2
The Signal Effect of Exchange Rates: Pass-Through under Dispersed Information

2.1
Introduction

This paper is concerned with the theory of exchange-rate pass-through to prices (henceforth, ERPT or simply pass-through). According to international trade theory, if transportation costs are negligible, retail prices should be very responsive to exchange rate changes. However, the typical findings of the empirical literature challenge this view. Understanding the degree to which exchange rate variations are transmitted to prices is a perennial topic of discussion among scholars; however, in addition, few, if any, policymakers would seek to guide monetary policy while ignoring the effect of exchange rates on prices.[1]

We examine pass-through in a model of dispersed information based on the assumption that the nominal exchange rate imperfectly transmits information about the underlying fundamentals. Foreign intermediate goods exporters and home final goods producers receive noisy private signals about foreign and domestic fundamentals. All firms also observe a noisy public signal, the nominal exchange rate, relating the two fundamentals. We solve our model for the unique (linear) equilibrium and evaluate ERPT. If information is complete, ERPT is also complete, meaning that a 1% change in local currency prices for both intermediate imported goods and domestic final goods results from a 1% change in the exchange rate. Under dispersed information, however, our model is consistent with three stylized facts of the empirical pass-through literature:

1. **Incomplete Pass-Through**: ERPT lies between 0 and 1;

[1]See Gagnon and Ihrig (2004), Engel (2002), and Mishkin (2008) for the implications of exchange rate movements for the conduct of monetary policy. Ball (2009) also considers the role of fiscal policy and the coordination of both fiscal and monetary policies.

2. **Exchange Rate-Consumer Price Puzzle**: ERPT is usually the highest for imported goods prices, lower for producer prices, and lowest for consumer prices; and

3. **Macroeconomic Environment**: ERPT is higher for emerging market countries and declines over time for both industrial and emerging market economies.

To focus on the informational content of exchange rates, we exclude from our model important factors in explaining pass-through suggested by the theoretical literature.[2] While the theoretical literature typically assumes exporters setting prices in the consumers' currency (local currency pricing) and significant local costs of assembly and distribution, our approach relies on exporters setting their prices in their own currency (producer currency pricing) and ignores substantial local inputs and distribution costs. As a result, we convey our main intuition in a simple and stylized auto-parts model to highlight that our results are driven primarily by the signal role of the exchange rate under dispersed information.

The rationale of our approach is based on three central issues in macroeconomics. The first is the role of private and public signals under dispersed information. The second is the link between economic fundamentals and exchange rate behavior. The third is the impact of macroeconomic stability on the documented slowdown in the pass-through in the last few decades. We consider these issues below.

2.1.1
Private and Public Signals under Dispersed Information

In recent years, there has been growing interest in models that feature heterogeneous information about aggregate economic conditions and a moderate degree of complementarity in actions.[3] Following this literature, this paper takes steps toward linking dispersed information and exchange rates in the spirit of Bacchetta and van Wincoop (2006), who introduced information dispersion about future macroeconomic fundamentals in a dynamic rational expectations model in order to explain the Exchange Rate Determination Puzzle. We, instead, use a very simple and stylized model to focus on the information content of exchange rates to explain pass-through to prices.

[2]We present a brief review of the literature in Section 2.5.

[3]These models were used to capture applications such as the effects of monetary or fiscal policy, as in Woodford (2002), Angeletos and Pavan (2009), and Lorenzoni (2009), and the welfare effects of public information dissemination, as in Morris and Shin (2002), Hellwig (2005), and Angeletos and Pavan (2007).

We base our discussion on a beauty contest-type model where individual prices are strategic complements depending not only on fundamentals but also on the mean of prices. The relevant fundamentals are not observable. Instead, firms observe noisy private and public signals about these fundamentals. In the terminology of the relevant literature following Morris and Shin (2002), the nominal exchange rate works as a public signal of the underlying fundamentals. Under dispersed information, equilibrium prices depend not only on the relative precisions of private and public information but also on the degree of strategic complementarity. As the precision of the public signal increases, more weight is given to the nominal exchange rate in the price-setting process. Although complementarity is not crucial for our results, it amplifies the signal effect of nominal exchange rates. As the signal effect of exchange rates increases, there is a decrease in the impact of converting foreign currency export prices to domestic currency import prices.

2.1.2
Fundamentals and Exchange Rates

We assume that the nominal exchange rate follows an exogenous stochastic process compounded by fundamentals plus a white noise component. This noise term may represent short-run deviations from the fundamental exchange rate value.

Although economic theories state that the exchange rate is determined by macroeconomic fundamental variables, such as money supplies, a long-standing puzzle in international economics is the difficulty of tying floating exchange rates to such fundamental variables. This difficulty was first established by Meese and Rogoff (1983) using data from the 1970s to evaluate the out-of-sample fit of several models of exchange rates. The work of Campa et al. (2005) reaches the same conclusion for the most recent available models.

Our model, however, is consistent with recent works that offer new insights into the relation between exchange rates and fundamentals. Engel and West (2005) demonstrate that in a rational expectations present value model, under the assumptions that fundamentals are nonstationary and the discounting factor is near unity, the exchange rate will behave as a 'near' random walk process. This implies that the difficulty of predicting exchange rates using fundamentals may well be consistent with conventional exchange rate determination models. Sarno and Valente (2009), employing a predictive procedure that allows the relationship between exchange rates and fundamentals to evolve over time, find that the weak out-of-sample predictive ability of exchange rate models may be caused by poor performance of model selection criteria rather

than by a lack of information content in the fundamentals. In order to explain the exchange rate determination puzzle, the model of Bacchetta and van Wincoop (2006) implies that observed fundamentals account for very little of the exchange rate volatility in the short to medium run, but over long horizons, the exchange rate is closely related to observed fundamentals.[4]

2.1.3 Macroeconomic Environment and ERPT

In our model, the noise component of the nominal exchange rate may represent instability of the macroeconomic environment due to policy decisions. As the precision of the noise term increases, the link between exchange rates and fundamentals becomes stronger.

