Puzzling Exchange Rate Dynamics and Delayed Portfolio Adjustment

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Motivation

- Richard Thaler received the 2017 Nobel prize, focusing on deviations from "rational efficient markets"

- One example is the Froot and Thaler (1990) paper, where they suggest that to explain the forward discount puzzle one must take into account that
  
  "...at least some investors are slow in responding to changes in the interest differential... It may be that these investors need some time to think about trades before executing them, or that they simply cannot respond quickly to recent information"
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  \textit{“...at least some investors are slow in responding to changes in the interest differential...It may be that these investors need some time to think about trades before executing them, or that they simply cannot respond quickly to recent information”}

- In a 2010 AER paper we formalized the Froot and Thaler suggestion to explain the forward discount puzzle through gradual portfolio adjustment
Motivation

- But Engel (AER 2016) argues that the delayed portfolio adjustment mechanism is inconsistent with the evidence.

- We revisit this issue with a simpler, more transparent approach to modeling gradual portfolio adjustment.

- Enables to derive analytical results.

- We show that it can explain a much broader set of six puzzles related to the connection between exchange rates and interest rates.
Six Puzzles

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2. *Forward discount puzzle*: higher interest rate currencies have higher expected returns over the near future
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3. *Predictability reversal puzzle*: higher interest rate currencies have lower expected returns after some period of time
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4. **Engel puzzle**: high interest rate currencies are stronger then implied by UIP
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4. *Engel puzzle*: high interest rate currencies are stronger then implied by UIP

5. *Forward guidance exchange rate puzzle*: the exchange rate is more strongly affected by expected interest rate in the near than distant future (Gali, 2018)
Six Puzzles

1. *Delayed overshooting puzzle*: a monetary contraction that raises the interest rate leads to a period of appreciation, followed by gradual depreciation.

2. *Forward discount puzzle*: higher interest rate currencies have higher expected returns over the near future.

3. *Predictability reversal puzzle*: higher interest rate currencies have lower expected returns after some period of time.

4. *Engel puzzle*: high interest rate currencies are stronger than implied by UIP.

5. *Forward guidance exchange rate puzzle*: the exchange rate is more strongly affected by expected interest rate in the near than distant future (Gali, 2018).

Modeling Gradual Portfolio Adjustment

- Most of the literature on gradual portfolio adjustment assumes that there are overlapping agents that change their portfolio every $T$ periods

- We did so in our 2010 paper

- Two drawbacks:
  1. leads to “wobbly” impulse response to shocks
     - because of the anticipation that agents who adjust their portfolio at the time of the shock will change their portfolio again exactly $T$ periods later
  2. Not analytically tractable: numerical methods are needed to solve such models due to investor heterogeneity ($T$ generations of investors)
Modeling Gradual Portfolio Adjustment

- Alternative: agents have a fixed probability $p$ of adjusting their portfolio (like Calvo price setting):
  - Bacchetta and van Wincoop (2017)
  - Even more complex to solve
Modeling Gradual Portfolio Adjustment

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- Here, we take a shortcut by assuming that there is an adjustment cost to portfolio changes

- No heterogeneity of investors

- The first 5 puzzles are addressed through 5 propositions that are derived analytically; a numerical calibration is only used for illustration
Model with Short-Term Bonds

- We use real variables as real exchange rate is stationary
  - many of the puzzles with either nominal or real variables

- We focus on the effect on the exchange rate of interest rate shocks
  - Other shocks are not explicitly modeled; only affect exchange rate to the extent that they have an effect on the variance of excess returns, which affects the portfolio response to interest rate shocks

- Two-country model where agents hold nominal short-term bonds of both countries

- We add nominal long-term bonds of both countries in extension to address the LSV puzzle
Model with Short-Term Bonds

- Overlapping generations of agents that each make one portfolio decision

- Home agents maximize

\[ E_t \frac{C_t^{1-\gamma}}{1-\gamma} - 0.5\psi (z_t - z_{t-1})^2 \]

- \( z_t \) is the portfolio share invested in Foreign bonds
- \( \psi \) is the portfolio adjustment parameter that will drive the results
- Tax \( \tau \) on foreign investment to justify home bias

- Agents start with 1 unit of wealth in real terms and consume their portfolio return + lump-sum transfer from tax
Some Notation

