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The Signaling Effect of Exchange Rates: pass-through under dispersed information*

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Abstract

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We examine exchange-rate pass-through (ERPT) to prices in a model of dispersed information in which the nominal exchange rate imperfectly conveys information about the underlying fundamentals. If the information is complete, ERPT is also complete. Under dispersed information, we derive conditions under which our model displays three properties that are consistent with the stylized facts of pass-through. First, ERPT lies between 0 and 1 (incomplete ERPT). Second, ERPT is usually higher for imported goods prices than for consumer prices (exchange rate-consumer price puzzle). Third, there is a link between ERPT and macroeconomic stability.

Keywords: Dispersed information, Exchange rate pass-through, Public signal

JEL Classification: D82, D83, E31, F31

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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, policy-makers 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. Monopolistically competitive intermediate goods producers in the Foreign country (exporters) sell their production to monopolistically competitive final goods producers in the Home country. The Home final goods producers use the Foreign intermediate goods as inputs to produce consumer goods. We consider the case where firms face uncertainty concerning two relevant fundamentals representing the economic conditions of the Home and Foreign countries, but they have access to noisy private signals about these 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;
2. **Exchange Rate-Consumer Price (ERCP) Puzzle** : ERPT is usually higher for intermediated imported goods prices than for consumer prices; and

[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.

3. **Macroeconomic Environment**: ERPT is related to macroeconomic stability.

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 primarily driven by the signaling 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 relation of macroeconomic stability and pass-through. We consider these three issues below.

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.

We base our discussion on a model where individual consumer prices depend not only on fundamentals but also on the mean of imported input prices. In our model, the relevant fundamentals are not observable. Instead, firms observe noisy private and public

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

[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).

signals about these fundamentals. In the terminology of the relevant literature following Morris and Shin (2002), the nominal exchange rate works as an exogenous public signal of the underlying fundamentals[4]. Under dispersed information, equilibrium prices depend on the relative precisions of private and public information. As the precision of the public signal increases, more weight is given to the nominal exchange rate in the price-setting process.

Fundamentals and Exchange Rates. 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 Cheung, Chinn and Pascual (2005) reaches the same conclusion for recent available models.

Recent works, however, 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.[5]

[4]Recent evidence from the microstructure literature to exchange rates, as **?**, suggests that information heterogeneity might also play a key role in explaining exchange rate variations. We are not following this approach here.

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

Following this recent literature, we link exchange rates and fundamentals assuming that the nominal exchange rate follows an exogenous stochastic process compounded by fundamentals plus a white noise component. We interpret this noise term as short-run deviations from the "fundamental" exchange rate value. By choosing the variance of this noise term, we determine how important fundamentals are to explain the exchange rate.

Macroeconomic Environment and ERPT. In our model, the noise terms present on the private signals about a specific fundamental captures macroeconomic instability of the country to which this fundamental is related (country-specific volatility). Analogously, the nominal exchange rate noise may represent instability of the macroeconomic environment unrelated to any specific country ("global" volatility). 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 advanced and emerging market countries.[6] Taylor (2000) conjectured that these two facts were due to changes in the macroeconomic environment, particularly changes in the level and variability of inflation.[7] 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 compare our approach to the literature in Section 2. We then present our major results in Section 4. We provide concluding remarks in Section 5 while the Appendix contains proofs omitted in

[6]Section 2 briefly covers both the empirical and theoretical literature on ERPT.

[7]Examples of studies showing that high inflation is often associated with complete pass-through are Choudhri and Hakura (2006), Devereux and Yetman (2002) and Ca'Zorzi, Hahn and Sánchez (2007). Gagnon and Ihrig (2004) also find inflation variability to be a determinant of the decline in pass-through.

the main text.

2 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.[8] Although most of the literature uses aggregate data, works about specific industries present similar results.[9] 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 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

[8]See, for example, Engel (1999), Parsley and Wei (2001), Campa and Goldberg (2005, 2006b), Frankel, Parsley and Wei (2005) and Parsley and Popper (2010).