Our approach is based on the role of macroeconomic variables in explaining the facts that (i) pass-through is higher for emerging market countries and (ii) declines over time for both industrial and emerging market countries.[5] Taylor (2000) conjectured that these two facts were due to changes in the macroeconomic environment, particularly changes in the level and variability of inflation.[6] More precisely, monetary policy aimed at keeping inflation low and stable may, by anchoring inflation expectations, increase firms' readiness to absorb exchange rate fluctuations in their profit margins. In a more stable inflationary environment, exchange rate shocks may be perceived as more temporary. Other determinants of the decline in the exchange rate pass-through are openness and country size. Soto and Selaive (2003) show that pass-through seems to be higher when a country is smaller and more open.

Organization. We introduce our model in the next section and its major results in Section 2.3. We then present an extension in Section 2.4 and compare our approach to the literature in Section 2.5. We provide concluding remarks in Section 2.6 while the Appendix contains proofs omitted in the main text.

2.2 An Organizing Framework

Our discussion is framed by a completely standard auto-parts model similar to the one used by Bacchetta and van Wincoop (2003). Our model

[4]See also Flood and Rose (1999), MacDonald (1999), and Bacchetta and van Wincoop (2009).

[5]Section 2.5 briefly covers both the empirical and theoretical literature on ERPT.

[6]Examples of studies showing that high inflation is often associated with complete pass-through are Choudhri and Hakura (2001), Devereux and Yetman (2002), and Ca'Zorzi et al. (2007). Gagnon and Ihrig (2004) also find inflation variability to be a determinant of the decline in pass-through.

is tractable yet flexible enough to capture the links among exchange rates, fundamentals, and macroeconomic volatility under dispersed information.

We keep the model simple. There is a continuum of monopolistically competitive foreign intermediate goods producers of mass one. They sell a small fraction of their production to a continuum of monopolistically competitive home final goods producers. The home final goods producers use the foreign intermediate goods as inputs. There are two relevant fundamentals, θ and θ^*, representing exogenous aggregate nominal demand conditions of the home and foreign countries in their respective currencies. Information is complete if every firm in the model observes both θ and θ^*. Because all variables are in logs and all distributions are Normal, prices under imperfect information equal the expected price under complete information.

Notation 8
(i) Exporters: Foreign intermediate goods producers are indexed by $f \in \Omega_F = [0,1]$;
(ii) Home Producers: Home final goods producers are indexed by $h \in \Omega_H = [0,1]$;
(iii) Variables outside home country are marked with a star *.

2.2.1 Price Setting

Consider first the foreign intermediate goods sector. We assume producer currency pricing and appeal to a very simple beauty-contest framework to capture the relationship between exchange rates and information in the export sector.

Condition 9 (Exporter Pricing) *Foreign intermediate goods producers set (log) prices* p_f^* *in their own (foreign) currency. For any given exporter, the optimal price under complete information equals marginal cost* mc^**, which is the convex combination of an exogenous unobserved foreign fundamental* θ^* *and the average price* $P_F^* \equiv \int_{\Omega_F} p_f^* df$:

$$mc^* \equiv (1 - r^*)\,\theta^* + r^* P_F^*, \tag{2-1}$$

where $r^* \in (0,1)$ *measures the complementarity of agents' decisions.*

The expression (2-1) for marginal costs is standard, and, although we do not do so explicitly, it can be derived from a firm's profit maximization problem in a model of monopolistic competition *à la* Blanchard and Kiyotaki (1987). If information is complete, a pricing rule that equates p_f^* to (2-1) can

be interpreted as the best response of monopolistic competitive firms using labor as the only input. The underlying fundamental θ^* represents exogenous aggregate nominal demand conditions in the foreign country.

Now consider domestic pricing. We adopt an auto-parts model to highlight the effects of dispersed information in pass-through. The continuum of home final producers of mass one assembles imported intermediate goods to produce final goods.

Condition 10 (Home Pricing) *Home final goods producers set (log) prices p_h in their own (home) currency. For any given home final good producer, the optimal price under complete information equals marginal cost mc, which is the convex combination of an exogenous unobserved home fundamental θ and the average home price of imports $P_F \equiv \int_{\Omega_F} p_f df$:*

$$mc \equiv (1-r)\,\theta + rP_F, \tag{2-2}$$

where $r \in (0,1)$ is the share of imports in home production, $p_f \equiv e + p_f^*$ is the home currency (import) price of p_f^*, and e is the nominal exchange rate measured in units of home currency per unit of foreign currency.

This condition can also represent monopolistic competitive behavior, with the slight difference that not only labor but also imported intermediate products are used as inputs. The underlying fundamental θ can be interpreted as exogenous aggregate nominal demand conditions in the home country.

2.2.2 Timing and Information

After presenting the agents and their actions, we need to define the information structure of the model. In accordance with the pertinent literature, we consider that each firm observes a private signal x about its own country's fundamental and a private signal y about the external fundamental.[7] In addition, all firms observe a public signal e, the nominal exchange rate, relating the two fundamentals.

Condition 11 (Timing and information) *Before firms move, nature draws θ and θ^* from independent uniform priors over the real line. Instead of observing the fundamentals, a home final producer h receives private signals*

$$x_h = \theta + \xi_h, \quad \xi_h \sim N\left(0, \sigma_x^2\right),$$
$$y_h = \theta^* + \varepsilon_h, \quad \varepsilon_h \sim N\left(0, \sigma_y^2\right)$$

[7]Prominent examples in the literature are Morris and Shin (2002) and Angeletos and Pavan (2007).

while an exporter f receives

$$x_f^* = \theta^* + \xi_f^*, \quad \xi_f^* \sim N\left(0, \sigma_{x^*}^2\right),$$
$$y_f^* = \theta + \varepsilon_f^*, \quad \varepsilon_f^* \sim N\left(0, \sigma_{y^*}^2\right).$$

In addition, all firms, foreign and home, observe a public signal e, the nominal exchange rate

$$e = f\left(\theta, \theta^*\right) + \epsilon, \quad \epsilon \sim N\left(0, \sigma_e^2\right),$$

where $f\left(\theta, \theta^*\right)$ is the fundamental value of the nominal exchange rate. All noises are independent of one another as well as of the fundamentals θ and θ^*. Finally, firms simultaneously set prices based on the information they received, $\Im_h = \{x_h, y_h, e\}$ or $\Im_f^* = \left\{x_f^*, y_f^*, e\right\}$. The structure of the signals, fundamental plus an error term, as well as the distributions of the errors, are common knowledge.

