Do Sticky Prices Increase Real Exchange Rate Volatility at the Sector Level?

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Facts About Real Exchange Rates

Macroeconomic real exchange rate (Mussa, 1986).

$$q_t = s_t + p_t^* - p_t$$

Fact 1: $Var(\Delta q_t)/Var(\Delta s_t)$ close to 1.
Fact 2: $Corr(\Delta q_t, \Delta s_t)$ about 0.9.

Microeconomic real exchange rates (Crucini and Landry, 2012).

$$q_{it} = s_t + p_{it}^* - p_{it}$$

Fact 3: $Var(q_{it})/Var(q_t)$ close to 2.
Fact 4: $Corr(q_{it}, q_t)$ about 0.45.

Facts 1 and 2 (Mussa/Obstfeld-Rogoff: sticky prices and nominal shocks)

"Exchange rate overshooting results from the rapid response of exchange rates to monetary policy and the sluggish adjustment of prices. A monetary expansion will lead to an immediate depreciation but only a gradual increase in prices. Exchange rate overshooting implies that real exchange rates are highly volatile." (Dornbusch-Fischer-Startz, 2004).

Intuition for the Sticky Price Story

Recall q_{it} is the log real exchange rate for good i

$$q_{it} = s_t + p_{it}^* - p_{it}$$

where s_t is the (floating) nominal exchange rate.

Suppose that home money supply increases: $\Delta M_t = \pi > 0$.

Scenario	Δs_t	Δp_{it}^*	Δp_{it}	Δq_{it}
Flexible price goods	π	0	π	0
Sticky price goods	π	0	0	π

Flexible prices - inconsistent with Facts 1 and 2
Sticky prices - consistent with Facts 1 and 2.

Facts 3 and 4 (Stockman/Corsetti Dedola and Leduc: flexible prices, real shocks and trade costs)

"Productivity shock that is location and good-specific generates relative price movements in the presence of consumption home-bias. For example, a bad harvest in the Riesling producing region of Germany will have a larger impact on wine prices in cafes located in Eltville than those in Nashville where California Cabernet is more popular."

Intuition for the Flexible Price Story

Recall q_{it} is the log real exchange rate for good i

$$q_{it} = s_t + p^*_{it} - p_{it}$$

where s_t is (flexible) nominal exchange rate.

Suppose that home labor productivity increases: $\varepsilon_{it} = \varepsilon > 0$ and let $\omega > 1/2$ be the home expenditure weight on the home good.

Scenario	Δs_t	Δp^*_{it}	Δp_{it}	Δq_{it}
Flexible price goods	0	$-(1-\omega)\varepsilon$	$-\omega\varepsilon$	$(2\omega - 1)\varepsilon$
Sticky price goods	0	0	0	0

Flexible prices - consistent with Facts 3 and 4
Sticky prices - inconsistent with Facts 3 and 4.

Summary of Findings

- New concept: “**the real exchange rate volatility curve**”
  - RER volatility rising in price stickiness conditional on nominal shocks
  - RER volatility falling in price stickiness conditional on productivity shocks
  - Overall RER ambiguous correlation with price stickiness (U-shaped).

- We use US-European micro-price data to assses
  - On average, 10-40 percent of forecast error variance is due to nominal shocks
  - Suggests dominance of real shocks

Related Literature

The importance of sticky prices for **aggregate** exchange rate volatility

- Simulaton by Chari-Kehoe-McGrattan (2002) in the New Open Economy Macroeconomics (NOEM) framework

Nominal vs. real shocks on **aggregate** real exchange rate volatility

- Clarida-Galí(1994), Eichenbaum-Evans (1995), Rogers (1999) compute forecast error variance using structual VAR models

Implications of heterogeneous sticky prices for **disaggregate** real exchange rate volatility

- Kehoe-Midrigan (2007) considered only nominal shocks
- Crucini-Shintani-Tsuruga (2010) considered only real shocks
- This paper combines these two theories.