[9]See Goldberg and Hellerstein (2007) for an example in the beer market and Nakamura and Zerom (2010) for an example in the coffee industry. Feenstra (1989) and Gron and Swenson (2000) are examples of studies in the automobile market.

the market structure.[10] 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 signaling 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.[11] 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.[12] 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.[13] However, a recent work by Gopinath, Itskhoki and Rigobon (2010) documents low pass-through at the dock in the US Exchange. A third explanation is that 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. Our explanation of the ERCP puzzle relies on the idea, supported by empirical findings,

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

[11] 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.

[12] Examples are Sanyal and Jones (1982), Feenstra (1998), Burstein, Neves and Rebelo (2003), Burstein, Eichenbaum and Rebelo (2005) and Corsetti and Dedola (2005).

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

that firms within a country know more about their own country than foreign firms do[14]. The signaling effect of exchange rates is lower in export pricing than in domestic pricing because exporters have more precise information about their own country's fundamental than domestic firms do.

Declining ERPT. Another important finding in the literature is that exchange rate pass-through is higher for emerging market countries and declines over time for both advanced and emerging market countries.[15] 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 not only country-specific volatilities but also global volatility on ERPT.

[14]Examples of empirical evidence are in footnote 19.

[15]Studies documenting declining ERPT in advanced countries include McCarthy (1999), Bailliu and Fujii (2004), Frankel et al. (2005), Marazzi, Sheets, Vigfusson, Faust, Gagnon, Marquez, Martin, Reeve and Rogers (2005), Otani, Shiratsuka and Shirota (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, Goldberg and González-Mínguez (2005), Daly, Hellerstein and Marsh (2006), Ihrig, Marazzi and Rothenberg (2006) and Marquez and Thomas (2009).

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

We keep the model simple. All variables are in log deviations from steady-state and all distributions are Normal. There is a continuum of monopolistically competitive intermediate goods producers of mass one in the Foreign country (exporters). They sell their production to a continuum of monopolistically competitive final goods producers in the Home country. The Home final goods producers use the Foreign intermediate goods as inputs to produce consumer goods. There are two relevant fundamentals, θ and θ^*, representing the economic conditions of the Home and Foreign countries in their respective currencies. As in Morris and Shin (2002), firms face uncertainty concerning θ and θ^*, but they have access to private and public information. Prices under imperfect information equal the expected price under complete information.[16]

Terminology and Notation 1 (Notation and Terminology) *In the model that follows, we denote:*

(i) Variables denominated in Foreign currency: marked with a star **;*

(ii) Exporters = Foreign intermediate goods producers: indexed by $f \in \Omega_F = [0, 1]$;

(iii) Consumer goods producers = Home final goods producers: indexed by $h \in \Omega_H = [0, 1]$.

3.1 Actions

We consider the following decision rules:[17]

Assumption 1 (Pricing Decisions) *The optimal (intermediate good) price* p_f^* *for an exporter* f *equals the expectation with respect to* f*'s information set* $\Im_f$ *of the exogenous*

[16] See Appendix for details.
[17] See Appendix for a proposed microfoundation.

unobserved Foreign fundamental θ^*.

$$p_f^* = E_f[\theta^*], \tag{1}$$

while the optimal (final or consumer good) price p_h *for a final good producer* h *equals the expectation with respect to* $h's$ *information set* $\Im_h$ *of a convex combination of the exogenous unobserved Home fundamental* θ *and the average Home price of imports* $p_F \equiv \int_{\Omega_F} p_f df$

$$p_h = E_h[(1-r)\theta + rp_F], \tag{2}$$

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.*

Consider first the exporters. Pricing rule (1) can be interpreted as the best response of monopolistic competitive firms using labor as the only input. We show in the Appendix that the underlying fundamental θ^* may represent exogenous costs of production or 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 in the most direct way. The continuum of final producers of mass one assembles intermediate imports to produce final goods. As a result, the pricing rule (2) can also represent monopolistic competitive behavior, with the slight difference that not only labor but also Foreign intermediate products are used as inputs. Once again, the underlying fundamental θ can be interpreted as exogenous labor cost or exogenous aggregate nominal demand conditions in the Home country.