According to Assumption 11, a home producer has a relative informational advantage about its country if $\frac{\sigma_x^2}{\sigma_y^2} \in (0,1)$. Analogously, a foreign exporter has a relative informational advantage about its country when $\frac{\sigma_{x^*}^2}{\sigma_{y^*}^2} \in (0,1)$. We then use the ratios $\frac{\sigma_x^2}{\sigma_y^2}$ and $\frac{\sigma_{x^*}^2}{\sigma_{y^*}^2}$ as measures of *informational home-bias*, or how much more a firm knows about its own country's fundamental than about that of another country.

The specific link between the nominal exchange rate and the fundamentals θ and θ^* can be explained as a particular case of a monetary model of exchange rate determination. In these models, the nominal exchange rate is function of the difference between external and domestic fundamentals. Denoting m and m^* as home and foreign money supplies, respectively, and remembering that θ and θ^* represent home and foreign nominal aggregate demand conditions, respectively, we use the simplest specifications possible: $m = \theta$ and $m^* = \theta^*$. Each equation can be viewed as a quantity-theory approach to aggregate demand, where (log) velocities are assumed to be constants at zero. Then, the equilibrium nominal exchange rate $e = f\left(\theta, \theta^*\right) = \theta - \theta^*$ is proportional to relative money supplies. This relationship is analogous to the equilibrium expression for the exchange rate in the two-country model of Devereux and Engel (2002), in which real balances enter the utility function logarithmically. If we consider ϵ as short-run deviations of equilibrium, we obtain e as our noisy public signal about the underlying fundamentals.

2.2.3 Equilibrium

Consider equilibrium under dispersed information. The state of the world is given by the realizations of fundamentals and signals. Because the private signal's errors are independent and identically distributed across agents, any aggregate variable is a function only of the fundamentals (θ, θ^*) and the public signal e. Because all variables are in logs and all distributions are Normal, the best response for an exporter that has $\Im^*$ as its information set is its forecast of marginal cost mc^* given the available information

$$\begin{aligned} p^*\left(x_f^*, y_f^*, e\right) &= E\left[mc^*\left(\theta^*, \theta, e\right) \mid \Im_f^*\right] \\ &= E\left[\left(1-r^*\right)\theta^* + r^* P_F^*\left(\theta^*, \theta, e\right) \mid \Im_f^*\right], \end{aligned} \tag{2-3}$$

and an analogous counterpart for a final producer is

$$\begin{aligned} p\left(x_h, y_h, e\right) &= E\left[mc\left(\theta, \theta^*, e\right) \mid \Im_h\right] \\ &= E\left[\left(1-r\right)\theta + r P_F\left(\theta, \theta^*, e\right) \mid \Im_h\right]. \end{aligned} \tag{2-4}$$

Equilibrium prices are functions of the signals observed by the firms. Under the proposed information structure, we are able to express the expected values of the fundamentals as functions of the signals. For the home producer, we obtain

$$E\left[\theta \mid \Im_h\right] = \left(1-\lambda\right) x_h + \lambda\left[y_h + e\right], \tag{2-5}$$

$$E\left[\theta^* \mid \Im_h\right] = \left(1-\eta\right) y_h + \eta\left[x_h - e\right], \tag{2-6}$$

while for the foreign exporters, we have

$$E\left[\theta^* \mid \Im_f^*\right] = \left(1-\lambda^*\right) x_f^* + \lambda^*\left[y_f^* - e\right], \tag{2-7}$$

$$E\left[\theta \mid \Im_f^*\right] = \left(1-\eta^*\right) y_f^* + \eta^*\left[x_f^* + e\right], \tag{2-8}$$

where the weights on e are functions of the variances

$$\lambda \equiv \frac{\sigma_x^2}{\sigma_x^2 + \sigma_y^2 + \sigma_e^2},\ \eta \equiv \frac{\sigma_y^2}{\sigma_x^2 + \sigma_y^2 + \sigma_e^2},$$

$$\lambda^* \equiv \frac{\sigma_{x^*}^2}{\sigma_{x^*}^2 + \sigma_{y^*}^2 + \sigma_e^2},\ \eta^* \equiv \frac{\sigma_{y^*}^2}{\sigma_{x^*}^2 + \sigma_{y^*}^2 + \sigma_e^2}.$$

The weights λ and λ^* measure the contribution of the nominal exchange rate in explaining the firm's own-country fundamental. In this sense, a final home producer attributes weight λ to the nominal exchange rate in the

process of forecasting the fundamental θ of the home country while foreign exporters attach a weight λ^* to the nominal exchange rate when forecasting the fundamental θ^*. Following the same reasoning, the weights η and η^* measure the contribution of the nominal exchange rate to explaining a fundamental from abroad. Note also that the ratios $\frac{\lambda}{\eta}$ and $\frac{\lambda^*}{\eta^*}$ equal our measures of informational home-bias $\frac{\sigma_x^2}{\sigma_y^2}$ and $\frac{\sigma_{x^*}^2}{\sigma_{y^*}^2}$.

2.3
Results

We are now able to map the solution of the model with the stylized facts of ERPT. First, we isolate the informational component of our model by setting $r^* = 0$ and $r = 1$. After, we consider how strategic complementarity in exporters' pricing decisions ($r^* \neq 0$) and local costs ($r \neq 1$) affects pass-through.

