. In an institutional investor-firm level dataset, I find that institutional investors have lower equity holdings in firms that are domiciled in a country with higher bilateral exchange rate volatility with respect to the investors' country.

In the model, foreign investors' future payoff differs from domestic investors' future payoff when they invest in the same domestic asset because of exchange rate fluctuations. Investors acquire private information about their future payoff. Because private information affects investors' demand, the equilibrium requirement that supply must equal demand makes the equilibrium price a function of private information. The equilibrium price aggregates this private information and acts as a public signal about the future payoff. Higher information acquisition by a domestic investor increases the relative information about domestic investors' payoff in the equilibrium price, thereby increasing price informativeness for domestic investors. This creates strategic substitutability in information acquisition among domestic investors, because other domestic investors' learning makes the public signal about future payoff more informative for a domestic investor, thereby reducing her incentive to acquire private information[2].

[2]As discussed in van Nieuwerburgh and Veldkamp (2009), such strategic substitutability in information acquisition makes investors learn about assets which other investors are not learning about.

However, higher information acquisition by foreign investors has two opposite effects on price informativeness for domestic investors. Because foreign asset payoffs are affected by exchange rate risk, foreign investors' private information about future payoffs from the domestic asset includes information on exchange rate variations along with information about risk factors that affect domestic investors' payoffs. Higher information acquisition by foreign investors consequently has two opposing impacts on the informativeness of the equilibrium price for domestic investors. First, by increasing relative information about risk factors affecting domestic investors' payoff, higher foreign investors' information acquisition tends to increase the informativeness of the equilibrium price for domestic investors'. Second, by increasing information about exchange rate changes in the equilibrium price, higher foreign investors' information acquisition tends to reduce relative information about domestic investors' payoff in the equilibrium price. In other words, the equilibrium price provides information about future domestic investors' payoff and exchange rate changes. The latter acts as noise in the signal from the equilibrium price about future payoffs for domestic investors. Depending on the mass of noise investors in the model, this channel generates strategic complementarities in information acquisition by home and foreign investors[3].

I find evidence of the negative effect of information acquisition by foreign investors on the informativeness of security prices in firm level data. Following Bai, Philippon and Savov (2016) and Kacperczyk et al. (2020), I measure price informativeness using the predicted variance of future cash flows from current market prices. I test two model predictions using firm-level institutional ownership and financial statement data from 27 emerging and 24 developed countries spanning the years from 2000 to 2016. First, my model predicts that the informativeness of the domestic asset equilibrium price is lower for domestic investors in countries that have high exchange rate volatility with their bilateral pairs. In firm-level

[3]Strategic complementarities in information acquisition make investors learn about assets which other investors are learning about. Higher information acquisition by foreign (home) investors decreases the informativeness of the public signal (equilibrium price) for home (foreign) investors. This gives home (foreign) investors an incentive to acquire more private information.

data, I find that holding total foreign and domestic institutional ownership constant, firms with foreign institutional ownership from a country that has high real exchange rate volatility with the firm's domicile country have lower price informativeness relative to firms owned by foreign institutional investors in a country that has lower exchange rate volatility with respect to the firm's domicile country.

Second, in the model, future real exchange rate changes impact equilibrium asset prices via a weighted average of bilateral real exchange rates. As the number of foreign countries investing in domestic asset increases, the variance of the weighted average of bilateral exchange rates reduces, washing away information about future exchange rate changes in the price provided bilateral real exchange rates are not perfectly correlated and have similar variance. As a result, price informativeness for domestic investors increases. In firm-level data, I find that holding exchange rate volatility and total foreign and domestic institutional ownership constant, firms with ownership from a larger number of countries have higher price informativeness.

Equity home bias is one of the most robust empirical patterns discovered in our quest to understand cross-country equity holdings. My model demonstrates that home bias in portfolio holdings can be caused by higher informativeness of the equilibrium price for domestic investors. I consider special cases in the model to show mechanisms in the model that affect home bias in portfolio holdings. I first consider a symmetric world with noise investors and show that my model generates a home bias in portfolio holdings. I consider a second special case of a two-country symmetric world without noise investors. In this two-country symmetric case, investors give equal weight to home and foreign assets, and home bias disappears. This case emphasizes the role of the informativeness of the equilibrium price for domestic investors in generating a home bias pattern in the model and shows that exchange rate volatility is not sufficient to generate home bias when we allow for endogenous information acquisition and learning from the equilibrium price.

In the second case, the negative effect of information acquisition by foreign investors (discussed above) dominates, and higher information acquisition by foreign investors decreases the informativeness of the equilibrium price for domestic investors, thereby providing them with an incentive to acquire more private information. This leads to strategic complementarities in information acquisition among investors in different countries. Both domestic and foreign investors' posterior precision about future payoffs, conditional on observing the equilibrium price, is the same in equilibrium. Even in the presence of exchange rate risk in foreign investors' payoffs, there is no home bias in portfolio holdings in this special case. In the presence of noise investors, the model presented in this paper demonstrates how an endogenous equilibrium price, which is more informative for home investors, can result in a home bias in portfolio holdings, or more broadly, bias in any bilateral portfolio holdings relative to predictions of standard ICAPM predictions. The estimated model shows that reducing the variance of noise investors' biased beliefs by half, increases price informativeness for domestic investors by an average increase of 36%. This increase in price informativeness for domestic investors results in an average increase of 2.4% in home bias and a 2.9% reduction in the risk premium.

Using data at the investor-firm level, I find that institutional investors have lower equity holdings in firms that are domiciled in a country with higher bilateral exchange rate volatility with respect to the investors' country. I also find that information cost proxy employed in earlier research on aggregate equity holdings (Portes and Rey (2005)) also have a significant effect on the institutional ownership in investor-firm data. In particular, institutional investors own more shares in firms domiciled in countries that are closer geographically or have higher social connection index (Bailey, Cao, Kuchler, Stroebel and Wong (2018)) values with respect to the investor country. The estimated model shows that moving to a fixed nominal exchange rate regime reduces home bias by 16% on average, reduces risk premium by 6.16% on average, and increases price informativeness by 7.59% on average.

Related Literature. This work is related to the literature on the information production role of financial markets. I explore the role of exchange rate risk in foreign investors' payoff on the information production role of financial markets, which this literature has generally not considered. Bai et al. (2016) documents a rise in the informativeness of security prices in a sample of US firms from 1960 to 2014 and shows that this increase is concentrated among firms with greater institutional ownership. With the rise of globalization, foreign institutional ownership has increased. Kacperczyk et al. (2020) shows that greater foreign institutional ownership increases price informativeness. They also find that, in comparison to developed countries, the impact of foreign institutional ownership on the informativeness of stock prices is lower in emerging countries. Kacperczyk et al. (2020) propose that this differential effect across countries could be because developed countries have more sophisticated investors, who, in turn, have a bigger impact on price informativeness. In this paper, I explore the impact of exchange rate volatility on this differential impact of foreign institutional ownership across countries.

This paper demonstrates that endogenous informativeness of security prices can generate patterns in international portfolio holdings observed in data, which relates this work to a large literature on international portfolio diversification. International portfolios are biased towards home assets (French and Poterba (1991)), investors' bias their portfolios depending on informational advantages they have (Gehrig (1993), Coval and Moskowitz (1999), Brennan and Cao (1997), De Marco, Macchiavelli and Valchev (2018)), and we see investors' holdings biased towards their domestic currency as countries typically hold most of the foreign-debt securities denominated in their currency (Maggiori, Neiman and Schreger (2019)). van Nieuwerburgh and Veldkamp (2009) shows how endogenous information acquisition can amplify initial information asymmetry between domestic and foreign investors and increase home bias. The mechanism that causes home bias in this paper is different from those discussed in this literature. This paper shows that even in the absence of initial information asymmetry, when equilibrium prices are more informative for home investors relative to foreign investors, as equilibrium prices contain little information about exchange rates, signal from the equilibrium price provide an information advantage to home investors, and investors' portfolios are biased towards home assets. This mechanism naturally creates a bias towards the local currency. The price informativeness mechanism discussed in this paper relies only on exchange rate volatility and not on the correlation of the exchange rate with local equity payoff. Fidora et al. (2007) shows that exchange rate volatility is an important determinant of home bias and bilateral equity holdings. Hedging real exchange rate risk (Obstfeld and Rogoff (2000)) has been considered as one of the plausible explainations of home bias in equity holdings. van Wincoop and Warnock (2010) show that hedging real exchange rate risk cannot account for portfolio home bias.

I also allow for information cost to differ across bilateral pairs in the model and estimate information cost using proxy variables commonly used in the literature on gravity in international finance (Portes and Rey (2005), Okawa and van Wincoop (2012)), such as geographical distance, common official language. This model does not produce a gravity equation for bilateral portfolio holdings, but bilateral portfolio holdings depend on geography because of information cost. I discuss how to estimate information costs and conduct comparative statics analysis.

In the literature on efficient capital markets, Grossman and Stiglitz (1980) demonstrates the difficulty of prices perfectly aggregating information in a rational expectation model and shows a setting where we cannot have an informationally efficient market in the presence of information acquisition costs. Vives (2014) argues that when investors' payoff has a common and a private value component and they acquire a bundled private signal about both the common and the private value of the asset, then prices aggregate information about the common value of the asset perfectly. In such a setting, a fully revealing rational expectation equilibrium exists without resorting necessarily to commonly used noisy traders.

Exchange rate risk naturally creates differences in payoffs for investors in different countries. In the model presented in this paper, rational expectation equilibrium exists even in the absence of noisy investors. Vives (2014) assumes that all agents have the same correlation between their valuations and that they all acquire the same signal precision. Because of these assumptions, price informativeness is the same for all agents. Rahi (2021) in an endogenous information acquisition model shows the role of learning externalities when the correlation between valuations of different types of agents is not the same. As agents of one type learn more about their valuations, prices become more informative about their valuations and less about the valuations of other types of agents. They show strategic complementarities in information acquisition because of learning externalities.

In this paper, the correlation between the payoffs of all investors is the same, but in equilibrium, investors do not acquire the same signal precision. A special case of the model presented here, in which there are two countries and the mass of noise investors is zero, restores Vives (2014) results. Equilibrium prices are equally informative for both domestic and foreign investors and they acquire the same signal precision. Equilibrium prices are affected by the exchange rate through a weighted average of bilateral exchange rates. The information about the exchange rate in the equilibrium price diminishes as the number of countries rises, making the equilibrium price more informative for domestic investors. To compensate for the information disadvantage created by the equilibrium price, foreign investors acquire more private information than domestic investors in equilibrium.

When there are more than two countries, the mass of noise investors is zero, and all bilateral exchange rates have the same volatility, the model presented in this paper displays learning externalities as discussed in Rahi (2021). In the presence of noise investors, the presence of learning externalities depends on the volatility of biased noise investors' beliefs and the mass of noise investors.

1.2 Theoretical framework and discussion

In an endogenous information acquisition portfolio choice model with dispersed information, I incorporate exchange rate risk. In my model, foreign investors receive payoffs adjusted for exchange rate risk and acquire private information about their payoffs. This setup allows me to study the impact of exchange rate risk in foreign investors' payoffs on the informativeness of the equilibrium price and portfolio allocation choices. In this section, I provide a brief introduction of the model environment, a summary of equilibrium conditions, and discuss model implications related to the informativeness of the equilibrium asset price and portfolio allocation choices

1.2.1 Environment

The model consists of N counties. There are two periods. In period one, investors in each country use their initial wealth to invest in a portfolio of assets and receive a payoff in period two. They derive utility from their portfolio payoff realized in period two.

Agents: Each country has a continuum of investors of unit mass. In the model, there are two different groups of investors. Within a country, each group's investors are identical and behave competitively.

- *Institutional Investors*: Institutional investors are rational agents who obtain an informative private signal about asset payoffs. Based on the private signal realization and signal from the equilibrium price, they update their prior beliefs about asset payoffs. Let λ_i denote the mass of institutional investors in a country i.

- *Noise/sentiment investors*: Noisy investors do not learn from the equilibrium price and have a biased belief about future asset payoffs.

Assets: There are N risky assets, one issued by each country, and one risk-free asset. The price of the risk-free asset is normalized to 1 and it returns r in period

2. I will suppress the notation k whenever a variable has the same value for all investors in a country, for example, I will denote period two payoff of an investor k from country i when she invests in country j asset by f_{ij} in place of f_{kij}. When country i investors invest in domestic assets, the risky asset payoff (f_{ii}) depends on a constant payoff μ_i and a country i specific risk factor Z_i

$$f_{ii} = \mu_i + Z_i.$$

The risk factor specific to country i, Z_i, has a normal distribution with a mean of zero and a variance of $\sigma^2_{Z_i}$

$$Z_i \sim N(0, \sigma^2_{Z_i}).$$

Risky asset payoff for country i investors when they invest in a foreign country j asset (f_{ij}) depends on constant payoff μ_j, country j specific risk factor Z_j, and bilateral exchange rate risk factor ζ_{ij}[4]

$$f_{ij} = \mu_j + Z_j + \zeta_{ij}.$$

The bilateral exchange rate risk and country specific risk factors are assumed to be independent of each other. The bilateral exchange rate risk has a normal distribution with a mean of zero and a variance of $\sigma^2_{\zeta_{ij}}$

$$\zeta_{ij} \sim N(0, \sigma^2_{\zeta_{ij}}).$$

Information and beliefs: For all institutional investors, prior belief about distribution of country-specific risk factors (Z_i) and bilateral exchange rate risk factors

[4]This assumption reflects that investors care about the return in their home consumption units (for example, an investor from the United States buys French assets in order to buy a house in the United States).

(ζ_{ij}) is the same as unconditional distribution of these risk factors

$$Z_i \sim N(0, \sigma^2_{Z_i}) \quad \text{and} \quad \zeta_{ij} \sim N(0, \sigma^2_{\zeta_{ij}}).$$

Institutional investors can acquire costly private information regarding the future realization of payoffs. An investor k in a country i observes a noisy private signal (η_{kii}) regarding domestic asset payoff. This signal is centered around the future state of the country i specific risk (domestic asset payoff is solely dependent on the domestic country specific risk) and has a mean zero Gaussian noise with variance $\sigma^2_{\eta_{kii}}$

$$\eta_{kii} = Z_i + \epsilon_{\eta_{kii}} \quad \text{and} \quad \epsilon_{\eta_{kii}} \sim N(0, \sigma^2_{\eta_{kii}}).$$

The noisy private signal regarding foreign country j's asset payoffs (η_{kij}) is centered on the sum of the country j specific risk and bilateral exchange rate risk between country i and j, along with mean zero Gaussian noise with variance $\sigma^2_{\eta_{kij}}$

$$\eta_{kij} = Z_j + \zeta_{ij} + \epsilon_{\eta kij} \quad \text{and} \quad \epsilon_{\eta_{kij}} \sim N(0, \sigma^2_{\eta_{kij}}).$$

Institutional investors learn about future payoffs via equilibrium prices, in addition to learning from private signals. Noisy investors don't use bayesian updating to form an expectation about future asset payoffs. They believe that country i asset payoff equals a constant payoff of μ_i along with a random variable X_i. X_i is distributed normally with a mean of zero and a variance of $\sigma^2_{X_i}$

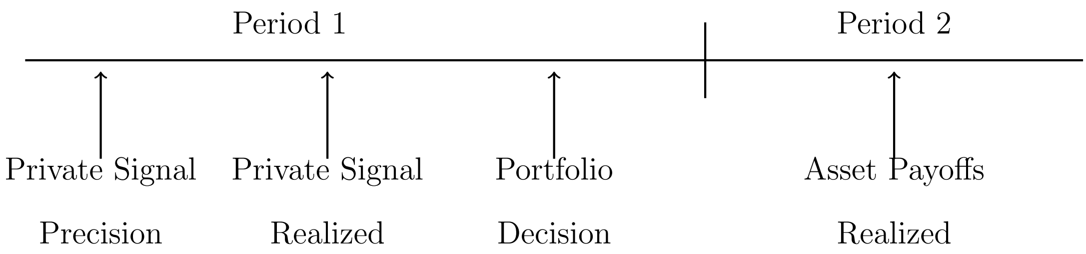
$$X_i \sim N(0, \sigma^2_{X_i}).$$

I assume that the future payoff variance perceived by noise investors is the same as the ex-ante future payoff variance of the asset.

An investor k in a country i begins with a certain amount of wealth W^0_{ki} in period 1. In period 1, an institutional investor k in a country i invests her initial wealth, W_{ki}^0, to buy a portfolio of assets and pay for information costs

$$W_{ki}^0 = \sum_{j=1}^{N} q_{kij} P_j + q_{ki}^f + \sum_{j=1}^{N} \alpha_{ij} \mathbb{C}(\tau_{\eta_{kij}})$$

where P_j denotes the price of the risky asset issued by country j, q_{kij} denotes the quantity of country j risky asset purchased by an investor k in the country i, q_{ki}^f is the quantity of the risk-free asset, $\mathbb{C}(.)$ is a function that maps private signal precision $(\tau_{\eta_{ij}})$ to the information cost. I will assume that $\mathbb{C}(.)$ is increasing in signal precision with an increasing marginal cost of information acquisition (convex function). The cost of acquiring zero precision is zero, $\mathbb{C}(0) = 0$, as well as the marginal cost of information acquisition at zero precision is also zero, $\mathbb{C}'(0) = 0$. For the analysis presented in this section, no functional form assumption is required on the $\mathbb{C}(.)$ function. α_{ij} denotes the information cost shifter, for the same private signal precision, the cost of information is allowed to differ depending on the investor-issuer country pair.



The timeline above depicts the sequence of events throughout two time periods. During the first period, institutional investors decide on the precision of private signals. Private signals are realized based on the precision of private signals, and institutional investors utilize these realized private signals to make portfolio decisions. In period 2, the institutional investor's portfolio pays off and her second-period wealth (W_{ki}) is given by

$$W_{ki} = \sum_{j=1}^{N} q_{kij} f_{ij} + r q_{ki}^f.$$

Noisy investor k in country i uses her period 1 wealth to buy solely domestic risky asset and global risk-free asset

$$W_{ki}^{0} = q_{kii} P_i + q_{ki}^{f}.$$

A noise investor uses her biased beliefs to make portfolio decisions and doesn't incur any information costs. Noise investors do not invest in foreign assets. Her period 2 wealth is given by

$$W_{ki} = q_{kii} f_{ii} + r q_{ki}^{f}.$$

Preferences: Conditional on observing prices and private signals, institutional investors have constant absolute risk aversion (CARA) preferences. The utility function for an institutional investor k in a country i is given by

$$\mathbb{E}\left(\mathbb{E}\left(-e^{-\rho W_{ki}} | \{P_j, \eta_{kij}\}_{j \in N}\right)\right)$$

where ρ denotes the coefficient of absolute risk aversion, the inner expectation is over the conditional distribution of wealth after observing signals, and the outer expectation is over all possible realizations of signals for given signal precision (different information sets).

Noise investors also have CARA preferences. The utility function for a noise investor k in a country i is given by

$$\mathbb{E}^{X}\left(-e^{-\rho W_{ki}}\right).$$

For the sake of tractability, I will assume all random components (country specific risk factors, bilateral exchange rate risk factors, and idiosyncratic noise in the signal) are independent of each other.

Supply: The supply of each risky asset is assumed to be constant. S_i denotes supply of country i risky asset.

1.2.2 Rational Expectations Equilibrium

Definition of Equilibrium: A competitive rational expectations (REE) equilibrium consists of a price function for the risky assets, investors' demand for assets, and private signal precision, such that

- investors' asset demand maximizes their expected utility given their beliefs and private information,
- aggregate demand equals the supply of asset, and
- investors choose private signal precision such that investors' ex-ante utility is maximized subject to information cost constraint.

To address the aforementioned problem of finding optimal portfolio and private signal precision, I first compute asset demand that maximizes expected utility for a given signal realization and signal precision. In the second step, I calculate optimal private signal precision that maximizes ex-ante utility by substituting the optimal portfolio as a function of private signal realization in the utility function. To solve for the optimal portfolio as a function of signal realization and signal precision, I conjuncture that the equilibrium price is a linear function of risk variables and then demonstrate that this price function clears the asset market in all states of the world

$$P_j = \frac{1}{r}\left(A_j + B_j Z_j + \sum_{i \neq j} C_{ij}\zeta_{ij} + D_j X_j\right).$$

Lemma 1 gives the optimal portfolio for an institutional investor as a function of realized value of private signals and price.

Lemma 1. *(REE) The optimal portfolio of institutional investor k in country i*

is given by

$$q_{kij} = \underbrace{\frac{\mu_j - A_j}{\rho\left(\tau_{\eta_{kij}} + \tau_{f_{ij}|P_j}\right)^{-1}}}_{I} + \frac{1}{\rho}\left(\underbrace{\tau_{\eta_{kij}}}_{II}\eta_{kij} - \left(\underbrace{\tau_{\eta_{kij}} + \tau_{f_{ij}|P_j}}_{III} - \underbrace{\tau_{f_{ij}|P_j}\frac{\sigma_{f_{ij},rP_j}}{\sigma^2_{rP_j}}}_{IV}\right)(rP_j - A_j)\right) \tag{1.1}$$

where $\tau_{\eta_{kij}}$ denote private signal precision about country j risky asset, $\tau_{f_{ij}|P_j}$ represents the posterior precision of country j asset payoff conditional on observing the equilibrium price, σ_{f_{ij},rP_j} denote covariance between country j asset payoff and its price times risk free asset payoff, $\sigma^2_{rP_j}$ denote variance asset price times risk free asset payoff.

Equation 1.1 shows the role of several forces in an investors' demand. Part I depicts the average demand of investors k in a country i for the risky asset in a country j. In the model this is equal to the average excess returns adjusted for the perceived variance of future payoffs under the given information set. An atomistic investor's higher private signal precision reduces perceived variation and leads to higher average demand (price function parameters are kept constant). Part II shows the effect of learning about future payoffs from the private signal, with higher signal realizations resulting in higher demand.

In a rational expectations model with dispersed information and investors behaving competitively, the equilibrium price serves a dual role. Parts III and IV demonstrate the competing effects of these two roles on asset demand. First, as in a Walrasian competitive equilibrium, the equilibrium price is an indicator of the relative scarcity of some commodity. Part III illustrates the standard effect of price on asset demand. When the price of an asset rises, quantity demand falls and investors substitute away from it for cheaper assets. Second, the equilibrium price is also a messenger of information. The equilibrium price conveys and aggregates private information dispersed among investors. Part IV shows the effect of this second role of the equilibrium price on asset demand. A higher equilibrium price signals a higher future payoff. Investors use this signal from the equilibrium price and update their beliefs about the future payoff, thereby increasing their demand for the asset. Depending on parameter values, this learning from prices can result in an upward sloping asset demand curve (Chahrour and Gaballo (2020)).

I conjuncture, later verify, that all institutional investors in a particular country acquire the same vector of private signal precision in equilibrium. Proposition 1 gives the rational expectations equilibrium price as a function of future states.