3.2 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, instead of observing the fundamentals, each firm observes a private signal x about its own country's fundamental and a private signal y about the external fundamental.[18] In addition, all

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

firms observe a public signal e, the nominal exchange rate, relating the two fundamentals.

Assumption 2 (Timing and Information) *The fundamentals θ and θ^* are drawn from (improper) uniform priors over the real line, but a final producer h observes private signals*

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

while an exporter f observes

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

In addition, all firms 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. The structure of the signals, fundamental plus an error term, as well as the distributions of the errors, are common knowledge.

According to Assumption 2, the precisions of the signals about a specific fundamental are equal among firms within a country, but not among firms located in different countries. Thus, although all firms receive private signals about the fundamental θ, the precision of this information is σ_x^{-2} for any firm in the Home country but σ_y^{-2} for firms inside the Foreign country. As a result, a Home producer has informational advantage about its country if $\frac{\sigma_x^2}{\sigma_y^2} \in (0,1)$. Analogously, a Foreign producer has informational advantage about its country when $\frac{\sigma_{x^*}^2}{\sigma_{y^*}^2} \in (0,1)$. The notion that an agent knows more about its own country's fundamental relative to foreign agents is empirically relevant and theoretically useful for the interpretation of our ERCP puzzle condition [19].

[19] For example, **?** investigates whether resident enterprises' managers have an informational advantage about the countries where they work. The authors test this informational advantage hypothesis by using

The specific link we use 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 (log deviations from steady-state of) Home and Foreign money supplies and remembering that θ and θ^* may represent Home and Foreign nominal aggregate demand conditions, 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 $e = f(\theta, \theta^*) = \theta - \theta^*$ 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 unrelated to any specific country, we obtain e as our noisy public signal about the underlying fundamentals.

3.3 Equilibrium

Equilibrium prices are functions of the signals observed by firms. As a result, the price p_f^* of an exporter f depends on $f's$ information set $\Im_f = \left\{x_f^*, y_f, e\right\}$

$$p_f^* = p^*\left(\Im_f\right),$$

while the price p_h of a final producer h depends on $h's$ information set $\Im_h = \{x_h, y_h^*, e\}$

$$p_h = p\left(\Im_h\right).$$

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.

a unique dataset, the Global Competitiveness Survey. Their findings suggest that local managers do have valuable information about the country where they reside. **?** examines whether analysts resident in a country make more precise earnings forecasts for firms in that country than non-resident analysts. Using a sample of 32 countries, the authors find an economically and statistically significant local analyst advantage even after controlling for firm and analyst characteristics.

Under the proposed information structure, we are able to express the expected values of the fundamentals as functions of the signals. For a final producer h, we obtain

$$E_h[\theta] = (1-\lambda)\, x_h + \lambda\left[y_h^* + e\right], \tag{3}$$

$$E_h[\theta^*] = (1-\eta)\, y_h^* + \eta\left[x_h - e\right], \tag{4}$$

while for a exporter f, we have

$$E_f[\theta^*] = (1-\lambda^*)\, x_f^* + \lambda^*\left[y_f - e\right], \tag{5}$$

$$E_f[\theta] = (1-\eta^*)\, y_f + \eta^*\left[x_f^* + e\right], \tag{6}$$

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 producer attributes weight λ to the nominal exchange rate in the process of forecasting the fundamental θ of the Home country while exporters attach a weight λ^* to the nominal exchange rate when forecasting the fundamental θ^* of the Foreign country. Following the same reasoning, the weights η and η^* measure the contribution of the nominal exchange rate to explaining a fundamental from another country.

4 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 $r = 1$. Later, we consider how local costs ($r \neq 1$) affects pass-through.