2.3.1
The Signal Effect of Nominal Exchange Rates

Before we analyze ERPT under dispersed information, it is useful to first consider the complete-information benchmark.

Theorem 12 (ERPT under Complete Information) *Consider that θ and θ^* are common knowledge. In the absence of both strategic complementarity in pricing decisions ($r^* = 0$) and local costs ($r = 1$), all exporters set prices equal to the foreign fundamental θ^* while all home firms set prices equal to the foreign fundamental plus the nominal exchange rate, e. As a result, ERPT both to imports and to final prices is complete:*

$$p_f^* \overset{\forall f \in \Omega_F}{=} P_F^* = \theta^* \Rightarrow p_f \overset{\forall f \in \Omega_F}{=} P_F = e + \theta^* \overset{\forall h \in \Omega_H}{=} p_h. \tag{2-9}$$

This result offers two benchmarks. The first relies only on information in the foreign economy: if it is complete, then ERPT to imports is also complete. This result is independent of the value of r^*. Even if we consider a relevant degree of strategic complementarity in exporters' pricing decisions, prices under complete information remains equal to the fundamental θ^*. The second benchmark depends also on our simplifying assumption about domestic inputs: if we isolate the effects of information and set $r = 1$, ERPT to final goods is also complete, and there is no exchange rate-consumer price puzzle (ERCP puzzle). If this is not the case, pass-through to final goods becomes incomplete and equal to $r \in (0, 1)$.

Now, consider the case of incomplete information. Our first result link the equilibrium prices of imports to the first stylized fact about ERPT.

Theorem 13 (Incomplete ERPT) *In the absence of strategic complementarity in exporter pricing decisions* ($r^* = 0$)*, the equilibrium price of an exporter under dispersed information equals the exporter's expected value of the foreign fundamental* θ^*

$$p_f^* = (1 - \delta^*)\, x_f^* + \delta^* \left[y_f^* - e \right], \tag{2-10}$$

where

$$\delta^* \equiv \lambda^* = \frac{\sigma_{x^*}^2}{\sigma_{x^*}^2 + \sigma_{y^*}^2 + \sigma_e^2} \in (0, 1)\,. \tag{2-11}$$

As a result, the equilibrium prices of imports are

$$p_f = (1 - \delta^*) \left[x_f^* + e \right] + \delta^* y_f^*, \tag{2-12}$$

meaning that ERPT to imports, $1 - \delta^* \in (0, 1)$*, is incomplete.*

In our model, the nominal exchange rate has two distinct effects. The first is the standard role of converting foreign currency prices to home currency prices. We consider, however, that nominal exchange rates also reveal information about economic fundamentals. Considering just the conversion effect, changes in e lead to proportional changes in a home currency import price p_f, while the price expressed in the producer currency, p_f^*, should remain constant. The point is that export price p_f^* also varies due to the *signal effect* of the nominal exchange rate. If this is the case, a change in e may induce variability in p_f^* through signaling that partially offsets the variability in p_f due to conversion. This result is consistent with empirical evidence that indicates that variability in exchange rates closely tracks the variability in p_f^*, while p_f remains fairly stable. It is also an alternative explanation for incomplete pass-trough. Goldberg and Hellerstein (2008) argue that for p_f^* to co-vary with exchange rates, it must be true that exchange rates lead to a change in markups, a change in marginal cost, mc^*, or both. Instead, in our model, *information* about marginal costs attached in the nominal exchange rate affects ERPT, even though marginal costs may remain fixed. Finally, this result reconciles the apparent incompatibility of producer currency pricing and incomplete ERPT.

The next step is to obtain domestic prices. Note that $P_F = (1 - \delta^*)\,[\theta^* + e] + \delta^* \theta$. We just need to substitute this result in (2-4) and use (2-6) to compute domestic prices. This result maps directly to the second stylized fact about ERPT.

Theorem 14 (ERCP Puzzle) *In the absence of both strategic complementarity in pricing decisions* ($r^* = 0$) *and local costs* ($r = 1$)*, the equilibrium price of a home final good producer under dispersed information equals the home firms' expected value of average home price of imports* P_F

$$p_h = (1-\delta)\, x_h + \delta\,[y_h + e]\,, \tag{2-13}$$

where

$$\begin{aligned}\delta &\equiv \lambda + (1-\delta^*)\,(1-\lambda-\eta) \\ &= \frac{\sigma_x^2 + (1-\delta^*)\,\sigma_e^2}{\sigma_x^2 + \sigma_y^2 + \sigma_e^2} \in (0,1)\,,\end{aligned} \tag{2-14}$$

meaning that consumer prices react less than import prices to exchange rates if and only if

$$\delta < 1-\delta^* \Leftrightarrow \frac{\sigma_{x^*}^2}{\sigma_{y^*}^2 + \sigma_e^2} < \frac{\sigma_y^2}{\sigma_x^2}. \tag{2-15}$$

We argue that the ERCP puzzle naturally arises in two steps. First, note that the ERCP puzzle becomes more likely to happen as the non-fundamental exchange rate variability σ_e^2 increases. Thus, in the most adverse scenario for condition (2-15) to hold, we obtain $\frac{\sigma_{x^*}^2}{\sigma_{y^*}^2} < \frac{\sigma_y^2}{\sigma_x^2}$. Second, remember the concept of informational home-bias. If firms within a country know more about their own country's fundamental than about another country's fundamental, we obtain $\frac{\sigma_{x^*}^2}{\sigma_{y^*}^2} < 1 < \frac{\sigma_y^2}{\sigma_x^2}$. In our model with $r^* = 0$ and $r = 1$, the nominal exchange rate e is used in diverse ways depending on the type of firm being considered. Exporters use e to obtain information about their *own* country's fundamental, θ^*, while home firms use e to obtain information about the *external* fundamental, θ^*. The signal effect of exchange rates is lower in export pricing than in home pricing because exporters have more precise private information about their own country's fundamental $\left(x_f^*\right)$ than do home firms (y_h). As a result, the signal effect partially offsets the conversion effect of foreign currency export prices, p_f^*, into home currency import prices, p_f, but not enough to compensate for the lower precision of home information about θ^*.