Proposition 1. ***(REE)*** *For given vector of precision τ_{η_j}, there is a unique linear equilibrium price function*

$$P_j = \frac{1}{r}\Bigg(\underbrace{\mu_j - \rho S_j \left(\sum_{i=1}^{N} \lambda_i \left(\tau_{\eta_{ij}} + \tau_{f_{ij}|P_j}\right)\right)^{-1}}_{I} + \Psi_j \underbrace{\left(Z_j + \sum_{i \neq j} \frac{\lambda_i \tau_{\eta_{ij}}}{\sum_{l=1}^{N} \lambda_l \tau_{\eta_{lj}}} \zeta_{ij} + \frac{(1-\lambda_j)\tau_{f_{jj}}}{\sum_{l=1}^{N} \lambda_l \tau_{\eta_{lj}}} X_j\right)}_{II}\Bigg). \tag{1.2}$$

where $\tau_{\eta_{ij}}$ denotes private signal precision, $\tau_{f_{jj}}$ denotes prior precision for domestic investor payoff, $\tau_{f_{ij}|P_j}$ denotes posterior precision of country i's institutional investor payoff when she invests in a country j asset conditional on observing prices, Ψ_j is a non-stochastic term with a value equal to the weighted average of covariance between various investor's payoff and a signal from the equilibrium price (part II in equation 1.2) relative to the variance of signal from the price.

In the equilibrium price function, part I of equation 1.2 reflects the average price level (non-stochastic part) of the price of a country's asset. The average price level increases when a country's asset mean payoff rises, decreases as asset supply rises, rises as aggregate private signal precision about asset payoff rises, and rises as informational content in the price function rises. Increased private signal precision or informational content in prices reduces asset payoff uncertainty, enhancing asset demand and raising the average price level.

Part II of the same equation gives the stochastic part of the price function after removing the common multiplicative factor Ψ_j. Because private signals affect an asset's demand, the equilibrium requirement that supply must equal aggregate demand causes the price to be a function of private signals, making them informative about future payoffs. Asset prices are affected by bilateral exchange rate risk factors via a weighted average of all bilateral exchange rate risk factors. Noise invesotrs' biased beliefs also makes the equilibrium price stochastic. As aggregate private signal precision increases, the effect of noisy traders on the stochastic part of prices reduces.

Proposition 2. *Optimal private signal precision for investor k in country i $\left(\{\tau_{kij}\}_{j=1}^{N}\right)$ is the solution to the following system of equations*

$$2\rho r \alpha_{ij} \mathbb{C}^{'}\left(\tau_{\eta_{kij}}\right)\left(\tau_{\eta_{kij}} + \tau_{f_{ij}|P_j}\right) = 1 \quad \forall j. \tag{1.3}$$

Proposition 2 gives the implicit solution for optimal private signal precision. For each given asset, investors establish a balance between the marginal cost of information acquisition and the posterior precision of payoff, such that the product of the marginal cost of information acquisition and the posterior precision remains constant across all assets. Only the private signal precision in equation 1.3 is affected by investor identity, as all other variables are the same for all investors in a country. This confirms the prior conjuncture that all investors in the same country choose the same private signal precision.

1.2.3 Model Implications on Price Informativeness

Since the payoff of investors from different countries differs when they invest in the same asset because of the exchange rate, the equilibrium price is not necessarily equally informative for investors from different countries. I will focus on the informativeness of the equilibrium price for domestic investors, since an increase in the informativeness of security prices for firm managers (which leads to increased capital allocation efficiency) is the same as an increase in the informativeness of the equilibrium price for domestic investors in this model. This section describes the implications of exchange rate volatility for the informativeness of the equilibrium price about domestic investors' payoff.

In dispersed private information models, noisy traders are usually employed to avoid perfect information aggregation in prices and to ensure the existence of a rational expectations equilibrium (Grossman and Stiglitz (1980)). Even in the absence of noisy traders, prices in the above-mentioned model are not fully revealing, and investors have an incentive to obtain costly information. The model's payoff and information structure, in which home and foreign agents have distinct but correlated payoffs and learn about their own payoffs, is sufficient to make prices an imperfect aggregator of private information. This result is analogous to prices not perfectly aggregating information in the Vives (2014) scenario, when agents gain knowledge about their heterogeneous values. Prices reflect more information about bilateral exchange rate risk as foreign investors acquire more information. Domestic investors, who are primarily interested in country-specific risk, find asset prices noisier as a result of higher information acquired by foreign investors (their payoffs are affected only by country-specific risk). As domestic institutional investors acquire more information, the relative information about the bilateral exchange rate risk factor in the asset price diminishes, making the asset price less revealing about foreign institutional investor payoffs. When both domestic and foreign investors acquire positive private signal precision about their payoffs, the equilibrium prices are not fully revealing even in the absence of noise investors.

Because their payoffs are the same when they invest in the same asset, investors within a country get the same information from the equilibrium price. Domestic and foreign investors extract different information from the equilibrium price because their payoffs are different. As a result, the informational content of the equilibrium price is determined by the investor's country. Though price informativeness varies by investor country, I'll focus on the informational content of equilibrium prices for domestic investors and use the word price informativeness interchangeably with price informativeness for domestic investors. Following Rahi and Zigrand (2018), price informativeness for domestic investors of country i is defined as a percentage reduction in perceived variation of country i asset payoff when investors learn from the equilibrium price

$$\mathbb{V}_i = \frac{Var(f_{ii}) - Var(f_{ii}|P_i)}{Var(f_{ii})}.$$

When the posterior variance of future payoffs is equal to the prior variance, this price informativeness measure has a value of zero, and it has a value of one when prices fully reveal future payoffs.

Lemma 2. *Price informativeness for domestic institutional investors is given by*

$$\mathbb{V}_j = \frac{\sigma^2_{Z_j}}{\sigma^2_{Z_j} + \left(\frac{\sum_{l\neq j}^N \lambda_l \tau_{\eta_{lj}}}{\sum_l^N \lambda_l \tau_{\eta_{lj}}}\right)^2 \sigma^2_{\zeta_j} + \left(\frac{(1-\lambda_j)\tau_{f_{jj}}}{\sum_{l=1}^N \lambda_l \tau_{\eta_{lj}}}\right)^2 \sigma^2_{X_j}}, \tag{1.4}$$

where

$$\sigma^2_{\zeta_j} = Var\left(\sum_{i\neq j} \frac{\lambda_i \tau_{\eta_{ij}}}{\sum_{l\neq j} \lambda_l \tau_{\eta_{lj}}} \zeta_{ij}\right).$$

Lemma 2 shows equilibrium price informativeness for domestic institutional investors. The more information domestic investors acquire, the more precise the aggregate private signal becomes. Higher aggregate private signal precision lowers the weight of the bilateral exchange rate risk component and the weight of noise investors' biased beliefs in the equilibrium price, improving price informativeness. Foreign institutional investors' access to more private information does not always have the same monotonic effect on price informativeness for domestic investors. This idea is formally shown in corollary 1.

Corollary 1. *Changes in price informativeness for domestic investors with change in private signal precision is given by :*

$$\frac{\partial log(\mathbb{V}_j)}{\partial \tau_{\eta_{ij}}} = \underbrace{\frac{2\lambda_i}{\sum_{l=1}^N \lambda_l \tau_{\eta_{lj}}}(1 - V_j)}_{I} - \underbrace{\frac{2\lambda_j^2 \tau_{\eta ji} \sigma^2_{\zeta ji}}{\sigma^2_{rP_i}}}_{II}.$$

Foreign investors' information acquisition has two conflicting effects on the price informativeness for domestic investors.

Corollary 1 demonstrates how the changes in the private signal precision of institutional investors affect price informativeness for domestic institutional investors. Domestic investors do not face exchange rate risk when they invest in domestic asset. For them, part II of equation 1 is absent and higher signal precision acquired by domestic institutional investors always translates into higher informativeness of the equilibrium price for domestic investors. This isn't always the case when foreign institutional investors learn about domestic asset payoffs. Higher information acquired by foreign institutional investors has two opposing effects, as shown by parts I and II of equation 1.

First, as shown in equation 1.2, foreign institutional investors' increased information raises the aggregate private signal precision, thereby reducing weight on exchange rate risk and biased noise investor beliefs in the equilibrium price. This tends to increase price informativeness for domestic investors. Second, higher private signal precision acquired by foreign investors increases the weight on exchange rate risk, thereby decreasing relative information about country specific risk in the equilibrium price. This tends to make the equilibrium price less informative for domestic investors. These two channels compete to determine the overall effect of higher information acquisition by foreign investors on the informativeness of the equilibrium price for domestic inventors. The negative effect is higher when bilateral exchange rate risk volatility or the mass of foreign institutional investors is high. The overall effect of foreign information acquisition on price informativeness for domestic investors is positive if the percentage change in covariance between country-specific risk and the equilibrium price is greater than the percentage change in variance in the equilibrium price.

In a two-country symmetric world without noise investors, the negative effect dominates and increased foreign investor information about domestic country assets always decreases price informativeness for the domestic investor. Such an economy exhibits strategic complementarities in information acquisition between domestic and foreign investors. In the presence of noise investors, the negative effect is dampened. Higher noise in prices because of noisy investors' biased beliefs reduces the percentage change in volatility of prices when foreign investors acquire more information without affecting the percentage change in covariance.

To understand this mechanism of price informativeness more clearly, I consider a symmetric world to conduct more analysis in this setting. A symmetric world is one in which domestic payoffs are identically distributed across all nations, bilateral exchange rate risk factors are identically distributed across all bilateral pairs, there is the same endowment of assets in all countries, the mass of institutional investors is uniform across all countries, and information cost parameters are the same in all bilateral pairs

- $\lambda_i = \lambda \quad \forall i;$
- $\mu_j = \mu, \quad \sigma_{Z_j} = \sigma_Z, \quad S_j = S \quad \forall j;$
- $\sigma_{\zeta_{ij}} = \sigma_\zeta, \quad \alpha_{ij} = \alpha \quad \forall i, j.$

Corollary 2. *In a symmetric world, an increase in the number of countries increases price informativeness for domestic investors.*

As seen in equation 1.2, bilateral exchange rate risk influences the equilibrium price through a weighted average of bilateral exchange rate risk factors. The volatility of this weighted average decreases as the number of countries grows. In a symmetric world where bilateral exchange rate risk variables are independent and have the same distribution (i.i.d.), by the law of large numbers, the variance of a weighted average decreases as the number of i.i.d. random variables increases. Corollary 2 demonstrates an increase in price informativeness for domestic institutional investors as the number of investor countries rises.

Corollary 3. *In a symmetric world, an increase in the mass of institutional investors in all countries increases price informativeness for domestic investors.*

Corollary 3 shows the impact of a symmetric increase in the mass of institutional investors on price informativeness for domestic investors. As seen in lemma 2, increased mass of domestic institutional investors increases price informativeness by reducing the weight of bilateral exchange rate risk factors and noisy investors' biased beliefs in the equilibrium price. Increases in the mass of foreign institutional investors have both a positive and negative effect on price informativeness for domestic investors, as they increase both asset price variance and correlation between the country-specific risk and the equilibrium price. The existence of noise in prices from noisy investors lowers the percentage increase in the equilibrium price variance when the mass of institutional investors in a foreign country rises. Corollary 3 takes all of these considerations into account and shows that a symmetric increase in the mass of institutional investors increases price informativeness for domestic investors.

1.2.4 Model Implications on Home Bias

Moving from the informativeness of the equilibrium price to portfolio decisions of investors acquiring information, corollary 4 shows that in a symmetric world, the posterior precision about asset payoffs conditional on observing the equilibrium price is greater for domestic assets than foreign assets. Investors acquire higher private signal precision for foreign asset payoffs to offset the informational disadvantage from the public signal (equilibrium price). Although the precision of private signals improves posterior precision for foreign asset payoffs, the convex cost of acquiring private information ensures that posterior precision conditional on observing both public and private signals is still lower for foreign asset payoffs than for home asset payoffs. Because the unconditional expected demand for an asset is directly proportional to posterior precision under a given information set (as shown in equation 1.1), the unconditional expected value of the quantity demanded for foreign assets is lower than for domestic assets in an institutional investors' portfolio. This results in a home bias in the model.

Corollary 4. *In a N country symmetric world ($\lambda_i \in (0,1)$)*

- *private signal precision is higher for foreign payoffs ($\tau_{ij} \geq \tau_{ii} \quad \forall j \neq i$).*
- *posterior precision conditional on observing the equilibrium price is higher for domestic asset payoffs relative to foreign asset payoffs ($\tau_{f_{ij}|P_j} \leq \tau_{f_{ii}|P_i} \quad \forall j \neq i$),*
- *unconditional expected quantity of foreign asset holdings in institutional investors' portfolios is lower compared to domestic asset holdings $E(q_{ij}) \leq E(q_{ii}) \quad \forall j \neq i$.*

Consider another special case of a two-country symmetric world with no noise investors. In this case, the negative effect of foreign investors' private signal precision on price informativeness for domestic investors dominates. This economy exhibits strategic complementarities in information acquisition. Higher information acquisition by foreign investors decreases the informativeness of the equilibrium price for domestic investors. When public signal (the equilibrium price) is less informative, domestic investors acquire more private signal precision. On the other hand, when domestic investors acquire more information, they reduce relative information about the exchange rate and makes the equilibrium price less informative for foreign investors. Lower information from public signals creates an incentive for foreign investors to acquire more private signal precision. Thus, higher signal precision acquired by one country's investor increases the private signal precision acquired by second country investors.

Corollary 5. *In a two country symmetric world without noise investors ($\lambda_i = 1$)*

- *private signal precision is the same for domestic and foreign asset payoffs ($\tau_{ij} = \tau_{ii} \quad \forall j \neq i$).*
- *posterior precision conditional on observing the equilibrium price is equal for domestic and foreign asset payoffs ($\tau_{f_{ij}|P_j} = \tau_{f_{ii}|P_i} \quad \forall j \neq i$),*

- *unconditional expected quantity of domestic and foreign asset holdings in institutional investors' portfolios are the same* $E(q_{ij}) = E(q_{ii}) \quad \forall j \neq i$.

Corollary 5 shows that in a two-country symmetric world without noise investors, conditional on observing the equilibrium price, the posterior precision is equal for both domestic and foreign asset payoffs. Investors acquire the same private signal precision and hold the same quantity of domestic and foreign. The presence of exchange rate risk is not enough to generate home bias in portfolio holdings when we take into account endogenous information acquisition. The equilibrium price's endogenous informativeness eliminates any differences in posterior precision because of prior precision differences. Home bias generated by the equilibrium price's endogenous informativeness is dependent on model parameters. As we move away from the symmetric world and toward a more general setup, depending on model parameters, this endogenous informativeness of the equilibrium price can produce portfolio bias in all bilateral pairs, not only home vs foreign bias.

1.3 Data Description

Using data on firm-level financial variables and institutional ownership, I test the implications of exchange rate volatility for the informativeness of the equilibrium price about domestic investors' payoff and portfolio holdings suggested by the model. In particular, I test whether the informativeness of security prices for firms with institutional ownership from countries with high exchange rate volatility is lower than for similar firms with institutional ownership from countries with lower exchange rate volatility. In addition, I test whether institutional investors have lower equity holdings in firms that are domiciled in a country with higher bilateral exchange rate volatility with respect to the investors' country.

To examine the model implications, I construct two panel datasets. The first is a firm-level panel dataset covering the years 2000 to 2016, while the second is an investor-firm level dataset spanning the years 2000 to 2019. The firm-level panel dataset consists of data from Worldscope, Factset's Ownership database, and the International Monetary Fund's (IMF) International Financial Statistics (IFS) dataset on firm market capitalization, financial statement data, institutional ownership, and bilateral exchange rates. The firm level dataset contains 17,172 firms with 118,770 firm-year observations from 27 emerging and 24 developed countries. Institutional investors own 34% (11.52%) percent of the common stocks outstanding in an average firm in developed (emerging) countries (table 1.4). Emerging countries have higher foreign institutional ownership as a fraction of total institutional ownership (60.8%) relative to developed countries (32.3%). Figure 1.1 (1.2) shows the evolution of institutional ownership in developed and developing countries over time. The dataset at the investor-firm-level includes institutional ownership, exchange rate data, and proxies for bilateral information costs.

1.3.1 Market Capitalization and Financial Statement

Market capitalization and financial statement variables at the firm level come from the Worldscope database. Financial statement data for public firms based in and outside of the United States may be found in Worldscope. The firms themselves are Worldscope's major information source, as they provide them all publicly available papers and financial statements as soon as they are published. Many regulatory bodies also provide them comprehensive files.

As a measure of a business's earnings, the ratio of earnings before interest and taxes ($E_{e,t}$) to total assets ($A_{e,t}$) of firm e in year t, represented by $E_{e,t}/A_{e,t}$, is used. The natural logarithm of market capitalization ($M_{e,t}$) to total asset ratio $\log(M_{e,t}/A_{e,t})$ is used as a measure of the price of a company's shares. Investment controls include research and development ($R\&D/A_{e,t}$), capital expenditure ($CAPEX/A_{e,t}$), and total investment ($INVESTMENT_{e,t} = (CAPEX_{e,t} + R\&D)/A_{e,t}$) scaled by total asset value. Some of the other control variables include net sales scaled by total asset ($SALES_{e,t}$), foreign sales scaled by total asset ($FORSALES_{e,t}$), cash scaled by total asset ($CASH_{e,t}$), total debt to total asset ratio ($LEVERAGE_{e,t}$), property, plant and equipment value scaled by total asset ($TANGIBILITY_{e,t}$), insider ownership relative to common stock outstanding ($CLOSE_{e,t}$), and natural logarithm of total asset ($\log(Asset_{e,t})$). The values of all variables are converted to dollars. Following earlier literature (eg. Kacperczyk, Sundaresan and Wang (2020)) I limit attention to nonfinancial firms (SIC code 6) and firms with a market value of more than $1 million.

1.3.2 Institutional Ownership

Factset's ownership database provided information about firm ownership. Insider and institutional ownership statistics are included in Factset's ownership data. Institutional ownership of North American stocks is mostly derived through 13F filings, whereas institutional ownership of non-North American equities is derived from stakes-based sources or aggregating the positions of an institution's underlying funds. Mutual funds, hedge funds, pension funds, bank trusts, and insurance companies are among the entities that FactSet tracks. The Ownership dataset shows the percentage of common stock outstanding held by an investor k from country i in firm e domicied in country j in year t, $FOR_{kije,t}$. Other information includes the firm's ISIN number, institutional owner's name, and institutional investor's place of residence. These variables are utilized to create the above-mentioned second panel dataset at the investor-firm level. Total institutional ownership in firm e ($\mathrm{IO}_{e,t}$), domestic institutional ownership ($\mathrm{DOM}_{e,t}$), and foreign institutional ownership ($\mathrm{FOR}_{e,t}$) are all aggregate ownership variables at the firm-level. Domestic institutional ownership refers to the fraction of stocks held by institutional investors based in the firm's domicile country, while foreign institutional ownership refers to the fraction of stocks held by institutional investors based in countries other than the firm's domicile country. Firms having zero foreign institutional ownership are excluded from the sample. The domestic institutional ownership variable is set to 0 if no domestic institutions hold a firm's stock but at least one international institution does.

1.3.3 Real Exchange Rate Volatility

The International Monetary Fund's (IMF) International Financial Statistics (IFS) provide monthly data on the bilateral exchange rate and consumer price index. The investor-firm-level panel dataset's bilateral real exchange rate volatility, between investor k's residence country i and firm e's domicile country j (σ_{ij}), is the standard deviation of annual log changes in bilateral real exchange rate ($\text{RER}_{ij,t}$) in a sample containing data at monthly frequency from 2000 to 2019

$$\sigma_{ij} = std(log(\text{RER}_{ij,t}) - log(\text{RER}_{ij,t-12})).$$

As shown in lemma 2, price informativeness for domestic investors depends on a weighted average of bilateral exchange rate volatility, given by

$$\sigma^2_{\zeta_j} = Var\left(\sum_{i \neq j} \frac{\lambda_i \tau_{\eta_{ij}}}{\sum_{l \neq j} \lambda_l \tau_{\eta_{lj}}} \zeta_{ij}\right)$$

where weights depend on the private signal precision acquired by foreign investors in a country relative to the aggregate private signal precision acquired by all foreign investors. I use observed foreign institutional ownership to create weights for aggregating bilateral exchange rates. To build a firm level exchange rate index, I first create a real effective exchange rate index (REER) using firm-level weights, which measures average institutional ownership from country i in firm e in country j (w_{ije}) as a percentage of total foreign ownership, using data from 2000 to 2016

$$w_{ije} = avg\left(\frac{\text{FOR}_{ije,t}}{\text{FOR}_{je,t}}\right).$$

The geometric average of bilateral real exchange rates from all foreign countries is used to calculate the real effective exchange rate index for firm e.

$$\text{REER}_{e,t} = \Pi_i \left(\text{RER}_{ij,t}\right)^{w_{ije}}.$$

The sample standard deviation of yearly log changes in the real effective exchange rate estimated above is firm e's exchange rate volatility

$$\sigma_{\text{REER}_e} = std\left(log(\text{REER}_{e,t}) - log(\text{REER}_{e,t-12})\right).$$

I construct a foreign investor concentration index to account for changing weights over time. The foreign investor concentration index is a Herfindahl-Hirschman index of the share of ownership by institutional investors from a country i in firm e domiciled in country j relative to total foreign institutional ownership in firm e

$$\text{HHI}_{e,t} = \sum_i \left(\frac{\text{FOR}_{ije,t}}{\text{FOR}_{je,t}}\right)^2.$$

Foreign investor concentration index drops with an increase in the number of countries investing in a firm.

1.3.4 Information Cost Proxies

Following previous literature, I use bilateral geographic distance, a dummy variable that captures if two countries share a border (contiguity) and common official language as a proxy for information cost. These variables are from CEPII's gravity database. I have also used the social connectedness index (Bailey, Cao, Kuchler, Stroebel and Wong (2017)) that is based on the number of friendship links on Facebook.

1.4 Price Informativeness and Portfolio Holdings in Data

To measure price informativeness, I follow Bai, Philippon and Savov (2016) and use the predicted variance of future cash flows of firm e from current market prices as a price informativeness measure (PI)

$$\mathrm{PI}_{e,t} = \frac{Cov\left(\frac{E_{e,t+h}}{A_{e,t}}, log\left(\frac{M_{e,t}}{A_{e,t}}\right)\right)}{Std\left(log\left(\frac{M_{e,t}}{A_{e,t}}\right)\right)}$$

When the future earnings-to-asset ratio is used as a proxy for domestic asset payoff and the market-to-book ratio is used as a proxy for asset price in the model, the above price informativeness measure can be linked to price informativeness measure used in the model

$$\mathrm{PI}_j = \frac{Cov(f_{jj}, P_j)}{Std(P_j)} = \sqrt{Var(f_{jj}) - Var(f_{jj}|P_j)} = \sqrt{\mathbb{V}_j Var(f_{jj})}.$$

1.4.1 Effect of Exchange Rate Volatility on Price Informativeness

I utilized two methods to investigate the impact of exchange rate volatility on price informativeness. In the first method, I split firms in each country and year into two bins, one above and the other below the median exchange rate volatility. I compute the difference in price informativeness between the two bins. In the second technique, I use pooled firm-level data in a regression framework, along with additional controls for observable and unobserved firm characteristics.