Roadmap

1. **The Model**
   - Calvo time dependent pricing (good-specific)
   - Aggregate monetary and productivity shocks
   - Microeconomic productivity shocks
   - Trade costs generate home bias

2. **Empirical Results**
   - Numerical examples
   - The European Micro-data
   - Estimation of the volatility curve
   - Variance decomposition good-by-good

3. **Conclusions and Future Work**
   - Implications of aggregation
   - Do the results hold in other contexts?
   - Centers for International Price Research

Two-country New Keynesian General Equilibrium Model

Households

$U(C_t, L_t) = \log C_t - \chi L_t$ with cash-in-advance constraint

▸ Household Problem ▸ FOCs

Firms producing good i

- set good prices in monopolistically competitive Home and Foreign markets (local currency pricing)
- use technology: $Y_{it}(v) = A_{it} L_{it}(v)$, where A_{it} denotes sector specific shock
- must pay trade costs τ to send goods from a country to the other
- cannot change prices with prob. λ_i (note the subscript)

▸ CES aggregators ▸ Firm Problem

Nominal Money Shocks

- Governments alter money supplies
- Money growth rate differential $(\mu_t - \mu_t^*)$
- Generates the nominal exchange rate (s_t) fluctuations
- μ_t and μ_t^* calibrated such that the nominal exchange rate follows a random walk (as in the data)

Real Productivity Shocks

- Key is the sector-specific labor productivity differential $(a_{it} - a_{it}^*)$
- Stochastic process of (log) labor productivity a_{it}, a_{it}^*
- z_t is a common stochastic trend
- nation-specific and sector specific innovations are i.i.d.
- thus, a_{it} and a_{it}^* are cointegrated.

Real exchange Rate Volatility Curve

We focus on the k-period-ahead forecast error variance

$$Var_{t-k}(q_{it}) = E_{t-k}(q_{it} - E_{t-k}(q_{it}))^2$$

where $q_{it} = s_t + p^*_{it} - p_{it}$ is (log) real exchange rate for sector i.

The model implies

$$\begin{aligned} Var_{t-k}(q_{it}) &= \sum_{j=1}^{k} \lambda_i^{2(j-1)} [\lambda_i^2 Var(\mu_t - \mu_t^*) \\ &\quad + (1-\lambda_i)^2 (1-\lambda_i \beta)^2 \psi^2 Var(a_{it} - a^*_{it})] \end{aligned}$$

- ψ is the degree of home bias $\psi = \frac{1-(1+\tau)^{1-\theta}}{1+(1+\tau)^{1-\theta}}$
- λ_i affects the volatility of real exchange rates model

Real exchange Rate Volatility Curve

For one-period-ahead forecast error variance ($k = 1$), the curve simplifies to

$$Var_{t-1}(q_{it}) = \lambda_i^2 Var(\mu_t - \mu_t^*) + (1 - \lambda_i)^2 (1 - \lambda_i \beta)^2 \psi^2 Var(a_{it} - a_{it}^*)$$

Key features:

- Nominal effect increases with λ_i
- Real effect decreases with λ_i

Numerical Examples

In the figures

- Vertical distance = variance of $Var_{t-1}(q_{it})$
- Blue area = contribution of real shocks (decreases with λ_i)
- Red area = contribution of nominal shocks (increases with λ_i)

1. **Real shocks dominate** $Std(a_{it} - a_{it}^*)/Std(\mu_t - \mu_t^*) = 5$ ▸ Figure
2. **Both shocks are important** $Std(a_{it} - a_{it}^*)/Std(\mu_t - \mu_t^*) = 1$ ▸ Figure
3. **Nominal shocks dominate** $Std(a_{it} - a_{it}^*)/Std(\mu_t - \mu_t^*) = 1/5$ ▸ Figure