2.3.2 Macroeconomic Stability and ERPT

If we consider the noise term ϵ of the nominal exchange rate as short-run deviations of the equilibrium rate due to, for example, home and/or foreign monetary policy shocks, we can interpret exchange rate variability, σ_e^2, as an indicator of macroeconomic stability. To simplify the expressions, consider $\sigma_x^2 = \sigma_{x^*}^2$ and $\sigma_y^2 = \sigma_{y^*}^2$. We can then analyze the effect of exchange rate precision on ERPT; this analysis covers the third stylized fact about pass-through.

Theorem 15 (Macroeconomic Stability and ERPT) *In the absence of strategic complementarity in exporter pricing decisions* ($r^* = 0$)*, ERPT to*

import prices increases with non-fundamental exchange rate variability

$$\frac{\partial\left(1-\delta^{*}\right)}{\partial\sigma_{e}^{2}}=\frac{\sigma_{x^{*}}^{2}}{\left[\sigma_{x^{*}}^{2}+\sigma_{y^{*}}^{2}+\sigma_{e}^{2}\right]^{2}}>0. \tag{2-16}$$

The same is true for ERPT to consumer prices in the absence of local costs $(r=1)$ *if and only if* $\sigma_{e}^{2}>\sigma_{x}^{2}-\sigma_{y}^{2}$

$$\frac{\partial\delta}{\partial\sigma_{e}^{2}}=\frac{\left(\sigma_{y}^{2}-\sigma_{x}^{2}+\sigma_{e}^{2}\right)\left(\sigma_{x}^{2}+\sigma_{y}^{2}\right)}{\left(\sigma_{x}^{2}+\sigma_{y}^{2}+\sigma_{e}^{2}\right)^{3}}>0, \tag{2-17}$$

where we set $\sigma_{x}^{2}=\sigma_{x^{*}}^{2}$ *and* $\sigma_{y}^{2}=\sigma_{y^{*}}^{2}$.

The rationale behind Result 15 lies once again in the view of the nominal exchange rate as a signal about the fundamentals. If a signal becomes less precise, firms attach less weight to it. The signal effect of the nominal exchange rate then decreases. For foreign export prices, this is translated into a small value of δ^{*}. Imports and home prices, however, also depend on the conversion effect, which remains unchanged. For import prices, as the signal effect δ^{*} decreases, conversion minus the signal effect, $1-\delta^{*}$, increases. The same is true for domestic home prices if non-fundamental exchange rate volatility, σ_{e}^{2}, is sufficiently high or if there is an informational home-bias $\frac{\sigma_{x}^{2}}{\sigma_{y}^{2}}\in(0,1)$. These seem to be the most natural cases, where δ captures the net effect of conversion minus the signal effect. As a result, ERPT increases to both intermediate import and home final prices.

We now investigate the role of private information precisions in pass-through. First, note that ERPT both to import and home domestic prices increases with exporters' private volatility about the home country's fundamental, θ. We can see this by differentiating (2-11) and (2-14) with respect to σ_{y}^{2*}

$$\frac{\partial\left(1-\delta^{*}\right)}{\partial\sigma_{y^{*}}^{2}}=\frac{\sigma_{x^{*}}^{2}}{\left[\sigma_{x^{*}}^{2}+\sigma_{y^{*}}^{2}+\sigma_{e}^{2}\right]^{2}}>0,$$

$$\frac{\partial\delta}{\partial\sigma_{y^{*}}^{2}}=\frac{\sigma_{e}^{2}}{\sigma_{x}^{2}+\sigma_{y}^{2}+\sigma_{e}^{2}}\frac{\partial\left(1-\delta^{*}\right)}{\partial\sigma_{y^{*}}^{2}}>0.$$

These results have the same interpretation of Result 15 because, in our model, foreign exporters must combine y^{*} and e to obtain information about their country's fundamental, θ^{*}, besides the private signal x^{*}.

Using the same logic, it is natural to find that ERPT to both import and home prices decreases with exporters' private volatility about their own country's fundamental, θ^{*}. We can see this by differentiating (2-11) and (2-14)

with respect to $\sigma^2_{x^*}$

$$\frac{\partial\left(1-\delta^*\right)}{\partial\sigma^2_{x^*}} = -\frac{\sigma^2_{y^*}+\sigma^2_e}{\left[\sigma^2_{x^*}+\sigma^2_{y^*}+\sigma^2_e\right]^2} < 0,$$
$$\frac{\partial\delta}{\partial\sigma^2_{x^*}} = \frac{\sigma^2_e}{\sigma^2_x+\sigma^2_y+\sigma^2_e}\frac{\partial\left(1-\delta^*\right)}{\partial\sigma^2_{x^*}} < 0.$$

The first derivative above is the counterpart of condition (2-16). If $\sigma^2_{x^*}$ increases, foreign exporters attach more weight to e to the detriment of its private information x^* about θ^*. As a result, the signal effect, δ^*, increases, meaning that the sum of the net effect of conversion plus the signal effect on imports decreases. The same argument applies to home domestic products.

Finally, we can also analyze the effect of home firms' private precisions on pass-through. Note that while ERPT to imports is not affected by σ^2_x or σ^2_y, ERPT to domestic prices increases with σ^2_x. The derivative of (2-14) with respect to σ^2_x is

$$\frac{\partial\delta}{\partial\sigma^2_x} = \frac{\sigma^2_y+\delta^*\sigma^2_e}{\left(\sigma^2_x+\sigma^2_y+\sigma^2_e\right)^2} > 0.$$

The opposite is true for σ^2_y

$$\frac{\partial\delta}{\partial\sigma^2_y} = -\frac{\sigma^2_x+\left(1-\delta^*\right)\sigma^2_e}{\left(\sigma^2_x+\sigma^2_y+\sigma^2_e\right)^2} < 0.$$

Remember that home firms combine e with private signal x in order to obtain additional information about θ^*. As a result, the impact of σ^2_x on δ is explained in the same way as condition (2-17). The effect of σ^2_y on pass-through is just the counterpart of condition (2-17).