Sorting Approach

Two bins are constructed for firms in all countries and each year. Firms are divided into two groups based on whether the firm's effective exchange rate index volatility is higher or lower than the median value of effective exchange rate index volatility. By performing cross-sectional regressions of future earnings on current market prices, I create a measure of price informativeness inside each group for all countries and years. I include current earnings and sector (one-digit SIC code) fixed effects in the regression,

$$\frac{E_{e,h}}{A_i} = \beta_{g,0} + \beta_{g,1} log\left(\frac{M_e}{A_e}\right) + \beta_{g,2}\frac{E_e}{A_e} + \alpha_g^s + \epsilon_{e,h}, \tag{1.5}$$

where α_g^s denotes sector fixed effects within a group g of firms, $E_{e,h}$ represents h period ahead earnings before interest and taxes for firm i. Price informativeness, interpreted as dollars of future cash flows per dollar of current total assets, is given by $\beta_{g,1}$ multiplied by the cross-sectional standard deviation of the forecasting variable $log\left(\frac{M_e}{A_e}\right)$ within a group g

$$\text{PI}_g = \beta_{g,1} * Std_g\left(log\left(\frac{M_e}{A_e}\right)\right).$$

I compute the difference in price informativeness between firms with effective exchange rate index volatility above and below the median. To calculate this difference, I use the following regression of calculated values of price informativeness within groups

$$\text{PI}_g = \alpha_0 + \alpha_1 \text{I}\Big(g : \text{Std}\,(\text{REER}) > \text{median}\big(\text{Std}(\text{REER})\big)\Big) + \epsilon_g \tag{1.6}$$

where I(.) is an indicator function that returns 1 if the effective exchange rate index for a group g of firms is greater than the median. A similar exercise is adopted to find the effect of an increase in the number of investor countries using the concentration index (HHI) defined earlier.

Table 1.1 provides results from specification 1.6. Firms with higher effective exchange rate volatility have lower price informativeness. The second column of table 1.1 shows that firms that have foreign ownership from a fewer number of countries/ high concentration of foreign investors have lower price informativeness.

Table 1.1: The impact of volatility in real exchange rates and the number of investor countries on price informativeness for domestic investors (Sorting Approach)

	(REER) PI	(HHI) PI
Difference	-0.016***	-0.014***
	(0.001)	(0.001)
Constant	0.020***	0.019***
	(0.001)	(0.001)
Observations	842	842
R^2	0.1231	0.1096

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Regression Approach

To control for firm level observable (e.g. foreign ownership) and some unobservable variables that can create differences in price informativeness across groups in the above sorting approach, I employ a regression framework and provide further evidence in support of the results discussed in the previous section. Following Kacperczyk, Sundaresan and Wang (2020) methodology, I assess the influence of exchange rate volatility on price informativeness by interacting the volatility of the effective exchange rate index with current market prices in a regression of a firm's future earnings on current market prices. Regression specification is described in equation 1.7.

$$\begin{aligned}\frac{\overline{E_{e,t+h}}}{A_{e,t}} = \beta_0 + \beta_1 log\left(\frac{M_{e,t}}{A_{e,t}}\right) + \beta_2 log\left(\frac{M_{e,t}}{A_{e,t}}\right)\sigma_{\text{REER}_e} + \beta_3 log\left(\frac{M_{e,t}}{A_{e,t}}\right)\text{HHI}_{e,t} \\ +\beta_4 log\left(\frac{M_{e,t}}{A_{e,t}}\right)\text{DOM}_{e,t} + \beta_5 log\left(\frac{M_{e,t}}{A_{e,t}}\right)\text{FOR}_{e,t} \\ +\text{Controls} + \text{Fixed Effects} + \epsilon_{e,t+h}\end{aligned} \tag{1.7}$$

The dependent variable, $\frac{\overline{E_{e,t+h}}}{A_{e,t}}$, is a three-year average of future earnings (from t+1 to t+3) divided by the firm's present total assets. Among the controls are the level and interaction of insider ownership shares, leverage, tangibility, total sales, foreign sales, and cash holdings with the market-to-book ratio. Earnings-to-asset ratio, log of total assets, total foreign institutional ownership relative to total institutional ownership, and the interaction between relative foreign institutional ownership and volatility of the effective exchange rate index are other controls. Time invariant fixed effects and country time fixed effects are also included in the regression to account for firm time-invariant unobservables as well as any time changing country-level aggregate trend in firm earnings. Results from Kacperczyk, Sundaresan and Wang (2020) are replicated in table 1.8. Security prices of firms with more institutional ownership are more informative than security prices of firms with less institutional ownership (column 1). Both higher domestic and foreign institutional ownership is associated with higher price informativeness (column 2). The impact of foreign institutional ownership on price informativeness is lower in emerging countries (column 3).

Table 1.2 shows the impact of real exchange rate volatility and the concentration of foreign investors on price informativeness. Column 1 shows that, after controlling for total foreign and domestic institutional ownership, firms that receive institutional investment from countries with higher exchange rate volatility have lower price informativeness. The outcome of the concentration of foreign investors is shown in column 2. Firms having institutional ownership from a large number of foreign countries have greater price informativeness after adjusting for total domestic and foreign institutional ownership. Column 3 combines the impacts of exchange rate volatility and foreign institutional investor concentration, demonstrating that the coefficients do not vary much and that the two effects operate separately.

Table 1.2: The impact of volatility in real exchange rates and the number of investor countries on price informativeness for domestic investors

	(1)	(2)	(3)
	$\overline{\frac{E_{e,t+h}}{A_{e,t}}}$	$\overline{\frac{E_{e,t+h}}{A_{e,t}}}$	$\overline{\frac{E_{e,t+h}}{A_{e,t}}}$
$\ln(\frac{M_{e,t}}{A_{e,t}})$	0.014***	0.012***	0.021***
	(0.005)	(0.004)	(0.005)
$\ln(\frac{M_{e,t}}{A_{e,t}})*\sigma_{\mathrm{REER}_e}$	-0.098***		-0.089***
	(0.021)		(0.020)
$\ln(\frac{M_{e,t}}{A_{e,t}})*\mathrm{HHI}_{e,t}$		-0.014***	-0.013***
		(0.003)	(0.003)
$\ln(\frac{M_{e,t}}{A_{e,t}})*\mathrm{DOM}_{e,t}$	0.027***	0.020***	0.021***
	(0.005)	(0.005)	(0.005)
$\ln(\frac{M_{e,t}}{A_{e,t}})*\mathrm{FOR}_{e,t}$	0.059***	0.058***	0.049***
	(0.010)	(0.010)	(0.010)
$\mathrm{DOM}_{e,t}$	0.038***	0.035***	0.036***
	(0.009)	(0.009)	(0.009)
$\mathrm{FOR}_{e,t}$	-0.050***	-0.050***	-0.053***
	(0.013)	(0.013)	(0.013)
$\mathrm{HHI}_{e,t}$		-0.007**	-0.007**
		(0.003)	(0.003)
Observations	118767	118770	118767
R^2	0.8163	0.8163	0.8166

(Continued)

	(1)	(2)	(3)
	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$

As control variables, all regression models contain country-year fixed effects, firm fixed effects, and other firm level observables. To keep the table short, a full list of these firm-level control variables is supplied in the appendix table 1.7, along with estimated coefficients. Robust standard errors clustered at the firm and year levels are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

1.4.2 Portfolio Shares and Exchange Rate Volatility

Part I of equation 1.1 shows the ex-ante expected quantity of portfolio holdings in the model. The exchange rate volatility affects the portfolio decisions of domestic investors through its effect on the endogenous informativeness of the equilibrium price and average price level. Exchange rate volatility has a direct effect on foreign investors' demand for domestic asset through its effect on the prior volatility of future payoffs and an indirect effect through endogenous private signal precision choice, informativeness of the equilibrium price, and average price level. To investigate the overall effect of exchange rate volatility on institutional ownership, I use an institutional investor-firm level bilateral dataset. I use a gravity regression model (equation 1.8) with investor and firm time fixed effects, along with exchange rate volatility and other variables to proxy information cost,

$$FOR_{kije,t} = \beta\sigma_{ij} + \gamma X_{ij} + \alpha_{it} + \alpha_{jt} + \epsilon_{kije,t}, \tag{1.8}$$

where $FOR_{kije,t}$ denotes ownership of institutional investor k from country i in firm e domicile in country j at time t, and σ_{ij} denotes the volatility of bilateral real exchange rates between country i and country j. X_{ij} is a vector of bilateral variables that serve as a proxy for the cost of acquiring information between country i and country j. Except for fixed effects, independent variables are time invariant. The value of β captures the change in institutional investor k's ownership in firm e when the real exchange rate volatility between investor and firm's domicile countries is higher.

Table 1.3: The effect of volatility in real exchange rates on institutional ownership

	(1) $FOR_{kije,t}$	(2) $FOR_{kije,t}$
Real ER Volatility$_{ij}$	-0.25***	-0.13***
	(0.01)	(0.01)
SCI$_{ij}$		0.03***
		(0.01)
Distance$_{ij}$		-0.16***
		(0.01)
Contiguity$_{ij}$		0.06***
		(0.01)
Common Language$_{ij}$		0.04***
		(0.01)
Constant	-5.07***	-3.73***
	(0.02)	(0.12)
Observations	9320302	8751602
R^2	0.5705	0.5740

Both regressions contain investor-time and firm-time fixed effects.Robust standard errors clustered in firm and year levels are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.3 shows that institutional investors have lower equity holdings in firms domiciled in countries with higher real exchange rate volatility relative to equity holdings in similar firms domiciled in countries with lower exchange rate volatility. This conclusion is in line with findings from data on aggregate bilateral equity holdings (Fidora, Fratzscher and Thimann (2007)). In column 2 shows the impact of information proxies on institutional ownership. Informationally closer countries are associated with higher bilateral institutional ownership, similar to the pattern shown in aggregate stock holdings data (Portes and Rey (2005)).

1.5 Estimated Model

I now estimate the model using firm level, bilateral exchange rate, and aggregate equity holdings data to do two comparative static exercises. First, I reduce the volatility of biased beliefs of noise investors and show that an increase in the informativeness of the equilibrium price for domestic investors increases home bias in the model. Second, I remove variance because of nominal exchange rate in the bilateral real exchange rate and calculate changes in home bias, price informativeness, and risk premium.

Cross-section variation within a country of a firm's three period ahead earnings to asset level (2016) is used to get an unconditional distribution of domestic payoff parameters. The sample variance of annual changes in the bilateral real exchange rate is used as the variance of the bilateral exchange rate risk in the model. The information cost function $(C)(.)$ is assumed to be cube of private signal precision, and a parametric function of information cost proxies (geographic distance, common language, contiguity, social connectivity index) is used to estimate the information cost parameter

$$\alpha_{ij} = exp(\beta_0) * \Bigg(1 + I\,(i \neq j) * exp\Bigg(\beta_1 + \beta_2 ln(\text{Distance}_{ij}) + \beta_2 ln(\text{SCI}_{ij}) + \beta_3 \text{Contiguity}_{ij} + \beta_4 \text{Common Language}_{ij}\Bigg)\Bigg).$$

I match home bias and foreign bias in portfolio holdings, variance of market price (market to book ratio in data) and price informativeness in different countries between the model and the data to estimate the parameters of the information cost function mass of institutional investors and the variance of biased beliefs of noise investors. I match above mentioned quantities simultaneously (not sequential). Home bias (HB) is defined as in Coeurdacier and Rey (2013)

$$\mathrm{HB}_i = 1 - \frac{\frac{\text{Foreign equity holdings in country i portfolio}}{\text{Total Equity Holdings of country i}}}{\frac{\text{Market Capitalization of Country j}}{\text{World Market Capitalization}}}.$$

Foreign bias (FB) is defined as in De Marco, Macchiavelli and Valchev (2018)

$$\mathrm{FB}_{ij} = \frac{\text{Country j equity holdings in country i portfolio}}{\text{Total Equity Holdings of country i}} - \frac{\text{Market Capitalization of Country j}}{\text{World Market Capitalization}}.$$

The estimated model explains a 17.66% variation in home bias (explained variation calculated by regressing home bias observed in data on home bias generated in the model) and 22.93% variation in portfolio bias. To illustrate the role of price informativeness on home bias, I consider a comparative static exercise of reduction in variance of biased beliefs. Changes in the variance of noise investors' biased beliefs affect portfolio demand through learning from the equilibrium price. Reducing the variance of noise investors' biased beliefs by half, increases price informativeness for domestic investors by an average increase of 36%. This increase in price informativeness for domestic investors results in an average increase of 2.4% in home bias and a 2.9% reduction in the risk premium.

I consider a counterfactual experiment in the estimated model where I remove variance because of nominal exchange rate in the bilateral real exchange rate. This experiment shows the effect of moving from today's exchange rate regime to a fixed exchange rate regime on price informativeness and portfolio bias. Moving to a fixed nominal exchange rate regime reduces home bias by 16% on average, reduces risk premium by 6.16% on average, increases price informativeness by 7.59% on average, and reduces standard deviation in foreign bias by 2%.

1.6 Concluding Remarks

Higher informative content of security prices can improve capital allocation, thereby increasing global growth. A large literature is concerned with understanding changes in the informativeness of security prices. In this paper, I investigate the role of exchange rate volatility on price informativeness. In the model, I show that information acquisition by foreign institutional investors has two opposite effects on the equilibrium asset price. The negative effect of foreign investors' information acquisition depends on exchange rate volatility. The data at the firm level supports the mechanism in the model, suggesting that managing exchange rate volatility is important for improving capital allocation efficiency. Using firm level data, I show that firms with foreign ownership from high exchange rate volatility countries have lower price informativeness. Moreover, exchange rate volatility and price informativeness for domestic investors also affect international portfolio decisions, thereby affecting diversification gains that investors can get. The model illustrates how equilibrium prices that are more informative for domestic investors can result in low diversification in international portfolio holdings.

1.7 Appendix

1.7.1 Summary Statistics and Variable Definations

Table 1.4 reports breakup of observations from different countries along with average domestic institutional ownership, foreign institutional ownership and number of institutional investors per firm. The sample period is 2000-2016.

Table 1.4: **Summary Statistics : Ownership**

Country	# of firm	# of firm-year	FOR	DOM	Inst. per firm
		Developed Economies			
Australia	516	3246	6.77	11.57	8.00
Austria	57	542	10.81	2.21	12.00
Belgium	89	680	9.10	3.90	10.00
Canada	575	3280	10.82	17.86	9.00
Denmark	71	652	10.10	9.89	12.00
Finland	110	1054	11.30	13.06	11.00
France	421	3691	8.13	6.66	11.00
Germany	431	3661	10.57	5.74	11.00
Greece	75	440	7.42	0.88	8.00
Hungary	18	168	8.24	1.22	11.00
Israel	148	1057	10.35	3.66	6.00
Italy	202	1592	9.15	2.55	11.00
Japan	2111	19445	4.90	4.49	9.00
Jersey	19	105	16.59	0.00	7.00
Netherlands, The	146	1162	19.58	5.24	13.00
New Zealand	62	426	6.74	8.01	7.00
Norway	113	809	9.17	12.49	10.00
Poland, Rep. of	144	902	4.25	22.54	8.00

(Continued)

Country	# of firm	# of firm-year	FOR	DOM	Inst. per firm
Portugal	37	313	7.90	4.75	12.00
Spain	110	984	8.96	4.10	13.00
Sweden	224	1778	9.20	18.94	11.00
Switzerland	195	1922	12.68	7.69	13.00
United Kingdom	1115	8780	9.17	29.93	10.00
United States	3168	19580	4.18	58.01	13.00
		Emerging Economies			
Brazil	205	1494	11.10	5.37	14.00
Chile	67	404	4.84	5.72	10.00
China	1817	7952	5.65	6.82	6.00
Colombia	18	67	3.08	8.05	10.00
Egypt, Arab Rep. of	39	232	3.72	1.98	7.00
Hong Kong	656	5112	5.47	2.05	8.00
India	712	4955	5.75	7.87	7.00
Indonesia	177	1051	5.32	0.42	8.00
Korea, Rep. of	791	3758	4.88	5.95	8.00
Kuwait	16	86	0.87	2.53	4.00
Malaysia	377	2510	4.05	4.97	6.00
Mexico	84	532	10.82	2.13	15.00
Nigeria	17	99	3.47	0.33	8.00
Oman	17	92	1.49	3.30	3.00
Pakistan	59	351	1.78	4.36	4.00
Peru	21	101	6.15	4.92	7.00
Philippines	75	435	6.27	0.39	10.00
Russian Federation	113	716	5.61	0.67	14.00
Saudi Arabia	50	213	0.36	2.36	3.00

(Continued)

Country	# of firm	# of firm-year	FOR	DOM	Inst. per firm
Singapore	304	2338	5.60	1.64	7.00
South Africa	156	1235	8.35	15.18	12.00
Sri Lanka	28	172	5.03	2.73	4.00
Taiwan	802	5913	5.36	1.70	7.00
Thailand	215	1290	3.17	2.37	6.00
Turkey	138	1143	5.55	0.13	9.00
United Arab Emirates	23	113	7.70	1.09	8.00
Vietnam	38	137	6.24	4.31	6.00
Developed	10157	76269	7.02	23.00	11.00
Emerging	7015	42501	5.59	4.52	7.00
All	17172	118770	6.51	16.39	10.00

Table 1.5 reports the mean, standard deviation, median, 25 percent, and 75 percent quantiles for institutional ownership, market, and accounting variables. The sample period is 2000-2016.

Table 1.5: **Summary Statistics : Variables**

Variable	Mean	STD	Q25	Median	Q75
Ownership Variables (%)					
IO	22.89	25.66	4.04	12.99	31.53
FOR/IO	49.03	37.44	10.83	45.62	89.57
Firm Level Index					
σ_{REER}	0.11	0.06	0.07	0.10	0.13
HHI	0.55	0.29	0.30	0.48	0.83
Market and Accounting Varibales					
E/A	0.05	0.21	0.03	0.07	0.11

(Continued)

Variable	Mean	STD	Q25	Median	Q75
ln(M/A)	-0.25	0.98	-0.89	-0.27	0.38
ln(Assets)	14.05	2.02	12.65	13.95	15.32
R&D/A	0.02	0.06	0.00	0.00	0.02
CAPEX/A	0.05	0.06	0.02	0.04	0.07
INVESTMENT/A	0.08	0.08	0.03	0.05	0.10
LEVERAGE	0.22	0.19	0.06	0.20	0.34
TANGIBILITY	0.30	0.22	0.12	0.26	0.44
SALES	0.93	0.65	0.49	0.81	1.21
FORSALES	0.29	0.36	0.00	0.15	0.46
CASH	0.11	0.13	0.03	0.07	0.15
CLOSE	32.11	27.74	3.24	29.67	54.50

Table 1.6: **Variable Definition**

Variable	Definition
	Ownership Variables (Source: FactSet Ownership)
IO	Ownership by all institutions
DOM	Ownership by all institutions domiciled in the same country as where the stock is listed
FOR	Ownership by all institutions domiciled in a different country as where the stock is listed
	Exchange Rate Variables (Source: IFS(IMF))
$\sigma_{cc'}$	Real exchange rate volatility (observed) between country c and c'
	Key and Control Variables (Source: Worldscope)
E/A	EBIT divided by total assets
log(M/A)	Logarithm of market capitalization divided by total assets
R&D/A	Research and development expenditures divided by total assets
CAPEX/A	Capital expenditures divided by total assets
INVESTMENT	the sum of research and development expenditures and capital expenditures divided by total assets
LEVERAGE	Ratio of total debt to total assets

Continued on next page

Variable	Definition
TANGIBILITY	Net property, plant, and equipment divided by total assets
SALES	Total sales divided by total assets
FORSALES	Foreign sales divided by total sales
CASH	Cash and/or liquid items divided by total assets
CLOSE	Ratio of shares held by insiders to total shares

Figure 1.1: Institutional ownership in Developed Countries

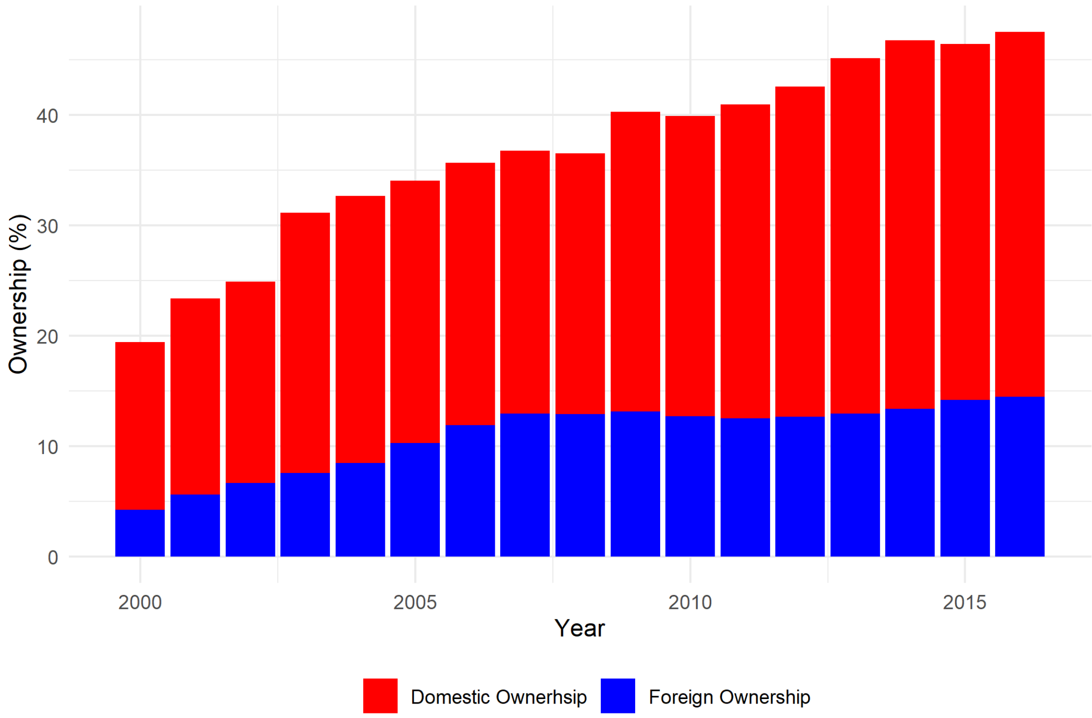
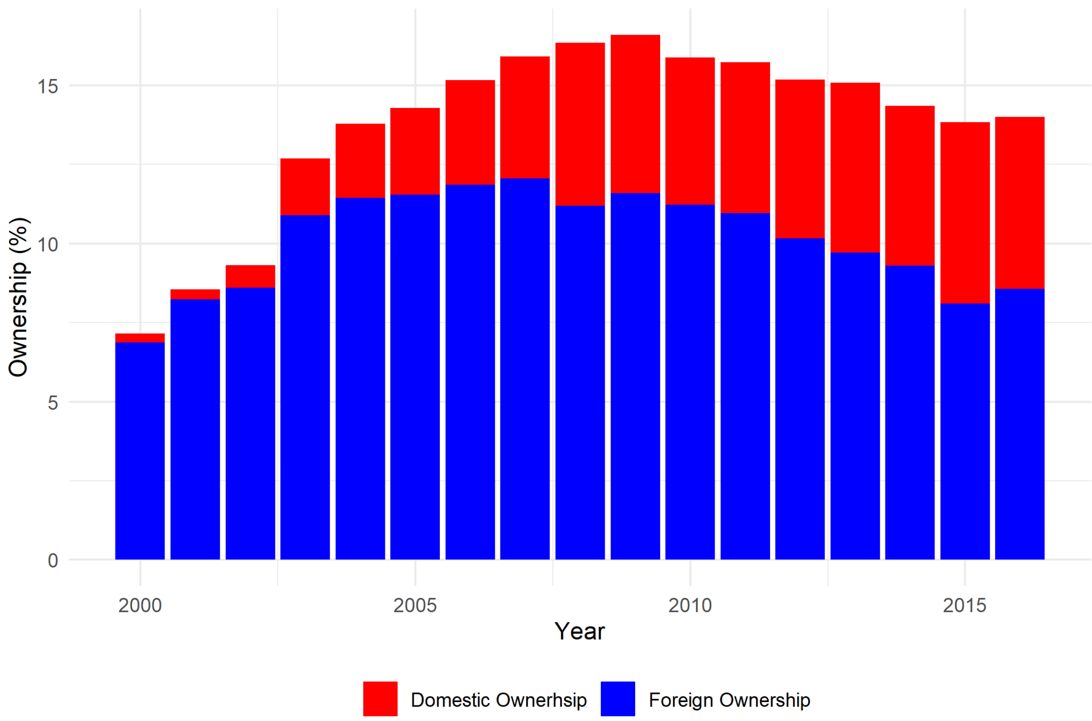