4.1 The Signaling Effect of Nominal Exchange Rates

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

Result 1 (ERPT under Complete Information) *Consider that θ and θ^* are common knowledge. In the absence of local costs ($r = 1$), all exporters set prices equal to the Foreign fundamental θ^* while all final producers set prices equal to the Foreign fundamental plus the nominal exchange rate, e. As a result, ERPT both to imports and final prices are complete:*

$$p_f^* \overset{\forall f \in \Omega_F}{=} \theta^* \Rightarrow p_f \overset{\forall f \in \Omega_F}{=} p_F = e + \theta^* \overset{\forall h \in \Omega_H}{=} p_h. \tag{7}$$

Result 1 offers two benchmarks. The first relies only on information in the Foreign economy: if it is complete, then ERPT to imports is also complete. 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 (ERCP) puzzle. If this is not the case, pass-through to final goods becomes incomplete and equals the share $r \in (0, 1)$ of imports in Home production.

Now, consider the case of dispersed information. Result 2 links the equilibrium prices of imports to the first stylized fact about ERPT.[20]

Result 2 (Incomplete ERPT) *The equilibrium price of an exporter f under dispersed information equals the exporter's expected value of the foreign fundamental θ^**

$$p_f^* = \delta^* x_f^* + (1 - \delta^*) \left[y_f - e \right], \tag{8}$$

where

$$\delta^* \equiv 1 - \lambda^* = \frac{\sigma_y^2 + \sigma_e^2}{\sigma_{x^*}^2 + \sigma_y^2 + \sigma_e^2}. \tag{9}$$

[20]Formally, for Result 2 to hold, we just need the information to be incomplete, with all firms receiving the same signals, not dispersed. Dispersed information is relevant, however, for Result 3 regarding ERCP puzzle.

As a result, the equilibrium prices of imports are

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

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

In our model, the nominal exchange rate has two distinct effects. The first is the standard role of converting Foreign currency prices into Home currency prices. We consider, however, that the nominal exchange rate also reveals information about economic fundamentals:

$$\frac{\partial p_f}{\partial e} = \frac{\partial}{\partial e} \left(e + p_f^* \right) = \Delta_{conversion} + \Delta_{signaling} = \delta^* < 1,$$

where

$$\begin{aligned} \Delta_{conversion} &= \frac{\partial e}{\partial e} = 1 > 0, \\ \Delta_{signaling} &= \frac{\partial p_f^*}{\partial e} = -\left(1 - \delta^*\right) < 0 \end{aligned}$$

Considering just the conversion effect, changes in e leads to proportional changes in a Home currency import price p_f, while the price expressed in the producer currency, p_f^*, remains constant. In our model, however, the export price p_f^* also varies due to the *signaling 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 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 final prices in the Home country. Note that $p_F = (1-\delta^*)\,\theta^* + \delta^*\,[\theta + e]$. We just need to substitute this result in (2) and use both (3) and (4) to compute Home prices. This result maps directly to the second stylized fact about ERPT.

Result 3 (ERCP Puzzle) *In the absence of local costs* $(r=1)$*, the equilibrium price of a final producer under dispersed information equals Home firms' expected value of average Home price of imports* p_F

$$p_h = (1-\delta)\,x_h + \delta\,[y_h^* + e]\,, \tag{11}$$

where ERPT to final prices is incomplete and given by

$$\delta \equiv \lambda + \delta^*\,(1-\lambda-\eta) \in (0,1)\,,$$

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

$$\delta < \delta^* \Leftrightarrow \frac{\sigma_x^2}{\sigma_y^2 + \sigma_e^2} < \frac{\sigma_{y^*}^2}{\sigma_{x^*}^2}. \tag{12}$$

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 (12) to hold, $\sigma_e^2 = 0$, we obtain $\frac{\sigma_x^2}{\sigma_y^2} < \frac{\sigma_{y^*}^2}{\sigma_{x^*}^2}$. Second, if firms within a country know more about their own country's fundamental than foreign firms, as supported by empirical evidence, we obtain $\frac{\sigma_x^2}{\sigma_y^2} < 1 < \frac{\sigma_{y^*}^2}{\sigma_{x^*}^2}$ and condition (12) is satisfied[21]. In our model without local costs $(r=1)$, 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 signaling effect of exchange rates is lower in export pricing than in final producer pricing because exporters have more precise private information about their own country's fundamental $\left(x_f^*\right)$ than do final producers (y_h^*). As a result, the signaling effect partially offsets the conversion effect of Foreign currency export prices, p_f^*, into

[21] Examples of empirical evidence are in footnote 19.