Empirical Work

1. **Compute $\mathbf{V}_i$, one-period ahead FEV of $\mathbf{q}_{it}$**

2. **Estimate relationship between $\mathbf{V}_i$ and λ_i**
   - simple linear function
   - restricted structural quartic function
   - unrestricted non-parametric function

3. **Variance decomposition good-by-good.**

European Micro-Price Data

- Data constructed by Kehoe and Midrigan (2007)
- European real exchange rate data (Austria, Belgium, France and Spain) relative to US
- Prices from Eurostat and BLS
- # of goods = 182
- Sample period: 1996:M1 - 2006:M12

Country	**Matches**	**Source of λ_i estimates**
Austria	57	Baumgartner et al (2005)
Belgium	46	Aucremanne and Dhyne (2004)
France	48	Baudry et al (2007)
Spain	31	Alvarez and Hernando (2004)
United States	-	Bils and Klenow (2004)

Linear Relationship Between RER Volatility and Price Stickiness

Table 1: Linear regressions

	Const	λ_i	Adj. R^2
Pooled Reg.	0.013	**-0.014**	0.70
	(0.001)	(0.001)	
Austria	0.016	**-0.016**	0.89
	(0.002)	(0.002)	
Belgium	0.011	**-0.011**	0.45
	(0.001)	(0.001)	
France	0.013	**-0.014**	0.83
	(0.002)	(0.002)	
Spain	0.014	**-0.015**	0.59
	(0.003)	(0.003)	

Structural Relationship Between RER Volatility and Price Stickiness

Recall, that volatility curve for one-period-ahead forecast error variance is given by

$$Var_{t-1}(q_{it}) = \lambda_i^2 Var(\mu_t - \mu_t^*) + (1-\lambda_i)^2(1-\lambda_i\beta)^2\psi^2 Var(a_{it} - a_{it}^*)$$

To allow this nonlinearity (quartic function), we run

$$V_i = \widehat{b}_1\lambda_i^2 + \widehat{b}_2(1-\lambda_i)^2(1-\lambda_i\beta)^2 + \widehat{u}_i$$

setting $\beta = 0.96^{1/12}$ and transforming the measured levels of price stickiness as indicated above.

Volatility Lower Bound

- From the estimated we can obtain λ_i which minimizes V_i
- $\sqrt{b_2 / b_1}$ can be used as a lower bound for std ratio:

$$\sqrt{\frac{b_2}{b_1}} = \psi \frac{Std(a_{it} - a^*_{it})}{Std(\mu_t - \mu^*_t)} \qquad 0 < \psi < 1$$

Estimated Structural Regressions (Quartic)

- Minimum volatility at $\lambda_i = 0.762$ (pooled data)
- Lower bound for $Std(a_{it} - a_{it}^*)/Std(\mu_t - \mu_t^*) = 5.28$, close to example 1. ▸ Figure

	λ_i^2	$(1-\lambda_i)^2(1-\lambda_i\beta)^2$	Adj. R_{uc}^2
Pooled Reg.	0.0016	0.0456	0.75
	(0.0001)	(0.0039)	
Austria	0.0012	0.0475	0.90
	(0.0001)	(0.0066)	
Belgium	0.0021	0.0419	0.62
	(0.0004)	(0.0056)	
France	0.0015	0.0411	0.91
	(0.0001)	(0.0040)	
Spain	0.0017	0.1567	0.72
	(0.0002)	(0.0292)	

Both coefficients are significantly positive (consistent with theory)

Unrestricted Nonparametric Relationship

Unrestriction version to allow for general non-linearity ▸ Figure

$$V_i = m(\lambda_i) + u_i$$

Nonparametric test for monotonicity

	$m(\lambda_i)$		$m'(\lambda_i)$	
	Null hypothesis		Null hypothesis	
	Increasing	Decreasing	Increasing	Decreasing
Pooled	10.33***	-1.83	-2.32	17.01***
Austria	4.93**	-1.55	1.88	9.36***
Belgium	4.61*	-0.65	1.87	9.38***
France	6.37***	-1.21	1.40	6.68***
Spain	5.10*	-1.28	-0.03	7.73***