Figure 1.2: Institutional ownership in Developing Countries



1.7.2 Regression Results

Table 1.7: Impact of exchange rate volatility and foreign institutional investor concentration on price informativeness

	(1)	(2)	(3)
	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$	0.014***	0.012***	0.021***
	(0.005)	(0.004)	(0.005)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\sigma_{\text{REER}_e}$	-0.098***		-0.089***
	(0.021)		(0.020)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{HHI}_{e,t}$		-0.014***	-0.013***
		(0.003)	(0.003)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{DOM}_{e,t}$	0.027***	0.020***	0.021***
	(0.005)	(0.005)	(0.005)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{FOR}_{e,t}$	0.059***	0.058***	0.049***
	(0.010)	(0.010)	(0.010)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{CLOSE}_{e,t}$	0.001	-0.000	0.000
	(0.003)	(0.003)	(0.003)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{LEVERAGE}_{e,t}$	-0.019***	-0.018***	-0.018***
	(0.004)	(0.004)	(0.004)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{TANGIBILITY}_{e,t}$	0.018***	0.018***	0.018***
	(0.005)	(0.005)	(0.005)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{SALES}_{e,t}$	0.014***	0.013***	0.014***
	(0.002)	(0.002)	(0.002)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*$\text{FORSALES}_{e,t}$	0.001	0.003	0.001
	(0.003)	(0.003)	(0.003)

(Continued)

	(1)	(2)	(3)
	$\overline{\frac{E_{e,t+h}}{A_{e,t}}}$	$\overline{\frac{E_{e,t+h}}{A_{e,t}}}$	$\overline{\frac{E_{e,t+h}}{A_{e,t}}}$
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*CASH$_{e,t}$	-0.032***	-0.033***	-0.032***
	(0.007)	(0.007)	(0.007)
$\ln(\frac{E_{e,t}}{A_{e,t}})$	0.073***	0.072***	0.072***
	(0.009)	(0.009)	(0.009)
ln(Asset$_{e,t}$)	-0.040***	-0.041***	-0.040***
	(0.003)	(0.003)	(0.003)
CLOSE$_{e,t}$	0.002	0.002	0.002
	(0.003)	(0.003)	(0.003)
LEVERAGE$_{e,t}$	0.049***	0.049***	0.049***
	(0.009)	(0.009)	(0.009)
TANGIBILITY$_{e,t}$	-0.002	-0.002	-0.002
	(0.009)	(0.009)	(0.009)
SALES$_{e,t}$	0.047***	0.047***	0.047***
	(0.004)	(0.004)	(0.004)
FORSALES$_{e,t}$	0.001	0.001	0.001
	(0.003)	(0.003)	(0.003)
CASH$_{e,t}$	0.017***	0.018***	0.018***
	(0.006)	(0.006)	(0.006)
DOM$_{e,t}$	0.038***	0.035***	0.036***
	(0.009)	(0.009)	(0.009)
FOR$_{e,t}$	-0.050***	-0.050***	-0.053***
	(0.013)	(0.013)	(0.013)
HHI$_{e,t}$		-0.007**	-0.007**

(Continued)

	(1)	(2)	(3)
	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$
		(0.003)	(0.003)
Constant	0.571***	0.586***	0.581***
	(0.047)	(0.046)	(0.046)
Observations	118767	118770	118767
R^2	0.8163	0.8163	0.8166

As control variables, all regression models contain country-year fixed effects and firm fixed effects. Robust standard errors clustered at the firm and year levels are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 1.8: Impact of foreign institutional ownership on price informativeness in developed Vs emerging countries

	(1)	(2)	(3)
	$\frac{E_{je,t+h}}{A_{je,t}}$	$\frac{E_{je,t+h}}{A_{je,t}}$	$\frac{E_{je,t+h}}{A_{je,t}}$
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$	-0.001	-0.001	-0.007**
	(0.003)	(0.003)	(0.003)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*Emerging$_j$			0.015***
			(0.003)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*IO$_{je,t}$	0.037***		
	(0.004)		
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*FOR$_{je,t}$		0.080***	0.098***
		(0.010)	(0.014)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*FOR$_{je,t}$*Emerging$_j$			-0.052**
			(0.018)

(Continued)

	(1)	(2)	(3)
	$\frac{E_{je,t+h}}{A_{je,t}}$	$\frac{E_{je,t+h}}{A_{je,t}}$	$\frac{E_{je,t+h}}{A_{je,t}}$
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*DOM$_{je,t}$		0.027***	0.033***
		(0.005)	(0.005)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*CLOSE$_{je,t}$	0.001	0.001	-0.001
	(0.002)	(0.002)	(0.002)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*LEVERAGE$_{je,t}$	-0.015***	-0.015***	-0.014***
	(0.003)	(0.003)	(0.003)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*TANGIBILITY$_{je,t}$	0.019***	0.018***	0.017***
	(0.004)	(0.004)	(0.004)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*SALES$_{je,t}$	0.012***	0.013***	0.013***
	(0.001)	(0.002)	(0.002)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*FORSALES$_{je,t}$	0.005*	0.004	0.004
	(0.003)	(0.003)	(0.003)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*CASH$_{je,t}$	-0.033***	-0.033***	-0.030***
	(0.007)	(0.007)	(0.006)
$\ln(\frac{E_{je,t}}{A_{je,t}})$	0.072***	0.071***	0.071***
	(0.008)	(0.008)	(0.007)
ln(Asset$_{je,t}$)	-0.042***	-0.042***	-0.042***
	(0.003)	(0.003)	(0.003)
CLOSE$_{je,t}$	0.001	0.000	-0.001
	(0.003)	(0.003)	(0.003)
LEVERAGE$_{je,t}$	0.047***	0.046***	0.047***
	(0.007)	(0.007)	(0.007)
TANGIBILITY$_{je,t}$	0.002	0.002	0.002

(Continued)

	(1)	(2)	(3)
	$\frac{\overline{E_{je,t+h}}}{A_{je,t}}$	$\frac{\overline{E_{je,t+h}}}{A_{je,t}}$	$\frac{\overline{E_{je,t+h}}}{A_{je,t}}$
	(0.008)	(0.008)	(0.008)
$\text{SALES}_{je,t}$	0.047***	0.047***	0.047***
	(0.004)	(0.004)	(0.004)
$\text{FORSALES}_{je,t}$	0.001	0.001	0.001
	(0.003)	(0.003)	(0.003)
$\text{CASH}_{je,t}$	0.022***	0.022***	0.022***
	(0.006)	(0.006)	(0.006)
$\text{IO}_{je,t}$	0.010		
	(0.007)		
$\text{DOM}_{je,t}$		0.031***	0.030***
		(0.009)	(0.008)
$\text{FOR}_{je,t}$		-0.047***	-0.047**
		(0.014)	(0.017)
$\text{FOR}_{je,t}$*Emerging_j			-0.001
			(0.021)
Constant	0.594***	0.588***	0.586***
	(0.042)	(0.042)	(0.042)
Observations	131056	131056	131056
R^2	0.8182	0.8186	0.8189

As control variables, all regression models contain country-year fixed effects and firm fixed effects. Robust standard errors clustered at the firm and year levels are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 1.9: Impact of interaction of relative foreign institutional ownership with exchange rate volatility and foreign institutional investor concentration, on price informativeness

	(1)	(2)	(3)
	$\frac{\overline{E_{e,t+h}}}{A_{e,t}}$	$\frac{\overline{E_{e,t+h}}}{A_{e,t}}$	$\frac{\overline{E_{e,t+h}}}{A_{e,t}}$
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$	0.012*	0.012**	0.027***
	(0.006)	(0.005)	(0.007)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\sigma_{\text{REER}_e}$	-0.172***		-0.156***
	(0.043)		(0.042)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\text{HHI}_{e,t}$		-0.050***	-0.044***
		(0.011)	(0.010)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}}*\text{HHI}_{e,t}$		0.004	0.005
		(0.006)	(0.006)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}}*\sigma_{\text{REER}_e}$	0.030		0.023
	(0.028)		(0.029)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\sigma^2_{\text{REER}_e}$	0.168**		0.157**
	(0.070)		(0.067)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*(\text{HHI}_{e,t})^2$		0.028***	0.025***
		(0.008)	(0.007)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\left(\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}}\right)^2$	-0.023***	-0.024***	-0.021***
	(0.007)	(0.007)	(0.006)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\text{IO}_{e,t}$	0.039***	0.034***	0.032***
	(0.004)	(0.004)	(0.004)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)*\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}}$	0.028***	0.031***	0.022**
	(0.008)	(0.009)	(0.009)

(Continued)

	(1)	(2)	(3)
	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*CLOSE$_{e,t}$	0.001	0.001	0.001
	(0.003)	(0.003)	(0.003)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*LEVERAGE$_{e,t}$	-0.019***	-0.019***	-0.019***
	(0.004)	(0.004)	(0.004)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*TANGIBILITY$_{e,t}$	0.018***	0.018***	0.018***
	(0.005)	(0.005)	(0.005)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*SALES$_{e,t}$	0.014***	0.014***	0.014***
	(0.002)	(0.002)	(0.002)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*FORSALES$_{e,t}$	0.000	0.002	0.000
	(0.002)	(0.003)	(0.002)
$\ln\left(\frac{M_{e,t}}{A_{e,t}}\right)$*CASH$_{e,t}$	-0.031***	-0.032***	-0.030***
	(0.007)	(0.007)	(0.006)
$\ln(\frac{E_{e,t}}{A_{e,t}})$	0.073***	0.073***	0.073***
	(0.009)	(0.009)	(0.009)
ln(Asset$_{e,t}$)	-0.041***	-0.041***	-0.041***
	(0.003)	(0.003)	(0.003)
CLOSE$_{e,t}$	0.002	0.002	0.002
	(0.003)	(0.003)	(0.003)
LEVERAGE$_{e,t}$	0.049***	0.049***	0.050***
	(0.009)	(0.009)	(0.009)
TANGIBILITY$_{e,t}$	-0.002	-0.002	-0.002
	(0.009)	(0.009)	(0.009)
SALES$_{e,t}$	0.047***	0.047***	0.047***

(Continued)

	(1)	(2)	(3)
	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$
	(0.004)	(0.004)	(0.004)
$\text{FORSALES}_{e,t}$	0.001	0.001	0.001
	(0.003)	(0.003)	(0.003)
$\text{CASH}_{e,t}$	0.017***	0.017***	0.017***
	(0.006)	(0.006)	(0.006)
$\text{IO}_{e,t}$	0.012	0.010	0.010
	(0.008)	(0.008)	(0.008)
$\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}}$	-0.027**	-0.029***	-0.023***
	(0.010)	(0.009)	(0.006)
$\left(\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}}\right)^2$	0.011	0.011	
	(0.007)	(0.007)	
$\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}} * \sigma_{\text{REER}_e}$	0.060		0.042
	(0.037)		(0.036)
$\frac{\text{FOR}_{e,t}}{\text{IO}_{e,t}} * \text{HHI}_{e,t}$		0.015**	0.014**
		(0.006)	(0.006)
$\text{HHI}_{e,t}$		-0.022**	-0.012***
		(0.008)	(0.003)
$(\text{HHI}_{e,t})^2$		0.007	
		(0.007)	
Constant	0.587***	0.606***	0.600***
	(0.047)	(0.046)	(0.047)
Observations	118767	118770	118767
R^2	0.8164	0.8164	0.8166

(Continued)

	(1)	(2)	(3)
	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$	$\frac{E_{e,t+h}}{A_{e,t}}$

As control variables, all regression models contain country-year fixed effects and firm fixed effects. Robust standard errors clustered at the firm and year levels are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Chapter 2

Exchange Rates as Trade Frictions: Estimates and Implications for Policy

***with* James E. Anderson (Boston College and NBER)** [1]

2.1 Introduction

2.2 Introduction

Exchange rate under-valuation acts like a tax on imports and subsidy to exports. This partial equilibrium reasoning fits awkwardly with the treatment of exchange rate movements in standard micro and macro quantitative general equilibrium trade models. Micro models of bilateral trade in the structural gravity setting either absorb exchange rate effects in country-time fixed effects or suppress exchange rates by implicitly assuming money neutrality. Macro trade models aggregate bilateral trade and suppress variation of bilateral exchange rate movements with atheoretic 'effective exchange rate' indexes. Partial equilibrium models of biltat-

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eral exchange rate change effects leave out the important general equilibrium forces of structural gravity. How far wrong are these treatments of exchange rates?

This paper provides answers. Bilateral exchange rate changes with heterogeneous passthrough are real trade frictions with real effects on bilateral trade at annual frequencies in the structural gravity model. Heterogeneous passthrough to buyer price movements is necessary and sufficient for real effects in this setting. Partial equilibrium exchange rate effects on imports and exports are damped by multilateral resistance changes. The model yields operational measures of buyer, seller and national real income effects of the vector of bilateral exchange rate changes. Applications reveal real national income effects of exchange rate movements at annual frequencies that are mostly small, but not negligible, and are substantial at the extremes. Sectoral income effects on buyers and sellers are sometimes large. Aggregate trade forecasting based on the extended structural gravity model improves significantly over standard aggregate trade forecasting models.

Credible methods for evaluating real effects of exchange rate movements on sectoral incomes have become urgent with the recent initiation of potential US trade policy punishment of 'currency manipulation' by its partners. Vietnam is now subject to countervailing duties (CVDs) on its tire exports to the US based on perceptions of its under-valued currency and a finding of material injury to US producers by the USITC on June 23, 2021. The same tire case investigation involved Taiwan and South Korea as potential targets of CVDs. (For more background see "Too Much of a Good Thing", *The Economist* March 27, 2021).

Unfortunately, received modeling is inadequate for the quantification of exchange rate changes as trade frictions and dubiously related to the under-valuation question [2]. This paper remedies the deficiency by embedding heterogeneous

[2] The effective exchange rates often used as over- or under-valuation measures are atheoretic trade weighted averages of bilateral exchange rate changes. When measured at the sectoral level for a country's exports, the effective exchange rate resembles an export tax or subsidy. Variants include Törnqvist indexes and chain weights. All the indexes suffer from at least four problems. (1) Treating exchange rate changes like price changes does not deal with the well-documented ubiquitous phenomenon of incomplete passthrough of exchange rates to prices. (2) If passthrough

passthrough of exchange rate movements in a structural gravity model [3]. Over- or under-valuation is measured by Effective exchange Rates with Gravitas (ERGs), ideal index numbers that aggregate exchange rate change vectors with weights adjusted for spatial general equilibrium effects. Sectoral ERGs for sellers and buyers measure the general equilibrium effects of exchange rate appreciation (under-valuation) or depreciation (over-valuation) on buyer and seller interests. The ERGs are interpreted as 'seller tax/subsidy equivalent' and 'buyer subsidy/tax equivalent' respectively. ERGs differ substantially from their 'effective exchange rate' counterparts in our application.

Producer compensation based on seller ERGs to mollify interest group pressure could potentially be consistent with the mutual exchange of market access logic of the WTO and its non-discriminatory MFN principle. Section 2.6.3 illustrates for the US tire case vs. Taiwan's export of tires. Buyer ERGs symmetrically provide a basis for buyer compensation. Political economy suggests this may be salient for sectoral intermediate product buyers.

In contrast, international trade law logic is weak when stretched from CVDs to offset export subsidies to the use of CVDs to offset exchange rate under-valuation.[4] (i) CVDs by buyers based on exchange rates have negative externalities on sellers that are absent from export subsidy cases. First, CVDs that force change in sellers'

is complete and prices are flexible, money is neutral and exchange rates are irrelevant. A proper real exchange rate index should converge on unity as passthrough becomes complete. Typical real effective exchange rate indexes do not have this relationship to incomplete passthrough. (3) Prominent received theory argues that trade costs affect the impact of exchange rate changes (for example, Obstfeld and Rogoff, 2001). There is no role for trade costs in the standard indexes despite abundant evidence from the recent gravity literature that trade costs are large and vary greatly between trade partners. (4) In a multi-country world, bilateral exchange rates do not appear sufficient to capture all the effects on the home country of the interaction between members of the set of foreign countries. The effective exchange rate concept developed in this paper solves all 4 problems within the framework of the structural gravity model.

[3] The US Treasury Department's guidelines now embedded in NAFTA 2.0 (USMCA) do not use under- or over-valuation measures, but focus on central bank activity and sharing information. The Treasury report on the Vietnam case focuses on the bilateral aggregate trade between the US and Vietnam and an evaluation of its central bank behavior. Since most central banks intervene in foreign exchange markets for stabilization purposes of various sorts that involve interactions with *all* trade partners, it is difficult to infer intent from activity. Even with correctly inferred intent, a mutually acceptable remedy requires quantification of the damage that is being offset.

[4] See Staiger and Sykes (2010) for similar conclusions in a simpler analytic setting.

exchange rate policy would have effects across all sectors in the source country's economy, unlike discouraging export subsidies. Conversely, the economy-wide effects of exchange rate policy would stiffen source country resistance to CVD punishment from destination countries. (ii) A broader negative externality to sellers is implied by the Trilemma of international macroeconomics (the interdependence of exchange rate policy, monetary policy and capital market openness policy). CVD threats that constrain source country exchange rate policy must tend to negate monetary policy autonomy or capital market openness. (iii) Both intent and quantification are straightforward with export subsidies, while neither is clear with exchange rates.

Structural gravity with appropriate treatment of exchange rate movements also improves aggregate trade forecasting. Current central bank methods use autoregressive lag structures of trade and of 'effective exchange rates' to project future aggregate trade by sector. Forecasts of aggregate trade movements improve dramatically when based on distributed lags of fitted trade where the fit is to the structural gravity model with heterogeneous passthrough of exchange rates. Forecasts of 2014 data using 2000-13 data for estimation imply that the percentage absolute error for imports is reduced by 46% and for exports is reduced by 25%.[5]

The application quantifies real effects of exchange rate movements on trade flows at annual frequencies in the period 2000-14 for 18 sectors and 43 countries using the WIOD (World Input-Output Database). Identification of exchange rate effects requires observations on sellers sales home markets, a necessary condition satisfied by the WIOD. Trade shifts due to exchange rate changes are substantial in some sectors. Real national income effects relative to counterfactual long run equilibrium exchange rates are small but not negligible and in some (country-year) cases are substantial. The (average-over-sectors) terms of trade change from

[5]Replacement of 'effective exchange rates' with ERGs alone results in only modest reduction in forecast errors. The big improvement comes from using the full disaggregated structural gravity model fitted values as a foundation for the aggregate forecasts. Intuitively, this is because ERGs, like all ideal index numbers, are *ceteris paribus* while the full model incorporates other important dynamic forces.

this calculation for the top decile ranges around 3.8% and for the bottom decile ranges around -4.5%. The global effect of the terms of trade changes (a size-weighted average of the country terms of trade changes) due to yearly exchange rate changes is close to zero (ranging between -0.26% and 0.44%.[6] Exchange rate passthrough friction at the sectoral level drives much wider variation in sectoral 'terms of trade'. This is due to variation in both buyer and seller components. We report swings of 40-50% in some sector-country cases.

ERGs for buyers and sellers differ significantly from their atheoretic effective exchange rate counterparts. Relatively high overall correlation is unsurprising since identical vectors of exchange rate changes are being aggregated with weights that are themselves positively correlated. More importantly for measuring real impacts, the magnitudes of ERGs and standard indexes differ significantly and for some country-sector-time intervals the correlations are low or negative. Nominal buyer (seller) ERGs have an overall correlation coefficient of 0.87 (0.74) with standard counterparts when averaged over multiple countries, with a sectoral low of 0.45 (0.33). For real ERGs the overall correlations and sectoral lows are somewhat lower.

The closest relative to the theoretical ERG here is proposed by Neary (2006). He derives a a theoretically consistent effective exchange rate index that answers the question: given a set of arbitrary changes in external prices or domestic costs, what change in the nominal exchange rate would restore the initial level of output or employment. The question is answered in a small country (price taking) setting where non-neutral money is due to a nominal fixed wage. Both the question and the environments differ here from Neary (2006). Importantly, the setting differs by departing from the small country assumption to deal with many non-price-taking countries in general equilibrium, and modeling non-neutral money as due to parametric incomplete exchange rate passthrough.[7]

[6]The deviation from zero arises because the exchange rate changes act on the unchanging part of trade frictions. This implies the effects on the world as a whole need not be zero.