Home currency import prices, p_f, but not enough to compensate for the lower precision of Home information about θ^*.

4.2 Macroeconomic Stability and ERPT

Finally, we use our framework to the deal with the link between ERPT and macroeconomic stability. To keep the model simple, we consider that, instead of observing private signals, firms have the following priors distributions about the fundamentals:

$$\theta \sim N\left(\mu, \sigma_\theta^2\right), \quad \theta^* \sim N\left(\mu^*, \sigma_{\theta^*}^2\right). \tag{13}$$

If this is the case, our model without local costs ($r = 1$) simplifies to:

$$\begin{aligned} x_h &= y_f = \mu, \quad x_f^* = y_h^* = \mu^*, \\ \sigma_x^2 &= \sigma_y^2 = \sigma_\theta^2, ...\sigma_{x^*}^2 = \sigma_{y^*}^2 = \sigma_{\theta^*}^2 \end{aligned}$$

and thus

$$\delta = \frac{\sigma_\theta^2 + \delta^* \sigma_e^2}{\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2} < \frac{\sigma_\theta^2 + \sigma_e^2}{\sigma_{\theta^*}^2 + \sigma_\theta^2 + \sigma_e^2} = \delta^*.$$

We are now able to analyze the effects of macroeconomic instability on ERPT; this analysis covers the third stylized fact about pass-through

Result 4 (Macroeconomic Stability and ERPT) *In the absence of local costs* ($r = 1$), *ERPT increases with non-fundamental exchange rate variability*

$$\frac{\partial \delta^*}{\partial \sigma_e^2}, \frac{\partial \delta}{\partial \sigma_e^2} > 0. \tag{14}$$

The same is true if there is an increase in the country´s volatility of the final producers

$$\frac{\partial \delta^*}{\partial \sigma_\theta^2}, \frac{\partial \delta}{\partial \sigma_\theta^2} > 0, \tag{15}$$

while the opposite is true regarding the volatility of the country of the exporters

$$\frac{\partial \delta^*}{\partial \sigma_{\theta^*}^2}, \frac{\partial \delta}{\partial \sigma_{\theta^*}^2} < 0. \tag{16}$$

The rationale behind Result 4 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. As a result, if σ_e^2 increases, the signaling effect of the nominal exchange rate decreases. For export prices, this is translated into a small value of $1-\delta^*$. Imports and final prices, however, also depend on the conversion effect, which remains unchanged. For import prices, as the signaling effect $-(1-\delta^*)$ decreases in modulus, the sum of conversion and signaling effects, δ^*, increases. The same is true for final prices. As a result, ERPT increases to both import and final prices.

We now investigate the role of country´s volatilities in pass-through. An increase in the volatility of the Foreign country means that the "signal" μ^* is less precise. If this is the case, exporters attach more weight to the composed "signal" $\mu - e$, which, given the conversion effect, decreases the ERPT to imports δ^*. Analogously, final producers rely less in the composed signal $\mu^* + e$, inducing a decrease in the ERPT to final goods δ. The same logic can be applied when there is an increase in the volatility of the Home country.

4.3 The Role of Local Costs

We now consider the role of local costs in pricing decisions. ERPT to imports is unaffected while ERPT to consumer prices becomes

$$\delta_r \equiv \lambda + r\delta^* (1 - \lambda - \eta) \in (0, 1) .$$

A direct implication is that if Home final goods sold to consumers incorporate a significant share of local costs, consumer prices will be less sensitive to exchange rate changes. As a result, we can interpret relation (12) of Result 3 as a condition for

$$\max_r \delta_r = \delta < \delta^*.$$

It becomes clear that the simplifying assumption of absence of relevant local costs in Home country ($r = 1$) is not relevant for explaining incomplete ERPT or the ERCP puzzle. In fact, its presence only reinforces our results.