Volatility curve is convex (consistent with U-shape prediction)

Variance Decomposition Methods

- Model implies $\Delta s_t = \mu_t - \mu_t^*$
- Thus the estimated contribution of the nominal shock is $\lambda_i^2 Var(\Delta s_t)$
- Relative contribution of nominal effect by: ▸ Figure

$$\frac{\lambda_i^2 Var(\Delta s_t)}{V_i}$$

Variance Decomposition Results

Table 4: Contribution of nominal shock on average

k	1	3	6	12	∞
Pooled	40.6	23.6	18.7	14.2	11.4
	(24.1)	(16.5)	(15.7)	(13.5)	(11.8)
Austria	48.6	30.5	25.7	20.3	17.1
Belgium	34.9	19.9	15.3	11.4	8.9
France	40.2	21.8	16.2	11.7	9.2
Spain	35.2	18.9	14.6	11.1	7.9

Contribution of nominal effect becomes smaller as k increases.

Consequences of Aggregation

Why is real shock so important?
In disaggregate RER:

$$q_{it} = s_t + p_{it}^* - p_{it}$$

Lots of idiosyncratic real shocks impinge upon p_{it} and p_{it}^*
However, in aggregate RER

$$q_t = s_t + p_t^* - p_t$$

Idiosyncratic shocks are washed out when aggregating p_{it} and p_{it}^*
$p_t = \frac{1}{N}\sum_i p_{it}$ and $p_t^* = \frac{1}{N}\sum_i p_{it}^*$
In fact, our variance decomp. suggests smaller contributions of nominal effect to disaggregate RER than to aggregate RER in the literature.

Conclusions and Ongoing Work

1. **Conclusions**

   - New concept: the "**real exchange rate volatility curve**"

   - Data suggests it is downward sloping, dominance of real shocks for most goods

   - Aggregation tends to exaggerate role of nominal shocks

2. **Ongoing work**

   - How does volatility curve shift across time, across locations and exchange rate regimes?

   - Centers for International Price Research

Households

Home consumers solve

$$
\begin{aligned}
&\text{Max}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t [\ln C_t - \chi L_t] \\
&\text{s.t.} M_t + E_t(\Upsilon_{t,t+1} D_{t+1}) = R_{t-1} W_{t-1} L_{t-1} \\
&\quad + (M_{t-1} - P_{t-1} C_{t-1}) + D_t + T_t + \Pi_t \\
&\quad M_t \geq P_t C_t
\end{aligned}
$$

Foreign consumer problems are analogously defined with "*" except budget constraint

$$
\begin{aligned}
&M_t^* + E_t\left(\Upsilon_{t,t+1} \frac{D_{t+1}^*}{S_t}\right) = \frac{S_{t-1} R_{t-1}}{S_t} W_{t-1}^* L_{t-1}^* \\
&+ (M_{t-1}^* - P_{t-1}^* C_{t-1}^*) + D_t^* + T_t^* + \Pi_t^*
\end{aligned}
$$

Return

FOCs from household problems are standard

$$\frac{W_t}{P_t} = \chi C_t \qquad \frac{W_t^*}{P_t^*} = \chi C_t^*$$

$$\Upsilon_{t,t+1} = \beta \left[\left(\frac{C_{t+1}}{C_t} \right)^{-1} \frac{P_t}{P_{t+1}} \right] = \beta \left[\left(\frac{C_{t+1}^*}{C_t^*} \right)^{-1} \frac{S_t P_t^*}{S_{t+1} P_{t+1}^*} \right]$$

$$M_t = P_t C_t \qquad M_t^* = P_t^* C_t^*$$

From FOCs, nominal wages are proportional to money supply and nominal exchange rate is given by money supply ratio:

$$W_t = \chi M_t \qquad W_t^* = \chi M_t^*$$

$$S_t = \kappa \frac{M_t}{M_t^*}$$

Return

CES aggregation

Two levels of CES aggregation

$$C_t = \left[\int C_{it}^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}, \quad \text{(agg.cons.inHome)}$$

$$C_{it} = \left[\int C_{it}(v)^{\frac{\theta-1}{\theta}} dv \right]^{\frac{\theta}{\theta-1}},$$

a brand $v \in [0, 1/2]$ produced in Home
a brand $v \in (1/2, 1]$ produced in Foreign

$$P_t = \left[\int P_{it}^{1-\theta} di \right]^{\frac{1}{1-\theta}}$$

$$P_{it} = \left[\int P_{it}(v)^{1-\theta} dv \right]^{\frac{1}{1-\theta}}$$

Return

Price setting

Max problem of Home firms to sell goods in home market

$$\underset{P_{H,it}}{\text{Max}} E_t \sum_{h=0}^{\infty} \lambda_i^h \Upsilon_{t,t+h} \left[P_{H,it} - \frac{W_{t+h}}{A_{it+h}} \right] \left(\frac{P_{H,it}}{P_{it+h}} \right)^{-\theta} C_{it+h}.$$

Max problem of Foreign firms to sell goods in home market

$$\underset{P_{F,it}}{\text{Max}} E_t \sum_{h=0}^{\infty} \lambda_i^h \Upsilon_{t,t+h} \left[P_{F,it} - (1+\tau) \frac{S_{t+h} W_{t+h}^*}{A_{it+h}^*} \right] \left(\frac{P_{F,it}}{P_{it+h}} \right)^{-\theta} C_{it+h}^*.$$

Max problem of price setting for foreign market is defined analogously

Return

Log-linearized Economy

Let $\bar{P}_{it} = P_{it}A_{it}/M_t$ & $\bar{P}^*_{it} = P^*_{it}A^*_{it}/M^*_t$

Let $\bar{p}_{it}$ ($\bar{p}^*_{it}$) is the log-deviation of the normalized price index for good i in home (foreign) country from the SS value

Under the stochastic processes of nominal and real shocks, Calvo-type price stickiness implies

$$\begin{aligned}\bar{p}_{it} &= \lambda_i \bar{p}_{it-1} - \lambda_i \mu_t + \lambda_i g_t^{A_i} \\ &\quad + (1-\lambda_i)\lambda_i\beta\left[\omega\varepsilon_{it} + (1-\omega)\varepsilon^*_{it}\right] + (1-\lambda_i)(1-\omega)(\varepsilon_{it} - \varepsilon^*_{it}) \\ \bar{p}^*_{it} &= \lambda_i \bar{p}^*_{it-1} - \lambda_i \mu^*_t + \lambda_i g_t^{A^*_i} \\ &\quad + (1-\lambda_i)\lambda_i\beta\left[\omega\varepsilon^*_{it} + (1-\omega)\varepsilon_{it}\right] - (1-\lambda_i)(1-\omega)(\varepsilon_{it} - \varepsilon^*_{it})\end{aligned}$$

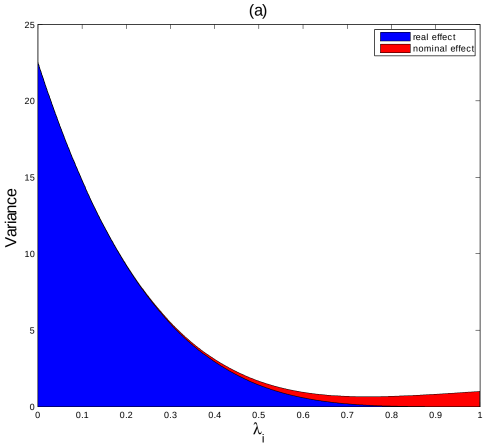
where $g_t^{A_i}$ is growth rate of a_{it} and ω is steady state expenditure share