[7]The structural gravity model with exchange rate frictions here extends and generalizes the treatment of the US-Canada exchange rate on Canadian provincial trade with the US in Ander-

The empirical model takes exchange rate passthrough as exogenous. This simplification is unavoidable given the state of the art in exchange rate modeling. When applied to sectoral trade, as here, the assumption of no causality from trade flows to exchange rates is plausible as well as simplifying. A key aspect is allowance for sector-destination-specific bilateral exchange rate passthrough elasticities. A wide range of pricing-to-market stories justify destination-specific passthrough while empirical confirmation is in Boz et al. (2017, 2019) based on passthrough regressions using bilateral export unit values. Boz et al. (2017) find low passthrough to their definition of bilateral terms of trade. This resembles our finding of low passthrough in gravity models of bilateral trade flows. The structural gravity setting suggests an interpretation of measured heterogeneous passthrough effects as a reflection of rising short run bilateral trade costs due to fixed bilateral 'marketing capital' (Anderson and Yotov, 2020).

The CES version of gravity is applied here because of its simplicity and familiarity, but all the methods developed here can be applied to more general spatial equilibrium models with trade frictions.[8]

2.3 Gravity with Exchange Rate Frictions

First we review structural gravity without consideration of exchange rates. Then we introduce exchange rates that are incompletely passed through to prices. Structural gravity assumes perfect spatial arbitrage (any inferred arbitrage profit is due to independent random errors). Exchange rate movements and their passthrough are introduced as an exogenous process like trade cost shocks. Exogeneity is justified by the extensive literature documenting the superiority of statistical models of exchange rate movements over models with real determinants of exchange rate movements.

All shipments are valued at end user prices. Let X_{ij}^k denote the bilateral

son, Vesselovsky and Yotov (2016).

[8]See Anderson and Zhang (2020) for a development of Almost Ideal gravity based on the Almost Ideal Demand System.

shipment from origin i to destination j in sector k; let Y_i^k denote the world value of shipments from origin i to all destinations, ; and let E_j^k denote the value of shipments from all origins to destination j. Trade requires incurring costs that drive wedge factors between origin and destination captured in cost factors t_{ij}^k. Let $Y^k = \sum_i Y_i^k = \sum_j E_j^k$.

The full structural gravity model is given by:

$$X_{ij}^k = \frac{E_j^k Y_i^k}{Y^k} \left(\frac{t_{ij}^k}{P_j^k \Pi_i^k} \right)^{1-\sigma_k}, \ \forall i, j, k; \tag{2.1}$$

$$(\Pi_i^k)^{1-\sigma_k} = \sum_j \left(\frac{t_{ij}^k}{P_j^k} \right)^{1-\sigma_k} E_j^k / Y^k, \ \forall i, k; \tag{2.2}$$

$$(P_j^k)^{1-\sigma_k} = \sum_i \left(\frac{t_{ij}^k}{\Pi_i^k} \right)^{1-\sigma_k} Y_i^k / Y^k, \ \forall j, k; . \tag{2.3}$$

The estimation of t_{ij}^k, the bilateral trade friction, is the main object of empirical gravity, while the restrictions of structural gravity imply the two equation systems (2.2)-(2.3). It has become standard practice to estimate (2.1) with importer and exporter fixed effects to control for both the mass variables Y_i^k, E_j^k and the multilateral resistance variables Π_i^k, P_j^k. The latter can be recovered using the mass variables Y_i, E_j and the equation systems. See Anderson and Yotov (2010) for details. The sales and expenditure variables are assumed to be measured at the end user's full price, meaning that the trade flow and the sales and expenditure variables are all measured with error because some user costs are not observable.

The theoretical foundation behind (2.1) supports multiple interpretations.[9] For present purposes it makes no difference which interpretation is adopted, but for convenience the CES demand system for products differentiated by place of origin will be used below.

[9] The three main ones are: (i) a representative user has CES demand for products differentiated by place of origin, where σ_k is the elasticity of substitution between varieties; (ii) a Ricardian technology produces homogeneous products with national labor productivities generated as random draws from a Frechet distribution where the parameter $1 - \sigma_k$ is interpreted as the dispersion parameter of the distribution; and (iii) aggregation heterogeneous users who make discrete choices of country varieties of good k where σ_k is the dispersion parameter of the heterogeneous users. See Anderson (2011) for details.

The derivation of (2.1) begins from the demand equation

$$X_{ij}^k = (\beta_i^k p_i^k t_{ij}^k / P_j^k)^{1-\sigma_k} E_j^k, \tag{2.4}$$

where p_i^k is the 'factory gate' price or unit cost of the variety of k sold by seller i, β_i^k is a parameter of taste or technology and P_j^k is the CES price index $\sum_i \left[(\beta_i^k p_i^k t_{ij}^k)^{1-\sigma_k}\right]^{1/(1-\sigma_k)}$. Market clearance implies $\sum_j X_{ij}^k = Y_i^k$, permitting substitution in the demand equation for $(\beta_i^k p_i^k)^{1-\sigma_k}$ using the definition of Π_i^k in (2.2). This same substitution also implies that for sellers shares Y_i^k/Y^k the gravity model implies that it is as if the seller makes all his sales on the world market, making them to a buyer whose CES share is given on the right hand side of the following equation:

$$Y_i^k/Y^k = (\beta_i^k p_i^k \Pi_i^k)^{1-\sigma_k}, \ \forall i, k. \tag{2.5}$$

This is a powerful implication because it permits treating the allocation of resources between sectors in each country as determined by aggregate demand on the world market, the effect of trade costs being aggregated into outward multilateral resistance Π_i^k. Moreover, multilateral resistance Π_i^k is interpreted as the sellers' incidence of trade costs to the world market.

Exchange rate changes passed through to prices are introduced as exogenous trade cost shocks that affect the system (2.1)-(2.3). The price wedge shock that results is transitorily a complex object reflecting currency invoicing in contracts and hedging choices along with pricing-to-market behavior.[10] At the annual frequency of standard gravity modeling focused on the value of trade, it seems reasonable to simplify the price wedges to the sector-destination-specific passthrough of bilateral exchange rate changes while also abstracting from dynamic quantity adjustment except for a common cross-border-time fixed effect.[11] We further simplify by ab-

[10]See Boz et al. (2017) for evidence based on bilateral export unit value comparison data. Focusing on currency invoicing practices, their results suggest low passthrough of bilateral exchange rates to destination prices (local currency invoicing) but substantial separate influence of the dollar exchange rate suggesting the importance of US dollar invoicing.

[11]The US dollar effect on destination prices that is emphasized by Boz et al. is in our gravity model setting absorbed in the cross-border-time fixed effect that also absorbs common global-

stracting from possible effects of exchange rate risk – volatility plays no role. The system (2.2)-(2.3) is shocked when the t_{ij}^k's change. These shocks also change the multilateral resistances, directly and through price changes due to (2.5) that change the Y_i^k's and E_j^k's at given t_{ij}^k.

Prices in the preceding model are in a numeraire currency. (In the application below the US dollar is the numeraire currency.) Prices in the numeraire currency relate to local currencies via exchange rates. By choice of units, all local currency prices in a base period can be set equal to 1. Exchange rates of currencies defined in numeraire units per unit of currency j appreciate (depreciate) relative to base as $r_j > (<)1$. Exchange rate changes incompletely passed through from origin i to prices in each destination j are represented by $(r_i/r_j)^{\rho_j}$ where $\rho_j \in [0, 1]$ is a destination specific passthrough elasticity. The property of destination-specific passthrough allows for pricing-to-market behavior in a reduced form. Evidence on destination-specific heterogeneous passthrough is provided by Boz et al. (2019). The passthrough of depreciation of j's currency in terms of i's currency (r_i/r_j rises) acts like a tax on imports and subsidy to exports from j's point of view, while from i's point of view the bilateral appreciation of its exchange rate acts like a tax on exports and a subsidy to imports. Drawing on this equivalence, the bilateral trade cost factor $t_{ij}^k = \tau_{ij}^k (r_i/r_j)^{\rho_j^k}$ where τ_{ij}^k is the trade cost factor exclusive of exchange rate passthrough (the usual function of proxy variables such as distance and borders). The passthrough elasticity is taken here and in much of the empirical passthrough literature to be a parameter.

In moving from (2.4) to the structural gravity equation (2.1), the market clearance condition is used to substitute for $(\beta_i^k p_i^k r_i)^{1-\sigma_k}$. Thus to analyze the effect of exchange rate changes on the new equilibrium, replace t_{ij}^k in (2.1)-(2.3) with $\tau_{ij}^k (r_i/r_j)^{\rho_j^k}$. Suppress for now considerations that changes in exchange rates or relative prices will lead to changes in E_j^k, Y_i^k.

The initial solution of (2.2)-(2.3) for multilateral resistances yields $\{\Pi_i^{k0}, P_j^{k0}\}$.

ization effects.

With the new bilateral trade costs due to incompletely passed through exchange rate changes, equilibrium bilateral trade is given by

$$X_{ij}^k = \frac{Y_i^k E_j^k}{Y^k} \left(\frac{\tau_{ij}^k (r_i/r_j)^{\rho_j^k}}{\Pi_i^k P_j^k} \right)^{1-\sigma_k} \tag{2.6}$$

and the multilateral resistances satisfy:

$$(\Pi_i^k)^{1-\sigma_k} = \sum_j \left(\frac{\tau_{ij}^k (r_i/r_j)^{\rho_j^k}}{P_j^k} \right)^{1-\sigma_k} E_j^k/Y^k; \ \forall i, k; \tag{2.7}$$

$$(P_j^k)^{1-\sigma_k} = \sum_i \left(\frac{\tau_{ij}^k (r_i/r_j)^{\rho_j^k}}{\Pi_i^k} \right)^{1-\sigma_k} Y_i^k/Y^k, \ \forall j, k. \tag{2.8}$$

Notice first that *money neutrality obtains when passthrough is uniform* ($\rho_j^k = \rho^k, \forall j$). Complete passthrough $\rho^k = 1$ is a special case. Neutrality follows because, given that $\{\Pi_i^{k0}, P_j^{k0}\}$ solve (2.2)-(2.3), the new multilateral resistances must satisfy $P_j^k r_j^{\rho^k} = P_j^{k0}$ and $\Pi_i^k / r_i^{\rho^k} = \Pi_i^{k0}$. Trade flows are unchanged, as the right hand side of (2.6) is constant. Real purchasing power of currency is constant for each country j, $r_j^{\rho^k} P_j^k / P_j^{k0} = 1$. That is, the appreciation passthrough factor $r_j^{\rho^k}$ is equal to the factor by which j's price index falls. Real income is likewise constant for each country after combining seller and buyer outcomes. This follows because in (2.5) the factory gate price p_i remains constant when Π_i^{k0} is replaced by its equal value $\Pi_i^k r_i^{\rho^k}$.

An implication of the money neutrality property is that gravity *estimates* of exchange rate effects on bilateral trade elasticity $\rho_j^k(1-\sigma)$ based on equation (2.6) are actually estimates of $(\rho_j^k - \bar{\rho}^k)(1-\sigma)$ for an arbitrary $\bar{\rho}^k$. To see this, introduce shock $r_i^{\bar{\rho}}, \forall i$. The effect on equilibrium bilateral trade flow equation (2.6) is given by $(r_i/r_j)^{(\rho_j - \bar{\rho})}$ because

$$\Pi_i P_j (r_i/r_j)^{-\bar{\rho}} = (\Pi_i / r_i^{\bar{\rho}}) P_j r_j^{\bar{\rho}} = \Pi_i^0 P_j^0.$$

The practical effect is that gravity regressions cannot identify $\bar{\rho}^k$, only the destination-specific deviations from $\bar{\rho}^k$. In the application below, we set $\bar{\rho}^k$ equal to an externally given passthrough elasticity for the US, hence the deviations from uniformity are relative to the US passthrough rate.

The triangular arbitrage condition implies theoretical limits on the variation of exchange rate influence $(r_i/r_j)^{\rho_j^k(1-\sigma_k)}$. A smell test of the logic of the model and its estimator checks whether the condition violated. Henceforth the sector k notation is dropped for simplicity. The limit condition is[12]

$$\frac{\tau_{ij}\tau_{jl}}{\tau_{il}} \geq (r_i/r_j)^{\rho_l-\rho_j}, \forall i, j, l.$$

With a uniform passthrough rate the right hand side of the limit condition reduces to 1, the standard triangular arbitrage condition. Our estimates imply that the estimated bilateral trade costs never violate the triangular arbitrage condition.

2.4 Effective Exchange Rate Indexes

Section 2.6 shows that exchange rates have real effects at annual frequencies. These act directly on bilateral trade in (2.1), a partial equilibrium effect, and through the shifts in equilibrium multilateral resistance that are determined by (2.7)-(2.8). This finding suggests a role for treating exchange rate effects as trade policy – heterogeneous passthrough seen in high frequency price comparison data is not sufficiently transitory or limited in scope to justify abstracting from it in the context of longer run policy making.

For this purpose it is useful to derive and quantify real effective exchange rate indexes for buyers and sellers. These differ from the trade weighted exchange rate indexes exemplified by appendix equation (2.24) in essential ways due to their general equilibrium treatment of the incidence of trade costs and their emphasis

[12] The condition comes from comparing p_{ij}, p_{il} with the indirect $p_{ij->l}$ yielding

$$\tau_{ij}\tau_{jl}(r_i/r_j)^{\rho_j}(r_j/r_l)^{\rho_l} \geq \tau_{il}(r_i/r_l)^{\rho_l}$$

where the initial inequality is divided through by the common factory gate price p_i.

on differential exchange rate passthrough as the source of non-neutrality. Less essentially, the CES structure of ERGs is a particular treatment of substitution effects relative to the variety of *ad hoc* treatments in standard effective exchange rates measures.

2.4.1 Buyer ERG

The purchasing power of a unit of j's currency rises (falls) as inward multilateral resistance – buyers incidence of trade costs including exchange rate change frictions – falls (rises). That is, purchasing power rises (falls) when inward multilateral resistance in the new equilibrium P_j is lower (higher) than inward multilateral resistance in the base equilibrium. Using (2.8) yields the key relationship between buyer's multilateral resistances:

$$P_j^{1-\sigma} = (P_j^0)^{1-\sigma} \sum_i \left(\frac{\tau_{ij}(r_i/r_j)^{\rho_j}}{\Pi_i P_j^0} \right)^{1-\sigma} Y_i/Y.$$

Exponentiate on both sides by $1/(1-\sigma)$. On the right hand side, factor out $1/r_j^{\rho_j}$ and then divide both sides by P_j^0. The left hand side is now the real purchasing power term P_j/P_j^0. On the right hand side substitute in the summation term the predicted value of trade in the initial equilibrium from (2.1), $\widehat{X}_{ij}^0 = (\tau_{ij}/\Pi_i^0 P_j^0)^{1-\sigma} Y_i^0 E_j^0/Y^0$. Rearrange the result to yield the real purchasing power change factor as

$$\frac{P_j}{P_j^0} = \left[\sum_i \frac{\widehat{X}_{ij}^0}{E_j^0} \frac{Y_i/Y}{Y_i^0/Y^0} \left(\frac{\Pi_i^0}{\Pi_i} \right)^{1-\sigma} (r_i/r_j)^{\rho_j(1-\sigma)} \right]^{1/(1-\sigma)}. \tag{2.9}$$

The real exchange rate with gravitas is the hypothetical exchange rate appreciation $\widetilde{R}_j$ required to offset the decline in purchasing power. It is defined from:

$$\frac{P_j}{\widetilde{R}_j P_j^0} = 1 \Rightarrow \widetilde{R}_j = \frac{P_j}{P_j^0}.$$

The sellers multilateral resistance changes Π_i/Π_i^0 play a key role in modifying the effect of exchange rate changes in (2.9) and thus in $\widetilde{R}_j$. More simplification and intuition comes by applying the the relationship of Π_i to sellers factory gate price p_i. Use equation (2.5) to solve

$$\frac{Y_i/Y}{Y_i^0/Y^0}\left(\frac{\Pi_i^0}{\Pi_i}\right)^{1-\sigma} = \left(\frac{p_i}{p_i^0}\right)^{1-\sigma}$$

where p_i is seller i's 'factory gate' price, the ultimate buyers cost less all trade costs. Substitute the right hand side into equation (2.9) to yield

$$\frac{P_j}{P_j^0} = \left[\sum_i \frac{X_{ij}^0}{E_j^0}\left(\frac{p_i}{p_i^0}\right)^{1-\sigma} (r_i/r_j)^{\rho_j(1-\sigma)}\right]^{1/(1-\sigma)} \tag{2.10}$$

The left hand side is the (buyer's) real exchange rate depreciation $\widetilde{R}_j = P_j/P_j^0$. The right hand side of equation (2.10) decomposes the buyers' real exchange rate depreciation into an average cost effect due to the vector of sellers factory gate price changes $\{p_i/p_i^0\}$ times the passthrough of the buyer's effective exchange rate depreciation factor. Thus

$$\widetilde{R}_j = \frac{P_j}{P_j^0} = C_j\left(\frac{\tilde{r}_j}{r_j}\right)^{\rho_j} \tag{2.11}$$

or

$$\frac{\widetilde{R}_j}{C_j} = \left(\frac{\tilde{r}_j}{r_j}\right)^{\rho_j} \tag{2.12}$$

where

$$\tilde{r}_j = \left[\sum_i \widetilde{w}_{ij} r_i^{\rho_j(1-\sigma)}\right]^{1/\rho_j(1-\sigma)}, \tag{2.13}$$

and

$$\widetilde{w}_{ij} = \frac{\frac{X_{ij}^0}{E_j^0}\left(\frac{p_i}{p_i^0}\right)^{1-\sigma}}{\sum_i \frac{X_{ij}^0}{E_j^0}\left(\frac{p_i}{p_i^0}\right)^{1-\sigma}}.$$

and

$$C_j = \left[\sum_i \frac{X_{ij}^0}{E_j^0}\left(\frac{p_i}{p_i^0}\right)^{1-\sigma}\right]^{1/(1-\sigma)}.$$

The average sellers cost change index C_j in practice is the effect on sellers' prices of all the forces of demand, supply and technology along with heterogeneous exchange rate passthrough. On the right hand side of (2.12), $(\tilde{r}_j/r_j)^{\rho_j}$ is the passthrough to buyers of the CES index (2.13), a function of country j's bilateral exchange rate change vector $\{r_i/r_j\}$. The CES index has elasticity $\rho_j(1-\sigma)$ with base expenditure weights adjusted for general equilibrium effects of sellers price changes. $\tilde{r}_j/r_j$ is the nominal Effective exchange Rate with Gravitas: country *j's effective depreciation of its exchange rate.*[13] $(\tilde{r}_j/r_j)^{\rho_j}$ is is the buyer subsidy factor required to compensate the purchasing power loss from buyer ERG depreciation. Potential compensation policy based on $(\tilde{r}_j/r_j)^{\rho_j}$ is operational with structural gravity estimation.

The buyer ERG $\widetilde{r}_j$ on the right hand side of (2.11) is not directly comparable to the typical effective exchange rate index $\bar{r}_j$ because it uses weights that embed general equilibrium effects, and it is a CES index with elasticity $\rho_j(1-\sigma)$. A decomposition based on local rates of change around equation (2.10) establishes a direct connection between $\widetilde{R}_j$ and a CES version of $\bar{r}_j$ defined to include home goods and denoted $\bar{r}'_j$. In general the local difference between $\tilde{R}_j$ and $\bar{r}'_j$ is given by differentiating (2.10):

$$(1-\sigma)d\ln(P_j/P_j^0) = \sum_i \frac{X_{ij}^0}{E_j^0}\rho_j d\ln(r_i/r_j) + \sum_i \frac{X_{ij}^0}{E_j^0} d\ln(p_i/p_i^0)$$

The right hand side can be rewritten as

$$(1-\sigma)d\ln(P_j/P_j^0) = \rho_j[d\ln\bar{r}'_j - d\ln r_j] + \sum_i \frac{X_{ij}^0}{E_j^0} d\ln(p_i/p_i^0).$$

Here $d\ln\bar{r}'_j$ denotes the percentage change in the CES version of the nominal effective exchange rate (including home goods) with elasticity $\rho_j(1-\sigma)$. With no real effects due to uniform passthrough the second term is equal to zero and the first term would need to be equal to zero to be consistent with the assumed no real

[13] C_j contains indirect effects of exchange rate changes. In principle it is possible to account for these with counterfactual general equilibrium calculations that hold constant all factors other than exchange rate changes.

effects property – the appreciation of j's currency would equal the appreciation of currencies in the basket of goods that it buys. Non-uniform passthrough has real effects due to the second term on the right hand side, the average sellers' price effect. $d\bar{r}_j$ may be understood as a Laspeyres index that attempts to control for the contribution to inflation of the buyers' price index that is due to exchange rates under partial equilibrium assumptions $p_i = p_i^0$ and disregarding incomplete passthrough. Refinements of $\bar{r}_j$ or $\bar{r}'_j$ such as chain weights to adjust for discrete changes in shares X_{ij}^0/E_j^0 between equilibria cannot be interpreted to approximate $\tilde{r}_j$ because even for infinitesimal changes they necessarily miss real effects associated with the second term. They do adjust for the sellers' price effect on the weights in the first term.[14]

Note that the elasticity parameter in $\tilde{r}_j$ in equation (2.13) is $\rho_j(1-\sigma)$ where ρ_j is the *level* of destination j's passthrough elasticity. An external value of the average $\bar{\rho}$ and the elasticity σ is required to solve $\tilde{r}_j$ from the inferred $(\tilde{r}_j/r_j)^{\rho_j(1-\sigma)}$. As the level of $\rho_j \to 0$, $\partial \ln \tilde{r}_j / \partial \ln r_i \to \tilde{w}_{ij}$ and thus $\tilde{r}_j \to \bar{r}_j$. For finite but small inferred passthrough elasticity deviation ρ_j, the cross country variation in exchange rate changes and in the effect of sellers' prices on weights $\tilde{w}_{ij}$ makes only small differences from $\bar{r}_j$. Results below thus indicate mostly high correlation between $\tilde{r}_j$ and $\bar{r}_j$ for small ρ_j inferred from annual gravity equations. In contrast, correlation falls dramatically with higher external values of passthrough elasticity $\bar{\rho}$.