Finally, consider the sensitivity of Result 4 to the inclusion of r. Local costs do not affect how ERPT to imports changes with σ_e^2, σ_θ^2 and $\sigma_{\theta^*}^2$. The same is not true for consumer prices. One again, if we consider the simplifying assumption (13), we still obtain $\frac{\partial \delta}{\partial \sigma_{\theta^*}^2} < 0 < \frac{\partial \delta}{\partial \sigma_\theta^2}$, but now, there is a value $\bar{r}$ such that

$$\left.\frac{\partial \delta}{\partial \sigma_e^2}\right|_{r<\bar{r}} < 0 < \left.\frac{\partial \delta}{\partial \sigma_e^2}\right|_{r>\bar{r}},$$

meaning that higher values of local costs may reverse condition (14) of Result 4. The value $1-\bar{r}$ of local costs thus functions as a limit to the signaling effect of exchange rates in affecting ERPT to final prices.

5 Conclusion

Considering that the nominal exchange rate imperfectly conveys information about the underlying fundamentals when information is dispersed in the economy, we are able to manage three stylized facts of ERPT in a simple and stylized auto-parts model: (i) ERPT is incomplete, (ii) ERPT is usually higher for imported goods prices than for consumer prices and (iii) ERPT is higher for emerging market countries and declines over time for both advanced and emerging market economies.

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 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 signaling 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 signaling 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.

To obtain the main results of our model, we diverged from much of the literature by ignoring substantial local costs and local currency pricing. The key elements of our model are the signaling role of the exchange rate under dispersed information and the notion of informational home-bias, or how much more firms within a country know about their own country's fundamental than foreign firms.

We can easily extend the model to include a more complex chain of production, as in Areosa (2011). There are other possible extensions, variations and applications of our model. We use a static model and treat the nominal exchange rate as exogenous. Future studies should consider dynamic and general equilibrium effects. Overall, we believe that our simple framework can be a very useful starting point for further research.

6 Appendix

6.1 Microfoundations of Pricing Decisions

The world economy consists of a Home and a Foreign countries. The production of a Home final consumption good $h \in \Omega_H = [0,1]$ requires labor and Foreign intermediate goods as inputs, according to the following technology

$$Y_h = \left[\int_0^1 Y_{h,f}^{\frac{1}{\mu}} df \right]^{\mu r} L_h^{1-r}$$

where Y_h is the output of a Home firm of type h, $Y_{h,f}$ is the input supplied to h by a Foreign firm of type $f \in \Omega_F = [0,1]$, $\mu > 1$ is function of the elasticity of substitution between Foreign goods, L_h is the labor input used by h and $r \in (0,1)$ is the share of composite of Foreign goods in h' production. Home firms behave as imperfect competitors in their output markets and are price-takers in their input markets. Given the constant-returns-to-scale technologies, the unit cost is also the marginal cost and is firm-independent. The optimal price decision under flexible prices is just a mark-up over marginal costs

$$P_h = \mu \left[\bar{r} \left(P_F \right)^r \left(W_H \right)^{1-r} \right], \tag{17}$$

where $\bar{r} \equiv r^{-r}(1-r)^{-(1-r)}$, $P_F \equiv \left[\int_0^1 P_f^{\frac{1}{1-\mu}} df\right]^{1-\mu}$ is a price index for Foreign imported goods and W_H is nominal wage per hour in the Home country.

We consider a labor supply decision of the Home representative household of the form

$$\frac{W_H}{P_H} = C_H, \tag{18}$$

where consumption C_H is a Dixit and Stiglitz (1977) composite of the Home final goods

$$C_H = \left[\int_0^1 Y_h^{\frac{1}{\mu}} dh\right]^{\mu} \equiv Y_H, \tag{19}$$