2.3.3
The Role of Strategic Complementary and Local Costs

We now consider the role of complementarity in pricing decisions. If r^* and $r \in (0,1)$, ERPT both to imports and to consumer prices remains incomplete:

$$1-\delta^* \equiv \frac{\sigma^2_{y^*}+\left(1-r^*\right)\sigma^2_e}{\sigma^2_{x^*}+\sigma^2_{y^*}+\left(1-r^*\right)\sigma^2_e} \in (0,1),$$
$$\delta \equiv \frac{\sigma^2_x+r\left(1-\delta^*\right)\sigma^2_e}{\sigma^2_x+\sigma^2_y+\sigma^2_e} \in (0,1).$$

A direct implication is that pass-through both to imports and to consumer prices is negatively related to strategic complementarity among exporters:

$$\frac{\partial\left(1-\delta^{*}\right)}{\partial r^{*}} \equiv -\frac{\sigma_{x^{*}}^{2}\sigma_{e}^{2}}{\left[\sigma_{x^{*}}^{2}+\sigma_{y^{*}}^{2}+\left(1-r^{*}\right)\sigma_{e}^{2}\right]^{2}} < 0,$$
$$\frac{\partial\delta}{\partial r^{*}} \equiv \frac{r\sigma_{e}^{2}}{\sigma_{x}^{2}+\sigma_{y}^{2}+\sigma_{e}^{2}}\frac{\partial\left(1-\delta^{*}\right)}{\partial r^{*}} < 0,$$

while local inputs decrease ERPT to consumer prices,

$$\frac{\partial\delta}{\partial\left(1-r\right)} = -\frac{\left(1-\delta^{*}\right)\sigma_{e}^{2}}{\sigma_{x}^{2}+\sigma_{y}^{2}+\sigma_{e}^{2}} < 0,$$

but do not affect ERPT to imports.

It becomes clear that the simplifying assumptions of absence of both strategic complementarity in export pricing ($r^{*}=0$) and relevant local costs in the home country ($r=1$) are not relevant for explaining incomplete pass-through. In fact, their presence only reinforces Result 13. The impact of r is straightforward. If home goods sold to consumers incorporate a significant share of local costs, consumer prices will be less sensitive to exchange rate changes. The role of r^{*} comes from the classical results of Morris and Shin (2002) and Angeletos and Pavan (2007). First, note that public information e is a better predictor of other exporters' prices than private information is. In equilibrium, this leads a foreign exporter to adjust his reliance upward on public information because he wishes to align his choice with other exporters' prices ($r^{*}>0$).

We now consider how r and $r^{*}\in(0,1)$ affect Result 14. Comparing δ and δ^{*}, it is easy to show that the ERCP puzzle still holds if and only if

$$\left[\frac{\sigma_{y^{*}}^{2}+\left(1-r^{*}\right)\sigma_{e}^{2}}{\sigma_{x^{*}}^{2}}\right]^{-1} < \left[\frac{\sigma_{y}^{2}+\left(1-r\right)\sigma_{e}^{2}}{\sigma_{x}^{2}}\right].$$

Thus, although the presence of local costs ($1-r\neq 0$) reinforces the ERCP puzzle by, increasing the right-hand side of the expression above, the opposite is true for strategic complementarity in export pricing ($r^{*}>0$) because it increases the left-hand side of the same expression. However, if we consider the least probable scenario for Result 14 to hold ($r=1, r^{*}=1$), we once again find that informational home-bias, $\frac{\sigma_{x^{*}}^{2}}{\sigma_{y^{*}}^{2}} < 1 < \frac{\sigma_{y}^{2}}{\sigma_{x}^{2}}$, induces the ERCP puzzle:

$$\delta < 1-\delta^{*} \Leftrightarrow \frac{\sigma_{x^{*}}^{2}}{\sigma_{y^{*}}^{2}} < \frac{\sigma_{y}^{2}}{\sigma_{x}^{2}}.$$

Finally, consider the sensitivity of Result 15 to the inclusion of r and r^*. Strategic complementarity r^* does not affect qualitatively how ERPT to imports changes with σ_e^2. Alternatively, $\frac{\partial(1-\delta^*)}{\partial\sigma_e^2}$ remains positive. In addition, remember that r does not affect δ^*, and so $\frac{\partial^2(1-\delta^*)}{\partial r\partial\sigma_e^2}=0$.

The same is not true for consumer prices. One again, if we set $\sigma_x^2=\sigma_{x^*}^2$ and $\sigma_y^2=\sigma_{y^*}^2$, we obtain

$$\frac{\partial\delta}{\partial\sigma_e^2}>0\Leftrightarrow r\left\{\left[\sigma_y^2+(1-r^*)\,\sigma_e^2\right]\left(1+\frac{\sigma_y^2}{\sigma_x^2}\right)+\frac{(1-r^*)\,\sigma_e^2\left(\sigma_x^2+\sigma_y^2+\sigma_e^2\right)}{\left[\sigma_x^2+\sigma_y^2+(1-r^*)\,\sigma_e^2\right]}\right\}>1$$

Higher values of local costs may reverse condition (2-17) and the signal of $\frac{\partial\delta}{\partial\sigma_e^2}$ depends non-monotonically on the values of r^*. Although we do not present the general results here, we use some particular cases other than $r^*=0$ and $r=1$ to show the relationship between local costs and informational home-bias. For example, if $r^*=r$ or $r^*=1$, we obtain:

$$r>\frac{\sigma_x^2}{\sigma_y^2}\in(0,1)\Rightarrow\frac{\partial\delta}{\partial\sigma_e^2}>0.$$

Thus, although higher local costs decrease the sensitivity of δ in relation to σ_e^2, ERPT to consumer home prices still increases with non-fundamental exchange rate variability if informational home-bias is not high enough.