2.4.2 Sellers Effective Exchange Rate

Seller earnings are inversely related to sellers incidence by equation (2.5), just as the buyers purchasing power is inversely related to buyers incidence. In relative

[14] Chain weights allow for changes in X_{ij}/E_j. The ratio of new to base shares is given in structural gravity by

$$\frac{X_{ij}/E_j}{X_{ij}^0/E_j^0} = \frac{Y_i/Y}{Y_i^0/Y^0}\left(\frac{\Pi_i P_j}{\Pi_i^0 P_j^0}\right)^{1-\sigma}(r_i/r_j)^{\rho_j(1-\sigma)} = \left(\frac{p_i}{p_i^0}\right)^{1-\sigma}\left(\frac{P_j}{P_j^0}\right)^{1-\sigma}(r_i/r_j)^{\rho_j(1-\sigma)}$$

where the right hand equation uses (2.5).

form (2.5) implies

$$\frac{Y_i/Y}{Y_i^0/Y^0} = \left(\frac{p_i\Pi_i}{p_i^0\Pi_i^0}\right)^{1-\sigma}.$$

For an endowments economy, the relative earnings change is given by[15]

$$\widehat{p_i} = \frac{p_i}{p_i^0} = \left(\frac{y_i^0}{y_i}\right)^{1/\sigma}\left(\frac{\Pi_i}{\Pi_i^0}\right)^{1/\sigma-1} \tag{2.14}$$

The effective exchange rate index that is equivalent in sellers' earnings power is based on using equation (2.7) for Π_i and steps parallel to (2.9). Relative earnings are inversely proportional to changes in sellers' multilateral resistance, given by the real sellers appreciation

$$\tilde{R}_i^x \equiv \frac{\Pi_i}{\Pi_i^0} = \left[\sum_j \frac{X_{ij}^0}{Y_i^0}\frac{E_j/Y}{E_j^0/Y^0}\left(\frac{P_j^0}{P_j}\right)^{1-\sigma}\right]^{1/(1-\sigma)}\left[\sum_j \widetilde{w}_{ij}^x (r_i/r_j)^{\rho_j(1-\sigma)}\right]^{1/(1-\sigma)}, \tag{2.15}$$

where

$$\widetilde{w}_{ij}^x = \frac{\frac{X_{ij}^0}{Y_i^0}\frac{E_j/Y}{E_j^0/Y^0}\left(\frac{P_j^0}{P_j}\right)^{1-\sigma}}{\sum_i \frac{X_{ij}^0}{Y_i^0}\frac{E_j/Y}{E_j^0/Y^0}\left(\frac{P_j^0}{P_j}\right)^{1-\sigma}}. \tag{2.16}$$

The second term on the right hand side of (2.15) is the passthrough of bilateral exchange rate appreciation (relative to appreciation in the individual seller's destination markets) to sellers incidence. This is the nominal ERG passthrough for sellers, inversely related to sellers' earnings as in the partial equilibrium case.

To complete the parallel of nominal ERG for sellers to buyers nominal ERG, define a seller-specific passthrough $\bar{\rho}_i$ as the local solution to

$$\left[\sum_j \widetilde{w}_{ij}^x (r_i/r_j)^{\rho_j(1-\sigma)}\right]^{1/(1-\sigma)} = \left[\sum_j \widetilde{w}_{ij}^x (r_i/r_j)^{\bar{\rho}_i(1-\sigma)}\right]^{1/(1-\sigma)}.$$

Then the passthrough to sellers incidence implies a sellers nominal ERG passthrough $\tilde{r}_i^x$ as:

[15] Allowing for substitutability in supply results in implicit functions for the within-country sectoral shares and their relationship to cross-country shares. The same principle governs the relationship of earnings to seller incidence but is complicated by supply side substitution.

$$\left[\sum_j \widetilde{w}^x_{ij}(r_i/r_j)^{\rho_j(1-\sigma)}\right]^{1/(1-\sigma)} = (r_i/\tilde{r}^x_i)^{\bar{\rho}_i}\,. \tag{2.17}$$

In the application below to potential seller compensation for or benefit from exchange rate changes, we report inferred estimates of the left hand side of (2.17), to be interpreted as the right hand side.[16] An appreciation of i's exchange rate relative to its partners raises $r_i/\tilde{r}^x_i$, which is passed through to sellers incidence at rate $\bar{\rho}_i$. Then under-valuation $r_i/\tilde{r}^x_i < 1$ delivers an effective producer subsidy $(r_i/\tilde{r}^x_i)^{\bar{\rho}_i}$ applied below to illustrate potential seller compensation policy measures.[17]

Returning to the real sellers exchange rate, the first term on the right hand side of equation (2.15) is a CES index of relative changes in buyer multilateral resistances, with endogenous weights. Buyers price increases in (2.15) reduce Π_i/Π^0_i and hence raise earnings.

The steps above for national income and expenditure carry through to the sectoral level under the common simplifying assumption (in gravity modeling) that the upper level preference/technology aggregator is Cobb-Douglas. Unbalanced trade is handled with the assumption that $E_i = \phi_i Y_i$ subject to $\sum_i \phi_i Y_i = Y = \sum_i Y_i$. At the sector level, the variables in the preceding expression have sector k superscripts and α^k_i is the expenditure share parameter for sector k goods from country i. On the left hand side of (2.15) for sector k the factor $\phi_i\alpha^k_i$ appears in numerator and denominator, hence it cancels.

Evaluation of (2.15) for local changes reveals important differences from the purchasing power index. Log-differentiate the sectoral form and suppress variation

[16] The exponent $\bar{\rho}_i$ is implicitly defined, unlike the exponent ρ_j in the nominal buyers ERG $\widetilde{r}_j$. When needed to solve for $r_i/\tilde{r}^x_i$, $\bar{\rho}_i$ is the minimum real root on the unit interval that satisifies (2.17). The economic rationale for selecting the minimum root is consistency with the standard story of monopolistically competitive sellers.

[17] In the endowments general equilibrium characterized by equation (2.14), earnings rise by the factor

$$\hat{p}^s_i = \left(\frac{r_i}{\tilde{r}^x_i}\right)^{\bar{\rho}_i(1/\sigma-1)} > 1.$$

To parallel reporting of the buyers measure (2.13), we report the all-else-equal measure (2.17).

in Y^{k0}/Y^k.[18] The result is

$$(1-\sigma_k) d \ln \Pi_i^k / \Pi_i^{k0} = \bar{\rho}_{ik} [d \ln \tilde{r}_{ik}] + Cov_{ik}(\overrightarrow{\rho}, \overrightarrow{r}) - \sum_j \frac{X_{ij}^{k0}}{Y_i^{k0}} \widehat{P}_j^k. \tag{2.18}$$

$\overrightarrow{\rho}$ denotes the vector $(\rho_1, ..., \rho_n)$, $\bar{\rho}_i$ is its i-specific trade weighted mean and $\overrightarrow{r}_j$ denotes the vector $(r_1/r_j, ..., r_n/r_j)$. The covariance term captures the effect on seller i's income of the interaction of destination-specific variation of exchange rate passthrough with destination-specific exchange rate variation. The covariance is seller-specific because the generalized trade weights $\tilde{w}_{ij}^x$ are seller-specific.

Compared to the local evaluation of the purchasing power index (2.11), (2.18) requires an origin specific $\bar{\rho}_i$ that is an export (for i) weighted average of the destination passthrough rates in the first term. A second difference is that the general equilibrium effects of sellers prices in (2.11) are replaced by the general equilibrium effects of buyers price index changes in P_j in (2.18). The third and more novel difference is the covariance term. Even with partial equilibrium assumptions that shut down the general equilibrium price terms, (2.18) implies that standard effective exchange rate indexes corrected for country specific passthrough are, in contrast to purchasing power indexes, inadequate to capture sellers income effects due to the variation in destination exchange rate passthrough rates.

By construction, the real ERGs $\widetilde{R}_j^k$ and $\widetilde{R}_i^{x,k}$ are consistent with equilibrium multilateral resistances (2.7)-(2.8). They share a close resemblance in structure but they generally diverge and tend to be negatively correlated because they inherit the normally negative correlation of buyer and seller multilateral resistances. Intuition from partial equilibrium applies – appreciation is good for buyers and bad for sellers.

[18]In a multi-sector endowments economy, the exchange rate changes would generally induce relative seller price variation.

2.4.3 Policy Implications

Charges of 'currency manipulation' are directed at individual countries perceived to be advantaging their national sellers with an undervalued exchange rate. The two real ERGs – purchasing power index $\widetilde{R}_j^k$ and earnings power index $\widetilde{R}_i^{x,k}$ – are theory-consistent measures of the real effects of exchange rate movements on sectoral buyers and on sellers. The real ERGs aggregated across sectors may be used to indicate desirable directions of change of exchange rates in the 'jawboning' commonly done between national economic policymakers in this context. Such measures do not, however, necessarily give reliable information about long run equilibrium exchange rate changes from current positions. Appendix A specifies a counterfactual long run general equilibrium simulation that that projects the equilibrium changes for comparison to the ERGs. The two are highly correlated but magnitudes differ and for some country-time intervals the correlation is low or even negative.

Policy response at the country level in the form of subsidies to offset domestic group injury is feasible and consistent with current allowance for adjustment assistance. Temporary compensation policies at the sectoral level could be based on movements in earnings power nominal ERG $(r_i^k/\tilde{r}_i^{x,k})^{\bar{\rho}_i^k}$ or purchasing power ERG $(\widetilde{r}_j^k/r_j)^{\rho_j^k}$ that exceed a threshold. This would be analogous to the producer price support payments or consumption subsidies that are prominent in primary and agricultural products on both production and consumption sides. Compensation in this form is consistent with the *all else equal* structure of the ERGs.[19] The temporary domestic compensation policies could be made subject to WTO rules and dispute settlement: allowed when justified by findings of harm, similar to the current WTO treatment of 'safe-guards' and anti-dumping cases.

This potential extension of 'adjustment assistance' might bleed off the political pressure associated with claims of 'currency manipulation', as it does with

[19]The real ERGs move over time due to many other factors with effects embedded in indexes $C_j^{x,k}$ and C_j^k. A policy aimed at compensation for exchange rate frictions should not compensate for the latter general equilibrium forces.

anti-dumping. A further advantage is that this setup would tend to neutralize countries' incentives to use exchange rate policy for temporary advantage, as the prohibition of export subsidies does in current WTO law.

2.4.4 Mult-sector ERGs

The extension from the one sector case to multiple sectors is simple under a standard (in the recent literature) Cobb-Douglas aggregation. For each sector k, the multilateral resistance systems and the sellers' price equations hold as in the 1 good per country case. Thus all the steps leading to (2.11) hold at the sectoral level:

$$\widetilde{R}_j^k = \frac{r_j^{\rho_j^k} P_j^k}{P_j^{k0}} = C_j^k (\tilde{r}_j^k / r_j)^{\rho_j^k}.$$

The aggregate ERG is the Cobb-Douglas aggregator of the sectoral ERGs:

$$\mathcal{R}_j = \prod_k (\widetilde{R}_j^k)^{\alpha_k}.$$

The second equation can be decomposed into

$$\mathcal{R}_j = \mathcal{C}_j \mathbf{r}_j^{\tilde{\rho}_j}$$

where $\mathcal{C}_j = \prod_k (C_j^k)^{\alpha_k}$, $\tilde{\rho}_j = \sum_k \alpha_k \rho_j^k$ and $\mathbf{r}_j^{\tilde{\rho}_j} = \prod_k ((\tilde{r}_j^k)^{\rho_j^k} / r_j)^{\alpha_k}$.

Full general equilibrium in the endowments model aggregates sectors in similar fashion. Aggregate incomes are the sum of sectoral incomes $Y_i = \sum_k Y_i^k$. Cobb-Douglas demand systems imply $E_j^k = \alpha_k E_j$; where $\alpha_k \in (0,1)$, $\sum_k \alpha_k = 1$. As in the 1 sector case, trade imbalance is modeled with a fixed ratio of expenditure to income ϕ_i, hence in combination with the requirement that global income equals global expenditure, $E_i = \phi_i Y_i / \sum_i \phi_i Y_i$. The normalization of sellers' prices is $\sum_{i,k} p_i^k y_i^k = \sum_{i,k} y_i^k$. Closure is given by $E_j = \phi_j Y_j$ subject to $\sum_j \phi_j Y_j = \sum_j Y_j = Y$.

2.5 Terms of Trade and Exchange Rates

The terms of trade in the one sector case equal the real earnings of country j given by $r_j p_j / P_j$.[20] The relative change in real earnings is given by

$$\hat{T}_j = \frac{r_j p_j / p_j^0}{P_j / P_j^0}$$

Use the market clearance equation (2.5) evaluated at the two equilibria to solve for

$$r_j p_j / p_j^0 = \frac{\Pi_j^0}{\Pi_j} \left(\frac{Y_j / Y}{Y_j^0 / Y^0} \right)^{1/(1-\sigma)}.$$

Substitute into the change in real earnings to yield:

$$\hat{T}_j = \frac{\Pi_j^0 P_j^0}{\Pi_j P_j} \left(\frac{Y_j / Y}{Y_j^0 / Y^0} \right)^{1/(1-\sigma)} = \frac{1}{\widetilde{R}_j \widetilde{R}_j^x} \left(\frac{Y_j / Y}{Y_j^0 / Y^0} \right)^{1/(1-\sigma)}. \tag{2.19}$$

$\hat{T}_j$ can be calculated using estimated gravity coefficients and data to construct bilateral trade costs and solving system (2.2)-(2.3). The second equation expression of $\hat{T}_j$ in (2.19) in terms of real ERGs decomposes the real income effects of non-uniform passthrough. For the money neutrality case when all other variables are constant, $\hat{T}_j = 1$: the terms of trade are constant.

2.5.1 Multi-sector Terms of Trade

Terms of trade more generally refers to an aggregate of sectors. The aggregate terms of trade for multiple sectors follows the technique of Anderson and Yotov (2016). Resuscitating the sector index k, (2.19) gives a terms of trade index for each sector k, T_i^k. Rather than mechanically forming an average of the sectoral indexes, it is preferable to build from sellers' and buyers' price indexes separately,

[20] This usage of 'terms of trade' is somewhat eccentric because in the numerator is the sellers' price of tradables (including sales to the home market) while in the denominator is the buyers' price of tradables (including purchases in the home market). The local rate of change of real income is equal to the local rate of change of the terms of trade because the income effect of local sales price changes is equal to zero. For discrete changes, the real income measure is preferred to the usual terms of trade measure approximation.

then form their ratio as the terms of trade index.

For the sellers' price index we follow Anderson and Yotov in building upon an endowment economy. Thus $Y_i^k = r_i p_i^k y_i^k$ where y_i^k is the endowment of country i's variety of the good in sector k (the resources used in both production and distribution). Because of the endowment assumption, $y_i^k = y_i^{k0}$. It is convenient to choose units such that $p_i^{k0} = 1, \forall i, k$. The price index for sellers is defined with the intuitive normalization $\sum_{i,k} r_i p_i^k y_i^k / \sum_{i,k} y_i^k = 1$, implying that the value of the world endowment is constant. This normalization along with the homogeneity restrictions of the model turns out to imply (Anderson and Yotov, 2016) a sector-by-sector restriction $\sum_i r_i p_i^k y_i^k = \sum_i y_i^k$. For any country i, the seller's price index relative to its initial value of 1 is given by $\sum_k r_i p_i^k y_i^k / \sum_k y_i^k$. Solving the effective market clearing condition (2.5) for the new price in the endowment economy, $r_i p_i^k = \left(\Pi_i^{k0}/\Pi_i^k\right)^{1-1/\sigma_k}$. Then $Y_i^k/Y^k = \left(\Pi_i^{k0}/\Pi_i^k\right)^{1-1/\sigma_k} y_i^k / \sum_i y_i^k$. For conducting counterfactual long run equilibrium experiments, $r_i p_i^k = r_i^*,\ \forall i, k$.

For buyers, the price index is formed by aggregating the sectoral indexes P_i^k. The Cobb-Douglas price index $\mathcal{P}_i = \prod_k (P_i^k)^{\alpha_k}$. In the present application evaluating the change in terms of trade, P_i^k is replaced by its relative change P_i^k/P_i^{k0}. In the counterfactual long run equilibrium experiment, P_i^k is the long run counterfactual value.

The terms of trade for country i is given by

$$\hat{T}_i = \frac{\sum_k \left(\Pi_i^{k0}/\Pi_i^k\right)^{1-1/\sigma_k} y_i^k / \sum_k y_i^k}{\prod_k (P_i^k/P_i^{k0})^{\alpha_k}}. \tag{2.20}$$

For the one good economy (2.20) reduces to (2.19). For the counterfactual long run equilibrium experiment, $\hat{T}_i = T_i^*$ and the multilateral resistances with superscript 0 denote the inferred values for the base year.

The form of (2.20) is based on the endowments economy structure, but the same value of $\hat{T}_i$ results from the Ricardian economy model of Eaton and Kortum (2002) extended to multiple sectors by Costinot, Komunjer and Donaldson (2012).

Under this interpretation the terms of trade change factor is interpreted as the real wage change factor.

2.6 ERGs in Practice

This section presents inferred ERGs and their implications based on structural gravity estimates of the effect of exchange rate changes on trade flows. First we detail the gravity equation to be estimated, then briefly describe the results with a focus on the exchange rate change term. The estimated exchange rate change term is used to calculate ERGs and their implications.

Next we examine the empirical relationship between the ERGs and the standard measures of effective exchange rates. Correlations are fairly high, but quantitatively the two measures differ significantly. Importantly, for some time periods and countries, the correlation is negative.

The counterfactual long run money neutrality equilibrium allows comparison of inferred real ERGs with their counterfactual long run Purchasing Power Parity (PPP) values. The correlation is high but quantitatively there are significant differences.

A second use of the counterfactual is to calculate the implied terms of trade effects of each year's deviation from long run money neutrality. Real income (terms of trade) effects are mostly small, but for the top and bottom deciles the average (within decile, across all years) terms of trade effect averages around 2% and -2% respectively.

2.6.1 Data

We require a data set capable of yielding internal trade along with cross border trade in multiple sectors.[21] The WIOD dataset concords production data with in-

[21] Observations on internal trade empower the gravity regression to distinguish exchange rate change effects from from the origin-time and destination-time fixed effects required to control for multilateral resistance. See the discussion of equation (2.21) below.

ternational trade data, hence it is convenient for this purpose. Structural gravity is estimated from the WIOD data (covering 2000-2014, 56 sectors, 43 countries) that includes sectoral production for each country, and bilateral trade data. Estimates of trade elasticity is taken from WIOD also provide exchange rate used to convert national values into US dollar. These exchange rates are used to construct bilateral exchange rates. Standard trade cost proxies like distance, RTAs, etc. are from the CEPII dataset.

2.6.2 Specification

The gravity estimator of the CES structural gravity model is applied to the bilateral trade, including internal trade, for all countries in each sector. The percentage of zero trade flows is shown in Table 2.1. The small proportion of zeros helps justify our use of the PPML estimator. For any sector k:

$$\begin{aligned} X_{ijt} = \exp\Bigg[\widetilde{\rho}_j \ln\left(\frac{r_{it}}{r_{jt}}\right) &+ \beta_{1t} INTR\_BRDR_{ij} * \delta_{t>2000} + \beta_2 RTA_{ijt} + \beta_3 comcur_{ijt} \\ &+\beta_4 \ln distw_{ij} + \beta_5 CNTG_{ij} + \beta_6 CLNY_{ij} + \beta_7 LANG_{ij} \\ &+\beta_8 INTR\_BRDR_{ij} + \alpha_{it} + \eta_{jt} + \alpha\Bigg] + \epsilon_{ijt};\ \forall i,j,t. \end{aligned} \tag{2.21}$$

The effect of exchange rate movements on bilateral trade costs is the first term of the first line of equation (2.21). The second term is a cross-border-time fixed effect that controls for time-varying investments in cross-border marketing capital (Anderson-Yotov, 2020). ϵ_{ijt} is a Poisson distributed random error term, α_{it} is an origin-time fixed effect, η_{jt} is a destination-time fixed effect, α is a constant, and superscript k is omitted to reduce clutter. The remaining cost controls are for implementation of a regional trade agreement (RTA), common currency (*comm-curr*), distance (*distw*), contiguity (CNTG), former colonial tie (CLNY), common language (LANG) and a time invariant cross border fixed effect (INTR_BRDR). The origin- and destination-time fixed effects control for $Y_i \Pi_i^{\sigma-1}$ and $E_j P_j^{\sigma-1}$ respectively.

The presence of internal trade flows on the left hand side of regression estimator (2.21) permits distinguishing exchange rate effects from the origin-time and destination-time fixed effects. Without internal trade, the exchange rate effects are absorbed by the fixed effects. Data on country-time production and expenditure in each sector combine with the theoretical interpretation of the estimated fixed effects to imply estimates of the multilateral resistances.

Table 2.1: Percentage of zero trade flows by sector (averaged over years)

Sector	Percentage of Zero Trade Flows	
	Mean	Standard Deviation
Agriculture	0.40	0.12
Mining	0.96	0.12
Manufacturing		
Food	0.07	0.07
Textile	0.02	0.05
Wood	0.38	0.24
Paper	0.12	0.11
Chemicals	0.05	0.07
Plastic	0.02	0.03
Minerals	0.05	0.04
Basic metals	0.44	0.20
Metal products	2.31	0.05
Machinery	0.05	0.07
Electrical	2.30	0.03
Communication	0.11	0.13
Medical	5.33	0.11
Auto	0.14	0.09
Other Transport	3.07	0.38

continued on next page

Sector	Percentage of Zero Trade Flows	
	Mean	Standard Deviation
Other	0.02	0.04

2.6.3 Results

Gravity Coefficients

The estimated sectoral gravity equation results have no elements of novelty except in the estimated exchange rate effects, so that is the focus of the discussion. As context, the equations fit the data well, bilateral distance is important, globalization effects (upward trending cross-border-time fixed effects, as in Anderson and Yotov, 2020) are revealed and the usual list of bilateral friction proxies performs as usual.

The estimated exchange rate effects $\tilde{\rho}_j$ in (2.21) are generally statistically significantly different from zero. Recall that the theoretical interpretation of $\tilde{\rho}_j$ is $(1-\sigma)(\rho_j - \bar{\rho})$ where $\bar{\rho}$ is benchmark value of the ρ_js. A t-test that cannot reject the null means that for the given sector, passthrough is close to uniform and exchange rates have no real effect. For 18 sectors and 43 countries we find 68% (80%) of cases where we cannot reject the null at the 5% (1%) significance level. Passthrough uniformity requires that all destinations taken as a group fail to reject the null. The joint test rejects the null in all sectors.

Moving from econometric inference of $\tilde{\rho}_j$s to construction of the ρ passthrough elasticities uses the theoretical structure $\rho_j = \tilde{\rho}_j/(1-\sigma) + \bar{\rho}$. The right hand side of the equation requires external estimates of average $\bar{\rho}$ and trade elasticity $1-\sigma$. Consistent with our use of the US dollar as numeraire currency, we use external estimates of the US passthrough rate where needed. The constructed ρs are used to calculate the ERGs.

Constructed Estimates of ρ

We apply the passthrough rate for the USA equal to 0.27 (Burstein and Gopinath, 2014) and apply the estimate of the sectoral trade elasticities from Caliendo and Parro (2015). The table reports the resulting mean and standard deviation of the sector-country point estimates of $\rho_j = \tilde{\rho}_j/(1-\sigma) + \bar{\rho}$. (We do not report standard errors because the external parameters are taken from different data and models than our estimate of $\tilde{\rho}_j$.)

The results we report should be taken as illustrating the method rather than precise measures. In two sectors, Auto and Other Transport, the constructed mean is above 1 and the standard deviation is above 2. These cases arise due to estimated trade elasticity < 1 reported by Caliendo and Parro (0.49 for Autos and 0.90 for Transport), with big standard errors (0.91 and 1.61). $\rho > 1$ is theoretically possible, depending on how passthrough is modeled, but the low trade elasticities suggest a measurement error issue for the constructed ρ reported for the Auto and Other Transport sectors, and perhaps for other sectors.