We combine equations (17), (18) and (19) to obtain

$$\frac{P_h}{P_H} = \mu \left(\frac{P_F}{P_H}\right)^r (Y_H)^{1-r}, \tag{20}$$

The production of each Foreign intermediate good requires labor services only, with a constant-returns-to-scale technology given by $Y_f = L_f$, where L_f is the labor input and Y_f is the output of a Foreign firm f. Foreign firms also behave as imperfect competitors in their output markets and are price-takers in their input markets. As a result, the optimal price decision under flexible prices is

$$P_f^* = \mu W_F^*,$$

where W_F^* is nominal wage per hour in the Foreign country. If the labor supply decision of the Foreign representative household is analogous to (18), we obtain

$$P_f^* = \mu P^* Y^*, \tag{21}$$

where P^*Y^* is nominal aggregate demand in the Foreign country expressed in Foreign currency. Note that we are not considering $P_F^* \equiv \left[\int_0^1 \left(P_f^*\right)^{\frac{1}{1-\mu}} df\right]^{1-\mu} = P^*$ because we are modeling just the fraction of the Foreign economy that is necessary for our results.

Log-linearizing conditions (20) and (21) yield pricing decisions (2) and (1) in the main text, where $\theta \equiv \hat{Y}_H + \hat{P}_H$ and $\theta^* \equiv \hat{Y}^* + \hat{P}^*$ are nominal aggregate demands and a variable

$\hat{Z}$ represents log-deviations of a variable Z from its steady-state value $\bar{Z}$. Pricing decisions like (1) and (2), which can be found in Woodford (2002) and Mankiw and Reis (2010), reflect the certainty-equivalence result that a price with imperfect information equals the expected price under full information. As pointed out in Mankiw and Reis (2010), this equivalence holds because a linearization of the optimality conditions is equivalent to a quadratic approximation of the objective function.

6.2 Proofs of Results

Proof of Result 1 (ERPT under Complete Information). If information is complete, the external price of any given exporter equals the Foreign fundamental

$$p_f^* = \theta^* = p_F^*.$$

As a result, the price of any imported good is $p_f = p_F = e + \theta^*$. Now, consider the prices of Home firms. Under complete information, all Home final goods' firms set the same price

$$p_h = (1 - r)\,\theta + r\,[e + \theta^*]\,.$$

Setting $r = 1$ establishes the result

$$p_h = p_F = e + \theta^*.$$

■

Proof of Result 2 (Incomplete ERPT). Under dispersed information, the optimal response for an exporter is

$$p_f^* = E_f\,[\theta^*] = (1 - \lambda^*)\,x_f^* + \lambda^*\,[y_f - e]\,.$$

As a result, import prices are

$$\begin{aligned} p_f &= e + p_f^* \\ &= e + (1 - \lambda^*) x_f^* + \lambda^* [y_f - e] \\ &= (1 - \delta^*) y_f + \delta^* \left[x_f^* + e\right], \end{aligned}$$

where ERPT to imports is

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

■

Proof of Result 3 (ERCP Puzzle). Given Result 2, the aggregate price of imports is

$$\begin{aligned} p_F &\equiv \int_{f \in [0,1]} p_f df \\ &= \int_{f \in [0,1]} \left[(1 - \delta^*) y_f + \delta^* \left[x_f^* + e\right]\right] df \\ &= (1 - \delta^*) \int_{f \in [0,1]} y_f df + \delta^* \left[e + \int_{f \in [0,1]} x_f^* df\right] \\ &= (1 - \delta^*) \theta + \delta^* [e + \theta^*]. \end{aligned}$$

As a result, Home prices are

$$\begin{aligned} p_h &= E_h [(1 - r) \theta + r p_F] \\ &= E_h [(1 - r) \theta + r [(1 - \delta^*) \theta + \delta^* [e + \theta^*]]] \\ &= [(1 - r) + r (1 - \delta^*)] E_h [\theta] + r \delta^* [e + E_h [\theta^*]] \\ &= (1 - \delta_r) x_h + \delta_r [y_h^* + e], \end{aligned}$$

where the pass-through coefficient equals

$$\delta_r \equiv \lambda + r \delta^* (1 - \lambda - \eta) \in (0, 1).$$

Note that

$$\frac{\partial \delta_r}{\partial r} \equiv \delta^* (1 - \lambda - \eta) > 0$$

and so

$$\max_r \delta_r = \delta.$$

Besides, we have ERCP puzzle if and only if

$$\begin{aligned} \delta^* &> \delta = \lambda + r\delta^* (1 - \lambda - \eta) \\ \overset{\lambda+\eta\in(0,1)}{\overbrace{\Longleftrightarrow}} \delta^* &> \frac{\lambda}{1 - r(1 - \lambda - \eta)}. \end{aligned}$$