Arranging these two equations yields

$$q_{it} = \lambda_i q_{it} + \lambda_i\left[\mu_t - \mu^*_t\right] + (1-\lambda_i)(1-\lambda_i\beta)\psi\left[a_{it} - a^*_{it}\right]$$

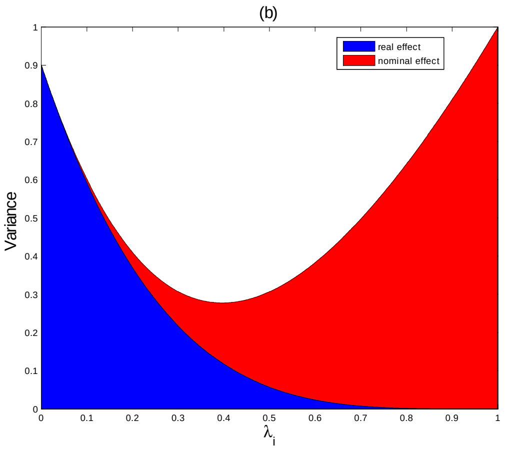
Return

Numerical Example: Large Real Shocks



Back

Numerical Example: Comparable Nominal and Real Shocks



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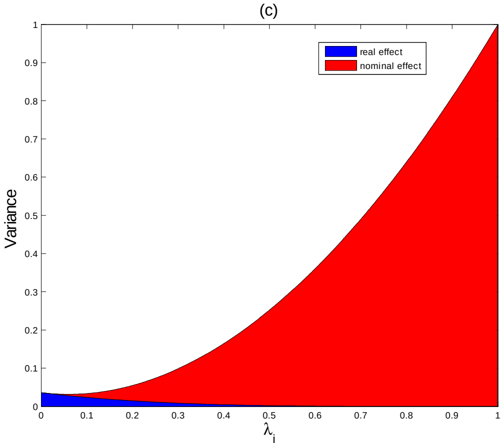
Numerical Example: Large Nominal Shocks



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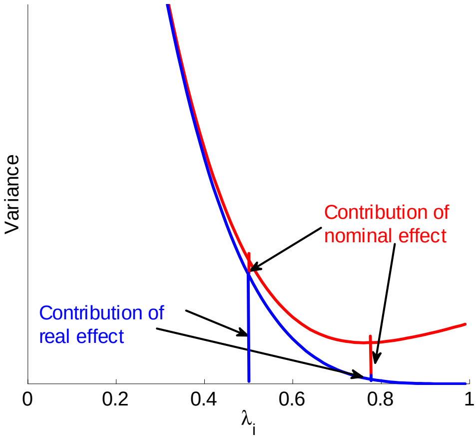
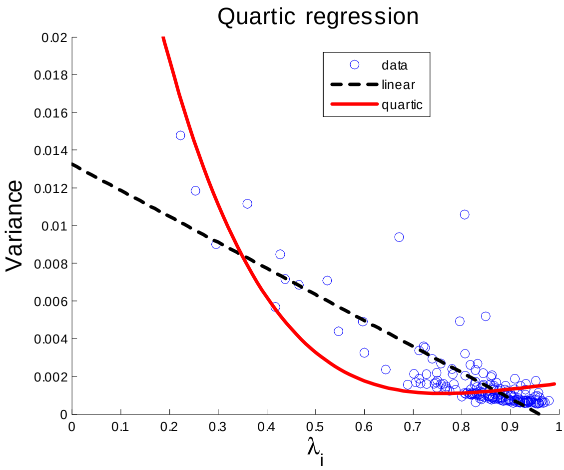
Variance Decomposition Method



Back

Estimated Structural (Quartic) and Linear Compared



Back

Estimated Non-Parametric Curve