More generally, our method of construction of ρ needs precisely estimated trade elasticities (ideally based on the same data and model), combined with passthrough elasticities ideally estimated at the sectoral level. Another issue with the Caliendo and Parro trade elasticities is that they are interpreted as long run elasticities, in contrast to the lower short run elasticities typically inferred from time series variation. Intuitively, exchange rate frictions are short run phenomena, requiring short run trade elasticities to construct estimates of passthrough ρ. This difference matters substantially because lowering the trade elasticity raises the dispersion in ρ implied by $\tilde{\rho}/(1-\sigma)$.[22]

[22] Anderson and Yotov (2020) provide a structural model of the ratio of short run to long run trade elasticities and call it the incidence elasticity. They estimate an incidence elasticity in manufacturing equal to 1/4. We do not report results for constructed ρ based on short trade elasticities because of no information on sectoral variation of either incidence or passthrough elasticities.

Table 2.2: Summary of Exchange Rate Passthrough Rate Estimates

Sector	Exchange Rate Passthrough	
	Mean	Standard Deviation
Agriculture	0.16	0.23
Mining	0.25	0.15
Manufacturing		
Food	0.65	0.78
Textile	0.25	0.19
Wood	0.33	0.19
Paper	0.43	0.24
Chemicals	0.83	0.41
Plastic	0.66	1.74
Minerals	0.08	0.46
Basic metals	0.18	0.20
Metal products	0.03	0.32
Machinery	0.29	0.45
Electrical	0.15	0.14
Communication	0.02	0.45
Medical	0.82	0.32
Auto	1.92	2.70
Other Transport	1.57	2.54
Other	0.17	0.34

Relation between buyer and seller ERG

The general inverse relationship between buyer ($\tilde{r}/r$) and seller ERG ($r/\tilde{r}^x$) is shown in Figure 2.1. As shown in equation (2.11), the buyer ERG captures the direct impact of exchange rate movements on purchasing power with elasticity ρ_j, and a rise in $r/\tilde{r}^x$ indicates a loss of earnings power (equations (2.15) and (2.17)) with elasticity $\bar{\rho}_i$. The direct effect of exchange rate fluctuations on sellers' earnings is captured by seller ERG, and increases in $r/\tilde{r}^x$ represent falls in sellers' earnings. As suggested by our intuition, an increase in the exchange rate is beneficial to buyers because it increases their purchasing power, but it is detrimental to sellers since it reduces their competitiveness. Figure 2.1 captures this intuition. Between 2003 and 2008, the US effective exchange rate fell, resulting in a fall in purchasing power and an increase in seller revenue.

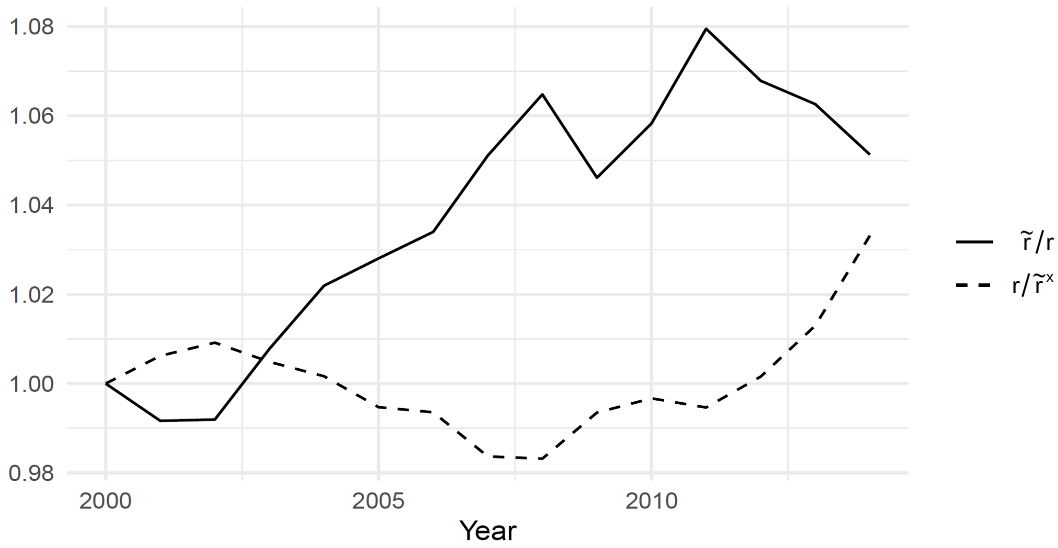

Figure 2.1: Buyer VS Seller nominal ERG for United States (Aggregate)

Figures 2.2 and 2.3 show the direct impact of exchange rate variations (as in Figure 1) and its passthrough to US purchasing power and sellers' earnings, respectively. Between 2000 and 2014, the direct effect of exchange rate variation was a 1% drop in US buying power and a 1.5% drop in sellers' earnings.

Figures 2.4 and 2.5 plot the time series of US aggregate real and nominal ERGs along with the aggregate price indexes C_{US} for the buyer and C^x_{US} for the seller. The price indexes combine the general equilibrium effects of exchange rate movements with the many other time varying forces that drive the changing pattern of world production. In some intervals $\tilde{r}^x$ and C^x are negatively correlated. In Figure 2.5, for example, the real seller ERG ($\tilde{R}^x$) declined roughly 4% in 2002 compared to 2001, owing to the general equilibrium impact of C^x, partially offset

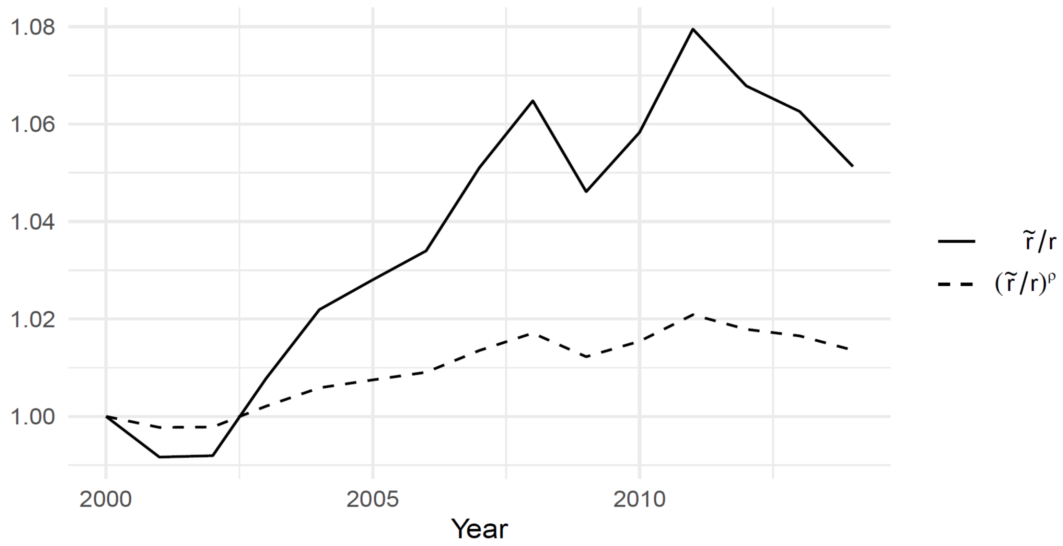

Figure 2.2: Buyer nominal ERG and its passthrough, United States (Aggregate)

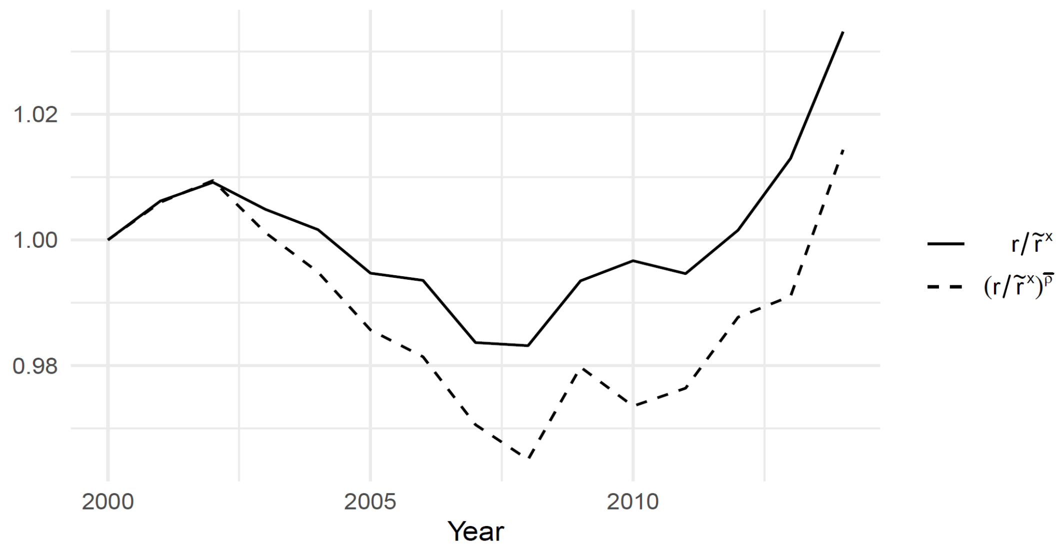

Figure 2.3: Seller nominal ERG and its passthrough, United States (Aggregate)

by a 0.5 percent increase in $(r/\tilde{r}^x)^{\bar{\rho}}$.

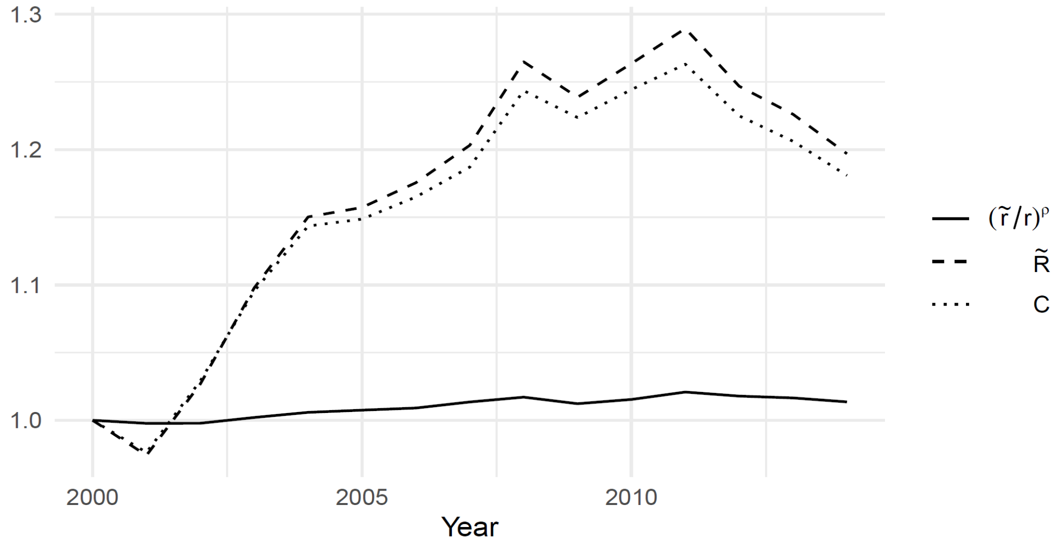

Figure 2.4: Buyer real ERG and components, United States (Aggregate)

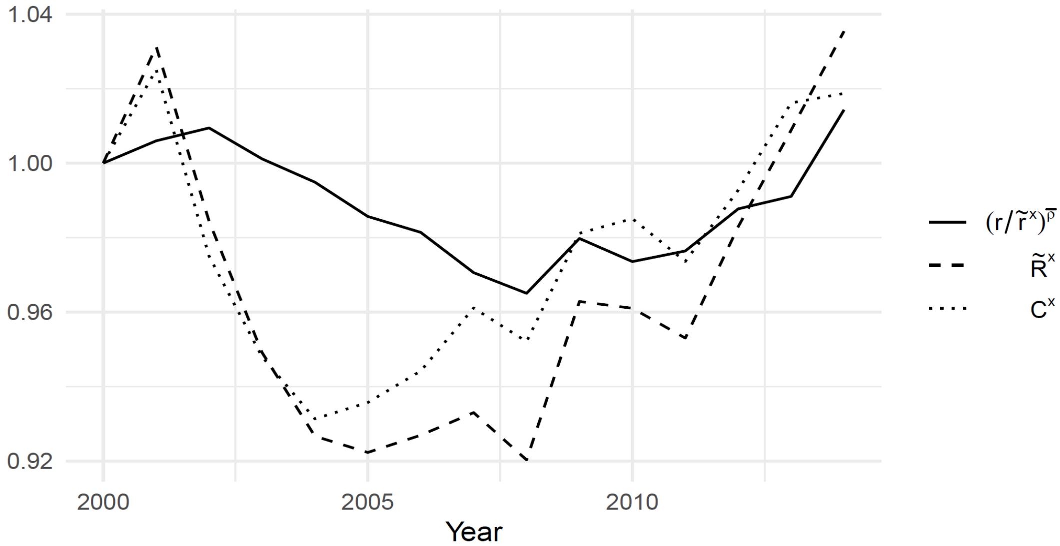

Figure 2.5: Seller real ERG and components, United States (Aggregate)

Relation of ERG to typical effective exchange rate

ERGs differ significantly from standard effective exchange rates in our results – magnitudes are quantitatively different and for some country-sector-time intervals are negatively correlated. The standard effective exchange rate measure requires an adjustment to make it comparable to the inclusion of domestic sales in the ERGs. Thus the standard effective exchange rate is modified to include domestic sales in the index: $\frac{\bar{r}_j}{r_j} = \sum_i w_{ij}(r_i/r_j)$ where the w_{ij}s are the expenditure share weights in j.

The overall correlation of the nominal ERGs with their effective exchange rate counterparts is fairly high, in the range of 0.33 to 0.97. This is because the indexes differ mainly in the weights, which locally are positive and sum to 1.[23] Also, the 2000-2014 era is unusual historically by the high and increasing dominance of the US dollar in global trade. Other eras may have lower correlation of bilateral exchange rates relative to the dollar. See the online Appendix for details on overall correlations.

Nominal ERGs and their effective exchange rate counterparts diverge over time by significant amounts. The divergence is greater for the sellers index than for the buyers index. At the sectoral level, there is even wider variation of the plots, dramatically different for some country-sector-time interval selections. For all countries, the movement of $\bar{r}/r$ and $\tilde{r}/r$ for buyers and $r/\bar{r}^x$ and $r/\tilde{r}^x$ for sellers is relative to 1 in the base year 2000. Figures 2.6 and 2.7 show two situations from Hungary's machinery manufacturing and the United Kingdom's electrical equipment manufacturing, where the conclusions from typical ER differ from ERG and show a considerable disparity. In the case of Hungary's machinery manufacturing sector, the seller ERG and the typical ER followed a similar path until 2008, but then diverged. According to typical ER, Hungary's equipment manufacturing sector depreciated by almost 8% between 2008 and 2014. Between 2008 and 2014, the effective exchange rate for Hungary's machinery manufacturing sector changed little or not at all, according to ERG. The seller ERG for the UK's electrical equipment manufacturing sector indicates a 25% appreciation in currency in 2014 compared to 2000, whereas typical ER measurements show an 8% depreciation.

[23]The ERGs also differ by an origin or destination specific passthrough exponent that has no counterpart in the standard formula.

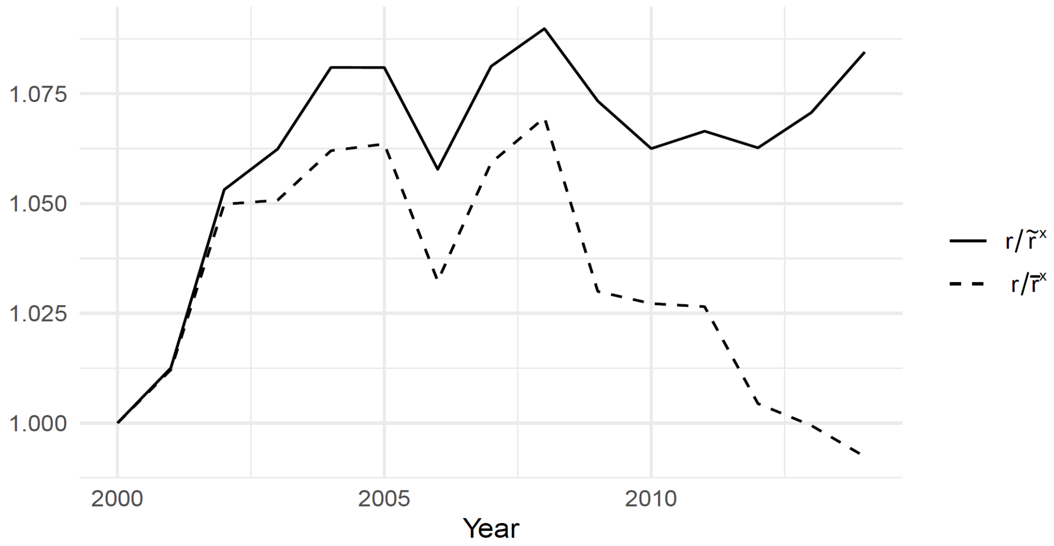

Figure 2.6: Seller ERG for Hungary (Sector: Machinery)

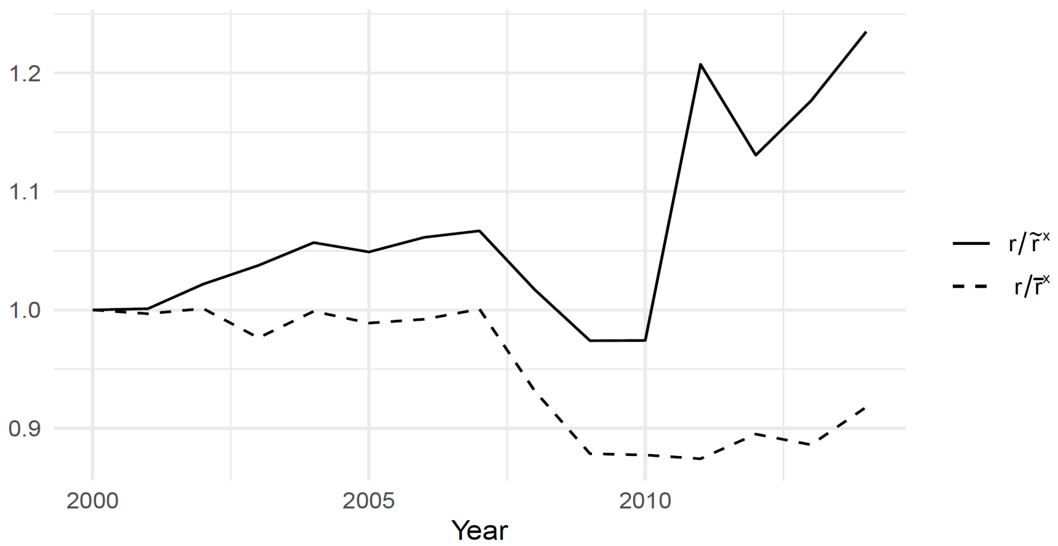

Figure 2.7: Seller ERG for United Kingdom (Sector: Electrical)

Policy Implications: ERG Compensation

As a pertinent example, Taiwan's seller ERG for tires is a production subsidy (or tax) equivalent of the effect of the world vector of exchange rate changes relative to a base period.[24] The Taiwan seller ERG is thus potentially relevant

[24] Missing data prevents calculation of the more pertinent case of Vietnam's seller ERG for tires. Production data for sellers is required to estimate real effects of exchange rate changes in the model. Vietnam is not reported in the WIOD data used in this paper. The more detailed USITC-ETPD database reports on Vietnam and also reports the sector rubber tires and tubes separately from the WIOD aggregate of rubber and plastics. Unfortunately, there is no production data for rubber tires and tubes available for Vietnam in the USITC-ETPD database.

for countervailing duty logic to be applied by the US. The US ERG for tires is a production subsidy (or tax) equivalent to the world vector of exchange rate changes relative to the base period. The US seller ERG is thus potentially relevant for a material injury finding due to the world vector of exchange rate movements.[25] The worldwide advantage provided to Taiwan tire producers via the Taiwan sellers ERG could be offset by a CVD in the same amount.[26]

The results for the two-digit group encompassing rubber and plastic product manufacturing suggest that the exchange rate adjustment between 2014 and 2000 had a small impact on tire vendors in Taiwan and the United States. As illustrated in Figure 2.8, overall seller producer prices in the United States increased by less than 2.5 percent in 2014 compared to 2000. This shift is less than 0.5 percent in Taiwan's rubber and plastic products manufacturing industry (figure 2.9).

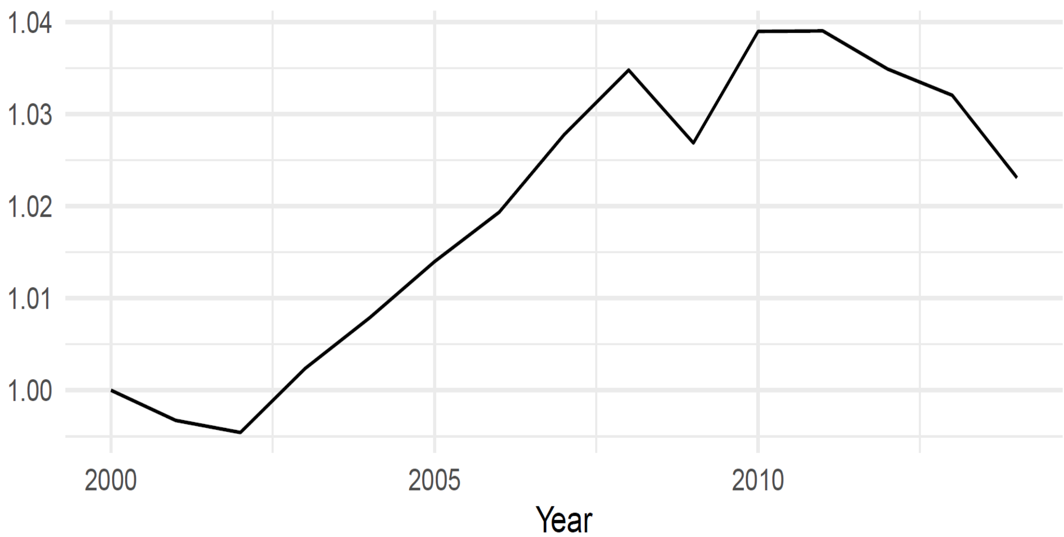

Figure 2.8: Producer Subsidy Equivalent, United States (Plastic and Rubber Manufacturing)

[25] It is not possible to isolate the effect of Taiwan's exchange rate on US seller interests except in a hypothetical world where Taiwan's exchange rate is the only variable that changes (and even in this case there are cross effects with other countries that change the 'subsidy equivalent').