Setting $r = 1$ establishes our result

$$\delta^* > \frac{\lambda}{\lambda + \eta}$$

or

$$\frac{\sigma^2_{y^*}}{\sigma^2_{x^*}} > \frac{\sigma^2_x}{\sigma^2_y + \sigma^2_e}.$$

■

Proof of Result 4 (Macroeconomic Stability and ERPT). Given our simplifying assumptions

$$\theta \sim N\left(\mu, \sigma^2_\theta\right), \quad \theta^* \sim N\left(\mu^*, \sigma^2_{\theta^*}\right).$$

our model simplifies to:

$$\begin{aligned} x_h &= y_f = \mu, \quad x^*_f = y^*_h = \mu^*, \\ \sigma^2_x &= \sigma^2_y = \sigma^2_\theta, ...\sigma^2_{x^*} = \sigma^2_{y^*} = \sigma^2_{\theta^*} \end{aligned}$$

and thus

$$\delta = \frac{\sigma^2_\theta + r\delta^*\sigma^2_e}{\sigma^2_\theta + \sigma^2_{\theta^*} + \sigma^2_e} < \frac{\sigma^2_\theta + \sigma^2_e}{\sigma^2_{\theta^*} + \sigma^2_\theta + \sigma^2_e} = \delta^*.$$

The derivatives of δ^* are

$$\begin{aligned}\frac{\partial \delta^*}{\partial \sigma_\theta^2} &= \frac{\partial \delta^*}{\partial \sigma_e^2} = \frac{\sigma_{\theta^*}^2}{\left(\sigma_{\theta^*}^2 + \sigma_\theta^2 + \sigma_e^2\right)^2} > 0, \\ \frac{\partial \delta^*}{\partial \sigma_{\theta^*}^2} &= -\frac{\sigma_\theta^2 + \sigma_e^2}{\left(\sigma_{\theta^*}^2 + \sigma_\theta^2 + \sigma_e^2\right)^2} < 0,\end{aligned}$$

while the derivatives of δ are

$$\begin{aligned}\frac{\partial \delta}{\partial \sigma_\theta^2} &= \frac{\sigma_{\theta^*}^2\left(1 + r\sigma_e^2\right) + \left(1 - r\delta^*\right)\sigma_e^2}{\left(\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2\right)^2} > 0, \\ \frac{\partial \delta}{\partial \sigma_{\theta^*}^2} &= \frac{\left(r\frac{\partial \delta^*}{\partial \sigma_{\theta^*}^2}\sigma_e^2\right)\left(\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2\right) - \left(\sigma_\theta^2 + r\delta^*\sigma_e^2\right)}{\left(\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2\right)^2} < 0, \\ \frac{\partial \delta}{\partial \sigma_e^2} &= \frac{r\left(\frac{\partial \delta^*}{\partial \sigma_e^2}\sigma_e^2 + \delta^*\right)\left(\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2\right) - \left(\sigma_\theta^2 + r\delta^*\sigma_e^2\right)}{\left(\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2\right)^2}.\end{aligned}$$

Note that

$$\begin{aligned}\left.\frac{\partial \delta}{\partial \sigma_e^2}\right|_{r=0} &= -\frac{\sigma_\theta^2}{\left(\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2\right)^2} < 0, \\ \left.\frac{\partial \delta}{\partial \sigma_e^2}\right|_{r=1} &= \frac{2\sigma_{\theta^*}^2\sigma_e^2}{\left(\sigma_\theta^2 + \sigma_{\theta^*}^2 + \sigma_e^2\right)^3} > 0.\end{aligned}$$

■

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