2.4 Extension: Production Chains

We can also extend the model to include multiple stages of processing.[8] Consider a version of the two-country model with production chains developed by Huang and Liu (2007) that has been simplified to focus on incomplete information. The major difference of our model is that we ignore capital.

The world economy consists of a home country H and a foreign country F. The production of final consumption goods in each country requires $N\geq 1$ stages of processing, from raw materials to intermediate goods, then to more advanced intermediate goods, and so on. At each stage, there is a continuum of home firms producing differentiated products indexed in the interval $[0,m]$ while the remaining $(m,1]$ producers reside in the foreign country F. The production of each type of intermediate good at stage $n\in\{2,...,N\}$ uses all types of intermediate goods produced at stage $n-1$, domestically produced or

[8]The idea of production chains as a propagation mechanism goes back to Means (1935). See also Blanchard (1984), Gordon (1990), Basu (1995), Clark (1999), Huang and Liu (2001), and Huang and Liu (2007). For an example with incomplete information, see Areosa (2009). Details of the derivations are available from the authors.

imported, along with labor supplied by domestic households. The production of goods at the first stage uses only domestic labor. The parameter m measures the relative size of the home country. The small home country case can be derived by taking the limit of the two-country model as $m \to 0$.

Firms continue to set prices in their own currency (producer currency pricing, or PCP). The optimal price of a firm $j \in [0,1]$ in stage $n \in \{1,2,...,N\}$ of the home country H is

$$p_{H,n} \equiv (1-r)\,\theta + rP_{n-1},$$

where $r \in (0,1)$ is the share of the previous stage's goods used in the production of stage n and θ is exogenous nominal aggregate demand in the home country for final (N^{th} stage) goods. The price index of stage n is an aggregate of two composites of prices

$$P_n \equiv (1-\chi)\,P_{H,n} + \chi P_{F,n},$$

where $P_{H,n} \equiv \frac{1}{m}\int_0^m p_{H,n}(j)\,dj$ is the aggregate price of stage-n home goods and $P_F \equiv \frac{1}{1-m}\int_0^1 p_{F,n}(j)\,dj$ is the aggregate price of foreign goods in the currency of H. The parameter $\chi \equiv \bar{\chi}(1-m)$ measure the share of imported goods in the production of goods in home country H.

The behavior of firms in country F is analogous. Prices are

$$p^*_{F,n} \equiv (1-r^*)\,\theta^* + r^*P^*_{n-1},$$

where the external aggregate price is $P^*_n \equiv (1-\chi^*)\,P^*_{F,n} + \chi^*P^*_{H,n}$, with $\chi^* \equiv \bar{\chi}^* m$.

Exports prices are simply

$$p^*_{H,n} = p_{H,n} - e,$$
$$p_{F,n} = e + p^*_{F,n},$$

where the nominal exchange rate e is measured in units of *H's* currency per unit of *F's* currency.

This model is much more complex than our simple model of intermediate exporters and domestic final producers. Under certain conditions, however, we still have very similar results. Consider that firms observe noise private signals about the fundamentals (θ, θ^*) and the exchange rate just as before. In order to facilitate the calculations, set $r = r^*$, $\sigma_x^2 = \sigma_{x^*}^2$, and $\sigma_y^2 = \sigma_{y^*}^2$. If we ignore home-bias ($\bar{\chi} = \bar{\chi}^* = 1$), ERPT declines along the chain for the country with

the highest share of imported goods in domestic production. If $\chi > \chi^*$, pass through in country H is given by

$$\begin{aligned} 1 - \lambda_n^* &< 1 - \lambda_{n-1}^*, \\ \lambda_n &< \lambda_{n-1}, \\ \delta_n &< \delta_{n-1}, \end{aligned}$$

where $1 - \lambda_n^*$, λ_n, and δ_n are the weights of the exchange rate for imports, domestic prices and aggregate prices, respectively.[9] ERPT to aggregate prices is lower than ERPT to imports, or $\delta_n < \lambda_n^*$.

2.5 Comparison to the Literature

Our explanation for ERPT is quite different from what is typically found in the theoretical pass-through literature. With its dispersed information framework, where the nominal exchange rate conveys information about domestic and foreign fundamentals, our model is consistent with the main facts of the empirical literature, even ignoring local currency pricing and substantial local inputs or distribution costs. We proceed by considering each stylized fact in turn.

Incomplete ERPT. A substantial body of empirical work documents that exchange rate pass-through to prices is delayed and incomplete.[10] Although most of the literature uses aggregate data, works about specific industries present similar results.[11] The first explanation relies on the behavior of exporting firms. Under local currency pricing (LCP), exporting firms fix the import price in the local currency of the market to which they are exporting. Exchange rate movements therefore need not be reflected in local currency prices. The other extreme is producer currency pricing (PCP), where prices of imported goods are quoted in foreign currency and imported goods are sold to consumers for local currency at the going market exchange rate. In such a case, any change in the exchange rate will be automatically transmitted to the consumer prices of the importing country, implying a complete exchange rate pass-through. Another explanation is distribution costs, with foreign exporters selling goods to local importers/distributors at prices quoted

[9] In fact, the same is true for any combination $\chi + \chi^* = 1$.

[10] See, for example, Engel (1999)(43), Parsley and Wei (2001)(98), Campa and Goldberg (2005,2006b), Frankel et al. (2005), and Parsley and Popper (2009).