[26] This quantification only approximates the logic of production subsidies. The economic mechanisms behind the ERGs imply that global third party interactions are important contributors to the measured ERGs, 'own' exchange rate of the source country is only one exchange rate factor acting on any source country's seller ERG in a particular sector.

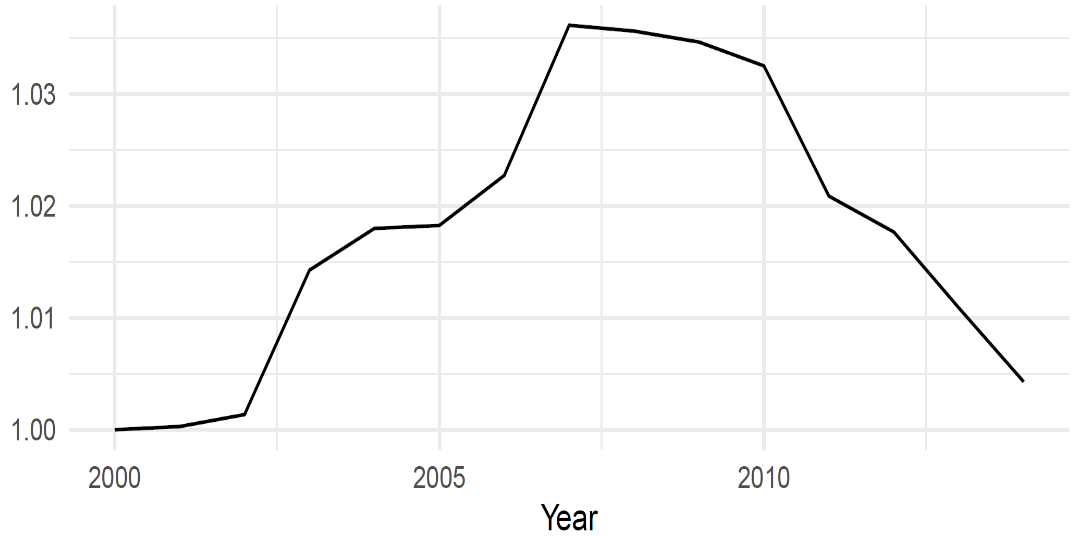

Figure 2.9: Producer Subsidy Equivalent, Taiwan (Plastic and Rubber Manufacturing)

Real Income Effects

Real income effects of exchange rate changes with passthrough frictions can be quantified by calculating the real income changes due to removing the frictions in the estimated model, simulation of the counterfactual long run equilibrium. The counterfactual yields the terms of trade effects of removing exchange rate passthrough frictions in the world economy consisting of 18 sectors and 43 countries. The calculation is based on each year's endowments and the yearly changes of exchange rates over the preceding year for the actual equilibrium, compared to the counterfactual long run equilibrium with the same endowments, tastes and trade costs except for removal of the exchange rate frictions.

The US is a representative case. the US terms of trade over the period 2000 to 2014 move within a band of around 0.4% up and down. Figure 2.10 plots the time series.

Table 2.3 reports the changes in terms of trade (T^*) from a counterfactual equilibrium, where the matrix of the exchange rate is the average of the previous five-year bilateral exchange rate matrix, to equilibrium with that year's exchange rate, while maintaining endowments, tastes, and trade costs (apart from those due to exchange rate changes) constant. The Second and third columns give the

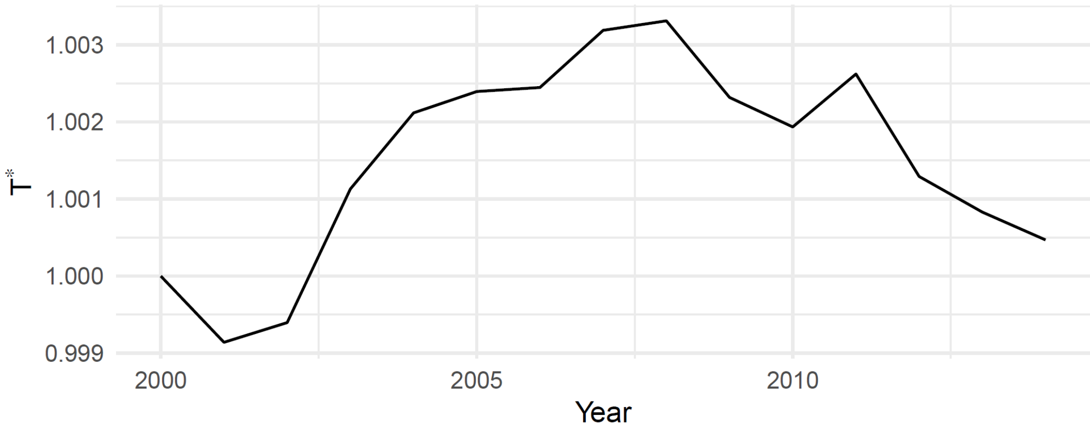

Figure 2.10: T^* for United States (Aggregate)

average in the top and bottom decile respectively in the cross-sectional distribution of terms of trade change. There is no obvious pattern to the countries in the top and bottom deciles of each year's terms of trade effects. Membership changes by year and includes both large and small economies. Some are commodity exporters, but some are highly diversified exporters. Deeper exploration awaits future work.

The last column in table 2.3 reports the world efficiency effect of exchange rate passthrough frictions (T^{**}) calculated as the size-weighted average of the country level terms of trade.

Table 2.3: Real Income Effects of Exchange Rate

Year	T^*		T^{**}
	mean(top decile)	mean(bottom decile)	
2000	1	1	1
2001	1.0086	0.9626	0.9989
2002	1.0069	0.9539	0.9987
2003	1.0198	0.9569	1.0014
2004	1.0256	0.9589	1.0026
2005	1.0263	0.9623	1.0029
2006	1.0288	0.9716	1.0038

Continued on next page

Year	T^*		T^{**}
	mean(top decile)	mean(bottom decile)	
2007	1.0378	0.9695	1.0044
2008	1.0231	0.9642	1.0006
2009	1.0162	0.9620	0.9979
2010	1.0151	0.9643	0.9984
2011	1.0152	0.9703	0.9986
2012	1.0152	0.9730	0.9974
2013	1.0095	0.9852	0.9983
2014	1.0146	0.9802	0.9982

2.7 Conclusion

Structural gravity is applied in the paper to quantify real effects of heterogeneous exchange rate passthrough. We define theory consistent operational indexes of bilateral exchange rates suitable for evaluating the real effects on buyers and sellers. The results reveal quantitatively significant real effects at the sectoral level, with much smaller but still non-negligible effects at the aggregate level.

We suggest potential policy implications in the form of domestic subsidies to politically significant losers. Domestic policies on these lines would relieve incoherent political pressure to act against 'currency manipulation' and could be consistent with WTO principles.

More speculatively, the gravity model connection to exogenously determined exchange rates here may be step toward a re-connection of real trade to exchange rate determination. The gravity model estimated here can be interpreted as a short run model in which bilateral 'marketing capital' capacities are fixed, and adjust slowly toward long run zero profit values (Anderson and Yotov, 2020). This setting suggests a structural dynamic channel from real trade to exchange rate movements.

2.8 Appendix

2.8.1 Equilibrium ERG Projection

The long run equilibrium obtains when money is neutral. Given the endowments and trade imbalances of a particular year in the data, the bilateral appreciation/depreciation elements r_i/r_j for that year are counterfactually set equal to 1. The full general equilibrium solution is calculated, yielding a set of seller and buyer incidences $\{\Pi_i^{k*}, P_j^{k*}\}$. The ratios of base year incidences to counterfactual long run equilibrium incidences form the set $\{\Pi_i^k/\Pi_i^{*k}, P_j^k/P_j^{*k}\}$. The decomposition steps used to separate direct and indirect effects of exchange rate changes in Sections 2.4.1 and 2.4.2 also apply here to yield long run ERGs.

The full general equilibrium solution required to project the effect of non-uniform exchange rate changes is completed by specifying a supply side of the model and closing the model with a relationship between expenditure and income. Assume to begin with that demand for all goods is aggregated in a single CES expenditure function. Supply is modeled as a vector of endowments.

For each origin i the value of sales at world currency prices is $Y_i = p_i y_i$ where y_i is the units of output of origin i and p_i is its 'factory gate' price in world currency units. Then $Y_i/Y_i^0 = p_i y_i/p_i^0 y_i^0$. Using equation (2.5)

$$\frac{p_i}{p_i^0} = \left(\frac{\Pi_i}{\Pi_i^0}\right)^{(1-\sigma)/\sigma} \left(\frac{y_i^0}{y_i}\right)^{1/\sigma}.$$

Sellers prices change in spatial equilibrium due to the shifting incidence of trade costs induced by non-uniform exchange rate passthrough. A full general equilibrium solution is found as a fixed point of (2.2)-(2.3), (2.5) with Y_i replaced by $p_i y_i$. Standard practice to resolve the indeterminacy of price levels in general equilibrium is to normalize the price vector $\{p_i\}$ for non-base projections by $\sum_i p_i y_i = \sum_i y_i$ where $p_i^0 = 1$ by choice of units.

For more intuition, begin from the short run model estimated for some end year

t using (2.7)-(2.8). The solution generates a set of inward multilateral resistances (equal in the setup to buyers' price indexes). For the same underlying data, the counterfactual long run equilibrium is based on solving system (2.2)-(2.3) for the long run multilateral resistances $\{\Pi_i^*, P_j^*\}$, taking away the effect of incomplete and non-uniform passthrough. The sellers' factory gate prices (in world currency units) in the endowments model case are solved from (2.5). The normalization is $\sum_i p_i y_i = \sum_i y_i$ where p_i is the factory gate price, y_i is the endowment (both in year t implicitly) and the year t sellers prices are set to 1 by units choice.

The full general equilibrium solution requires closure of the model with an assumption connecting expenditures to incomes. The simplest closure consistent with unbalanced trade (which is always observed) is $E_i = \phi_i Y_i$ where ϕ_i is observed in the benchmark equilibrium and assumed constant in moving to the counterfactual equilibrium.[27] The adding up condition for world equilibrium requires $\sum_i E_i = \sum_i Y_i \Rightarrow E_j/Y = \phi_j Y_j / \sum_j \phi_j Y_j$ for counterfactual equilibria. With these added structures in place, the counterfactual multilateral resistances can be computed.

In the long run there are no real effects of exchange rates. Given the endowments in year t, solve for the long run counterfactual equilibrium. The vector of consumer price indexes P_j^* gives the purchasing power of a unit of the world endowment (subject to the normalization) in country j in the long run equilibrium. The long run equilibrium exchange rate change vector given the endowments and exchange rates of year t is:

$$r_i^* = \frac{P_i^t}{P_i^*}, \ \forall i. \tag{2.22}$$

Vector r_i^* has several potentially important uses. Most obviously, it serves as the benchmark for deducing over- or under-valuation based on it relation to effective

[27] An intuitive justification for constant ϕ_is is that a counterfactual income deviation in one period would be intertemporally smoothed so that the marginal utility of external borrowing/lending remained equal to the marginal utility of wealth. The exact amount of smoothing depends on many details. Constant ϕs imply that deficit countries borrow more (less) as wealth rises (falls) due to income changes in the counterfactual period. The direction of change is intuitive with constant ϕs justified as simplification in a model focused on static equilibrium.

exchange rates as measured by

$$\frac{r_i}{r_i^*}.$$

r_i/r_i^* is a counterfactual concept that holds all variables constant except for the exchange rate. In contrast $\widetilde{R}_i$ compares a base year with a subsequent year using actual exchange rates, supply vectors and expenditure data for both base year and subsequent year. A second use of the counterfactual and implicitly of r^* is in calculating the terms of trade effects of going from the estimated actual equilibrium in each year to the counterfactual long run equilibrium. The details are covered in Section 2.5.

Mult-sector Long Run ER

The counterfactual long run equilibrium calculation yields a set of buyers' sectoral price indexes $\{P_j^{*k}\}$. The Cobb-Douglas aggregator of these is the economy wide price index in the long run. The short run price index for period t implied by gravity is similarly a Cobb-Douglas aggregate of the sectoral inward multilateral resistances. Then

$$r_i^* = \prod_k \left(\frac{P_i^{*k}}{P_i^{tk}}\right)^{\alpha_k}, \ \forall i. \tag{2.23}$$

ERG Vs Long Run ER in Data

The estimated gravity model is usefully deployed to examine the counterfactual long run equilibrium in which money is neutral, the deviations from uniform passthrough are removed. Two separate objectives suggest two variations on "long run" equilibrium. The first exercise examines how informative the ERGs are about the "long run" exchange rate. Given the focus on sector level effects due to treating exchange rates as trade policy, it makes sense to treat each sector as a "world" and examine the "long run" equilibrium of this sectoral "world economy". This implies a set of long run exchange rate changes r_i^{*k} for each country i in sector k. These are compared to the ERGs.

The correlation between r^* and both nominal and real ERGs for buyers is very high with the exception of Auto sector. The Auto sectors is suspect due to possible mis-specification (because their passthrough elasticities are greater than 1). Thus real ERG for buyers promises to be a usefully accurate indicator of long run exchange rates.

In contrast the nominal ERG ($r/\tilde{r}^x$) for sellers is much less highly correlated with r^*. The real ERG for sellers $\tilde{R}^x$ restores the high correlation with r^* observed for sellers ERG, with the same exception of Auto sector.

2.8.2 Effective Exchange Rates in Practice

A typical effective exchange rate index is calculated as:

$$\bar{r}_j = \sum_{i \neq j} r_i \frac{X_{ij}^0}{\sum_{i \neq j} X_{ij}^0}. \tag{2.24}$$

where X_{ij}^0 denotes the value of bilateral trade shipped from i to j in base period 0. Often r_j and $\bar{r}_j$ are in logs, in which case the levels are obtained by exponentiating. Sometimes (2.24) is calculated for exports as well as imports and sometimes for disaggregated trade. Recognizing that (2.24) is a Laspeyres index, some practitioners use Tornqvist indexes (for backward looking studies) or Laspeyres chain weights to replace the simple Laspeyres weights in (2.24).

The apparent intent of index definition (2.24) is to measure the impact on the buyer's purchasing power of the vector of bilateral exchange rate changes – $\bar{r}_j/r_j > (<) 1$ implies that j's currency has lost (gained) purchasing power. An appreciation (depreciation) of r_j would be needed to restore the base purchasing power of a unit of j's currency over a trade weighted basket of other currencies. Changes in actual purchasing power are measured by buyer price indexes P_j/P_j^0 where P_j is the current period local currency price index (for the bundle of goods imported) at j and P_j^0 is the base price index in local currency prices. Real purchasing power change in j's currency is measured by

$$\frac{\bar{r}_j/r_j}{P_j/P_j^0} = \frac{\bar{r}_j/P_j}{r_j/P_j^0}, \tag{2.25}$$

the hypothetical appreciation of j's currency needed to restore purchasing power parity with the base period.

Effective exchange rate indexes are also frequently calculated from the seller's point of view. Mechanically, sum over j rather than i in (2.24) to define seller i's effective exchange rate index of appreciation $\bar{r}_i^x$. Appreciation tending to drive down sellers' prices, the intent is to measure the effect of exchange rate appreciation on real earnings of sellers. The real effective exchange rate for sellers deflates by a sellers' price index in parallel to (2.25). Finally, while the most commonly reported effective exchange rate indexes are for aggregate trade, sectoral effective exchange rates are also often reported.

It is well recognized that effective exchange rate index (2.24) and the real exchange rate index (2.25) based on it are unsatisfactory for several reasons. Whether for buyers purchasing power or sellers earnings, aggregated or sectoral, here are the key problems:[28]

1. The price index structure does not specify links to incomplete exchange rate passthrough.

2. Theory suggests that trade costs affects the operation of exchange rates. Trade cost links to (2.24) are unspecified.

3. In a multi-country world, cross effects necessarily act on prices of goods to and from partners of j, affecting the trade shares in (2.24).

4. The preceding three problems all point to missing general equilibrium links of $\{r_j\}$ to $\{P_j\}$.

[28]There are many other purposes for which differing real exchange rates have been implemented. See Chinn (2006) for a useful survey. All the indexes surveyed there share the fundamental problems analyzed here: partial equilibrium assumptions that ignore trade costs and ignore incomplete passthrough.

This paper provides a real effective exchange rate index that appropriately treats all 4 problems within the restrictions of the structural gravity model, Effective exchange Rate with Gravitas (ERG). The structurally based real exchange rate index differs from (2.24) deflated by the price index deflator for all cases in which exchange rates matter; i.e., when money is not neutral.

2.8.3 Import/Export Forecast

Change in $\mathbf{R}^2$

The following specification is estimated (OLS) with and without exchange rate terms to get a rise in R^2 when we bring in exchange rate terms in basic gravity regression.

$$
\begin{aligned}
ln(X_{ij,t}) = \widetilde{\rho}_j \ln\left(\frac{r_{it}}{r_{jt}}\right) + \beta_{1t} INTR\_BRDR_{ij} * \delta_{t>2000} + \beta_2 RTA_{ijt} + \beta_3 comcur_{ijt} \\
+\beta_4 \ln distw_{ij} + \beta_5 CNTG_{ij} + \beta_6 CLNY_{ij} + \beta_7 LANG_{ij} \\
+\beta_8 INTR\_BRDR_{ij} + \alpha_{it} + \eta_{jt} + \alpha
\end{aligned}
$$

Table 2.4: Change in $\mathbf{R}^2$

$\mathbf{R}^2$	p50	Mean	SD	Max
Without ER terms	0.865	0.860	0.025	0.891
Without ER terms	0.868	0.863	0.024	0.893
Difference	0.003	0.003	0.001	0.004

Forecast Error

In this section, we compare forecast errors from the typical import/export forecast model using an effective exchange rate with a forecast error using our model. We compared the following four models.

Model 1

This model is the same as one mentioned in Cubeddu et al. (2019) to model imports and exports. This model is the basis for the IMF's External Balance Assessment (EBA) framework.

$$ln(X_{i,t}) = \sum_{j=1}^{n} \delta_j^X ln(X_{i,t-j}) + \sum_{j=0}^{m} \beta_j^X ln(\text{REER}_{i,t-j}) + \sum_{j=0}^{k} \gamma_j^X ln(\text{RY}_{i,t-j}^{TP}) + \epsilon_{it} \quad (2.26)$$

$$ln(M_{i,t}) = \sum_{j=1}^{n} \delta_j^M ln(M_{i,t-j}) + \sum_{j=0}^{m} \beta_j^M ln(\text{REER}_{i,t-j}) + \sum_{j=0}^{k} \gamma_j^M ln(\text{RY}_{i,t-j}) + \epsilon_{it} \quad (2.27)$$

where both specifications include time and country-industry fixed effects. Specification 2.26 (2.27) contains the real effective exchange rate and the trading partner's (domestic) gross domestic output value, along with a rich, dynamic lag structure.

Model 2

In model 2, we replace the real effective exchange rate index included in specifications 2.26 and 2.27 with an effective exchange rate from our model.

$$ln(X_{i,t}) = \sum_{j=1}^{n} \delta_j^X ln(X_{i,t-j}) + \sum_{j=0}^{m} \beta_j^R ln(\text{R}_{i,t-j}) + \sum_{j=0}^{m^x} \beta_j^{R^x} ln(\text{R}_{i,t-j}^x) + \sum_{j=0}^{k} \gamma_j^X ln(\text{RY}_{i,t-j}^{TP}) + \epsilon_{it} \quad (2.28)$$

$$ln(M_{i,t}) = \sum_{j=1}^{n} \delta_j^M ln(M_{i,t-j}) + \sum_{j=0}^{m} \beta_j^R ln(\text{R}_{i,t-j}) + \sum_{j=0}^{m^x} \beta_j^{R^x} ln(\text{R}_{i,t-j}^x) + \sum_{j=0}^{k} \gamma_j^M ln(\text{RY}_{i,t-j}) + \epsilon_{it} \quad (2.29)$$

Model 3

Here we predict import/exports using full model

$$\widehat{EX} = Y_i \left(1 - \frac{\widehat{E}_i}{\widehat{Y}} \left(\frac{\widehat{t}_{ii}}{\widehat{P}_i \widehat{\Pi}_i} \right)^{1-\sigma} \right)$$

$$\widehat{IM} = E_i \left(1 - \frac{\widehat{Y}_i}{\widehat{Y}} \left(\frac{\widehat{t}_{ii}}{\widehat{P}_i \widehat{\Pi}_i} \right)^{1-\sigma} \right)$$

Model 4

Model 4 uses predicted values from our structural model along with a dynamic lag structure to forecast imports/exports.

$$ln(X_{i,t}) = \sum_{j=1}^{n} \delta_j^X ln(X_{i,t-j}) + \sum_{j=0}^{m} \beta_j ln\widehat{EX}_{i,t} + \epsilon_{it} \tag{2.30}$$

$$ln(M_{i,t}) = \sum_{j=1}^{n} \delta_j^M ln(M_{i,t-j}) + \sum_{j=0}^{m} \beta_j ln\widehat{IM}_{i,t} + \epsilon_{it} \tag{2.31}$$

where both specifications include time and country-industry fixed effects.

We used WIOD sectoral data from 2000 to 2013 to estimate the model parameters. Then use the above four models, along with observed values of the exchange rate, real GDP, and sectoral production in 2014, to predict sectoral imports and exports in 2014. The absolute percent forecast error is calculated as a percentage difference between the predicted value of imports/exports relative to the observed value in 2014.

$$\widehat{\epsilon}^{IM} = \frac{IM_i - \widehat{IM}_i}{IM_i}$$

Results

Table 2.5 summary statistics for absolute percentage forecast error. The model that uses both predicted values and lag structure (Model 4) reduces absolute percentage forecast errors for both imports and exports relative to typical import/export forecast models. The mean absolute percentage error for exports has been reduced by 25%, while the mean absolute percentage error for imports has been reduced by 46%.

2.8.4 Data Description

Table 2.6 gives list of countries in our analysis.

Table 2.5: Absolute Percentage Forecast Error

	Median	Mean	SD	Max
Exports				
Model1	5.52	11.47	25.54	495.05
Model2	5.16	11.19	24.26	451.30
Model3	10.55	18.83	30.27	410.89
Model4	4.41	8.63	13.87	162.04
Imports				
Model1	4.66	8.62	22.37	493.55
Model2	4.70	8.66	21.89	482.74
Model3	6.70	11.08	13.11	113.69
Model4	2.89	4.60	6.27	86.07

Table 2.6: List of Countries

Australia	Korea
Austria	Latvia
Belgium	Lithuania
Brazil	Luxembourg
Bulgaria	Malta
Canada	Mexico
China	Netherlands
Croatia	Norway
Cyprus	Poland
Czech Republic	Portugal
Denmark	Romania
Estonia	Russia
Finland	Slovak Republic
France	Slovenia
Germany	Spain
Greece	Sweden
Hungary	Switzerland
India	Taiwan
Indonesia	Turkey
Ireland	United Kingdom
Italy	United States
Japan	

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