[11] See Goldberg and Hellerstein (2007) for an example in the beer market and Nakamura and Zerom (2009) for an example in the coffee industry. Feenstra (1989) and Gron and Swenson (2000) are examples of studies in the automobile market.

in foreign currency and distributors then reselling goods in the local market at prices quoted in local currency. If they operate in a competitive market, importers/distributors will partly absorb any effects of exchange rate changes by varying their mark-ups, so the pass-through will be incomplete. Finally, in oligopolistic markets, the response of prices to changes in costs depends both on the curvature of demand and the market structure.[12] Contrary to most of this theoretical literature, we obtain incomplete ERPT in a model of PCP and without substantial local inputs or distribution costs. The key element of our model is the signal role of the exchange rate under dispersed information.

Exchange Rate-Consumer Price (ERCP) Puzzle. ERPT is usually the highest for imported goods prices, lower for producer prices and lowest for consumer prices.[13] Our explanation of the ERCP puzzle relies on the idea that firms within a country know more about their own country than foreign firms do. The signal effect of exchange rates is lower in export pricing than in home pricing because exporters have more precise information about their own country's fundamental than home firms do. Several previous explanations have been offered for this hierarchy of pass-through effects. The first is that as imported goods reach consumers through wholesale and retail networks, their prices accumulate a substantial local input of services, such as transportation, marketing and advertising; this accumulation partly cushions the impact of exchange rate changes on final retail prices.[14] Engel and Rogers (1996), however, study the behavior of consumer prices between cities in Canada and the United States, which share a very large and relatively open border, and present evidence suggesting that geographical distance is not the main determinant of the lack of consumer price sensitivity to exchange rate movements. A second explanation is that imports are mainly intermediate goods to which foreign currency pricing applies, so the pass-through is complete for prices on the docks. In contrast, retail prices, as a combination of imported and local goods prices, are set in local currency and are adjusted only periodically due to price rigidity, menu costs or other dynamic factors.[15] However, a recent work by Gopinath et al. (2010) documents low pass-through at the dock in the US Exchange. A third explanation is that

[12]Some examples are Dornbusch (1987), Knetter (1989), Bergin and Feenstra (2001), and Atkeson and Burstein (2008).

[13]See Goldberg and Knetter (1997) and Valderrama (2006) for a review of the literature and Campa and Goldberg (2005, 2006a) for the most recent evidence.

[14]Example are Sanyal and Jones (1982), Feenstra (1998), Burstein et al. (2003), Burstein et al. (2005), and Corsetti and Dedola (2005).

[15]See Giovannini (1988), Kasa (1992), Devereux and Engel (2002), and Bacchetta and van Wincoop (2003) for examples.

consumers switch from imported goods to lower-quality, cheaper local brands when larger exchange rate depreciations occur, as described by Burstein et al. (2005). Similarly, when the local currency strengthens, consumers might switch to higher-quality, more expensive brands, so inflation might not decline in tandem with exchange rate appreciation.

Declining ERPT. Another important finding in the literature is that the exchange rate pass-through is higher for emerging market countries and declines over time for both industrial and emerging market countries.[16] Three explanations have been proposed for this finding. The first explanation relates to the above-mentioned macroeconomic stability. The second explanation focuses on shifts in the composition of imports from high pass-through goods to low pass-through goods, as in Campa and Goldberg (2005). In the more developed countries, the pass-through is nearly complete for energy and raw materials and is considerably lower than unity for food and manufactured products. A shift in the composition of imports from raw materials to manufactured goods could thus lead to a decline in the measured exchange rate pass-through for both import and consumer prices. The third explanation is that the globalization of economic activity has increased competition and the contestability of markets and reduced the pricing power of dominant firms in the tradable sector. In such an environment, firms may have to absorb temporary cost increases that are due to exchange rate movements, thereby reducing the exchange rate pass-through. To maintain profit margins, firms may outsource production to lower-cost countries, including the ones to which they are exporting, a change that might further reduce the pass-through. In our model, the nominal exchange rate acts as a signal about the fundamentals. If this signal becomes less precise, reflecting an increase in macroeconomic instability, firms attach less weight to it. We can then analyze the effect of exchange rate precision on ERPT.

2.6 Conclusion

We show how the observation of the nominal exchange rate may affect pass-through in a model of incomplete information. We treat the nominal exchange rate as a noisy public signal relating domestic and foreign fundamentals

[16]Studies documenting declining ERPT in industrialized countries include McCarthy (1999), Bailliu and Fujii (2004), Frankel et al. (2005), Marazzi et al. (2005), Otani et al. (2006), and Bouakez and Rebei (2008). See also Mihaljek and Klau (2001) and Ca'Zorzi et al. (2007) for emerging market economies. For a skeptical view of pass-through decline, see Campa and Goldberg (2005, 2006a), Campa et al. (2005), Daly et al. (2006), Ihrig et al. (2006), and Marquez and Thomas (2006).

and where the variance of the noisy term may reflect the degree of macroeconomic instability. If this is the case, export prices also vary due to the signal effect of the nominal exchange rate. Thus, a change in the nominal exchange rate may induce variability in export prices through signaling that partially offsets variability in import prices due to conversion. This result is consistent with empirical evidence showing that variability in exchange rates closely tracks the variability in export prices in the producer's currency, whereas import prices in the local currency remain fairly stable.

The rationale behind the idea of the signal role of exchange rates is based on three central issues in macroeconomics. The first is the role of private and public signals under dispersed information. The second is the link between economic fundamentals and exchange rate behavior. The third is the impact of macroeconomic stability on the documented slowdown in the pass-through in recent decades.

The main results of our model are consistent with empirical findings about ERPT: incomplete pass-through, exchange rate-consumer price puzzle, and higher ERPT for emerging market countries. To obtain these results, we diverged from much of the literature by ignoring substantial local costs and local currency pricing. The key elements of our model are the signal roles of the exchange rates under dispersed information and the notion of informational home-bias, or how much more a firm knows about its own country's fundamental than about that of another country.

We include a chain of production in our model to show that it can easily be extended. There are other possible extensions, variations, and applications of our model. We ignore dynamics and treat nominal exchange rates as exogenous. Future studies should consider dynamic and general equilibrium effects. Overall, we believe that the simple framework of our model can be a very useful starting point for further research.