- Real exchange rate: $Q_t$

- Log excess return: $e_{r_{t+1}} = q_{t+1} - q_t + r_t^D$

  where $r_t^D = r_t^* - r_t$

- $\sigma^2$ is the variance of $e_{r_{t+1}}$

- Home bias parameter $h$

- Define $b = (1 - h)/4$
Optimal Portfolio

- Optimal portfolio

\[ z_t = \frac{\psi}{\psi + \gamma \sigma^2} z_{t-1} + \frac{\gamma \sigma^2}{\psi + \gamma \sigma^2} z^f_t \]

where

\[ z^f_t = \bar{z} + \frac{E_{t+1} \text{er}_{t+1}}{\gamma \sigma^2} \]

\[ \bar{z} = \frac{0.5}{\gamma} - \frac{\tau}{\gamma \sigma^2} \]

\( z^f_t \) is no-adjustment cost portfolio

- Weighted average of past portfolio and frequent portfolio
Optimal Portfolio

- Portfolio can be rewritten as:

\[
z_t - \bar{z} = \frac{\psi}{\psi + \gamma \sigma^2} (z_{t-1} - \bar{z}) + \frac{1}{\psi + \gamma \sigma^2} E_t \text{er}_{t+1}
\]

- Portfolio persistence: larger \(\psi\) and lower \(\gamma\) increase the weight on the lagged portfolio.
- Return sensitivity: larger \(\psi\) and \(\gamma\) both lead to a weaker portfolio response to changes in the expected excess return.

Higher \(\psi\): raises portfolio persistence, but weakens return sensitivity.

Higher \(\gamma\): less portfolio persistence and weaker return sensitivity.
Optimal Portfolio

- Portfolio can be rewritten as:

\[ z_t - \bar{z} = \frac{\psi}{\psi + \gamma \sigma^2} (z_{t-1} - \bar{z}) + \frac{1}{\psi + \gamma \sigma^2} E_t e_{r_t+1} \]

- \( \psi \) and \( \gamma \) play two roles:

1. **Portfolio persistence:** larger \( \psi \) and lower \( \gamma \) increase the weight on the lagged portfolio

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  2. **Return sensitivity**: larger \( \psi \) and \( \gamma \) both lead to a weaker portfolio response to changes in the expected excess return.

- Higher \( \psi \): raises portfolio persistence, but weakens return sensitivity
- Higher \( \gamma \): less portfolio persistence and weaker return sensitivity
Equilibrium

- Analogous portfolio applies to Foreign investors, who invest $z_t^*$ in Foreign bonds.
- The supply of bonds is 1 in real terms in both countries.
- The Foreign bond market clearing condition is then:

$$z_t + z_t^* Q_t = Q_t$$
Log-linearizing, substituting the Home and Foreign portfolio expressions, we get

\[ E_t q_{t+1} - \theta q_t + b \psi q_{t-1} + r_t^D = 0 \] (1)

where \( \theta = 1 + \psi b + \gamma \sigma^2 b \)

Exchange rate \( q_t \) behaves as an \( AR(2) \)
Equilibrium

- Log-linearizing, substituting the Home and Foreign portfolio expressions, we get

\[ E_t q_{t+1} - \theta q_t + b \psi q_{t-1} + r_t^D = 0 \]  \hspace{1cm} (1)

where \( \theta = 1 + \psi b + \gamma \sigma^2 b \)

- Exchange rate \( q_t \) behaves as an \( AR(2) \)

- We can rewrite equation (1) as:

\[ E_t er_{t+1} = \gamma \sigma^2 b q_t + \psi b (q_t - q_{t-1}) \]  \hspace{1cm} (2)
Solution for the Exchange Rate

Solution

\[ q_t = \alpha q_{t-1} + E_t \sum_{i=0}^{\infty} \frac{1}{D_{i+1}} r_{t+i}^D \]  

where \( \alpha \) and \( D \) are the roots of the characteristic equation of (1):

\[ \alpha = \frac{\theta - \sqrt{\theta^2 - 4\psi b}}{2} \]

\[ D = \frac{\theta + \sqrt{\theta^2 - 4\psi b}}{2} \]
Solution for the Exchange Rate

Solution

\[ q_t = \alpha q_{t-1} + E_t \sum_{i=0}^{\infty} \frac{1}{D_{i+1}} r_{t+i} \]  

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\[ \alpha = \frac{\theta - \sqrt{\theta^2 - 4\psi b}}{2} \]
\[ D = \frac{\theta + \sqrt{\theta^2 - 4\psi b}}{2} \]

Lemma

- As \( \psi \) rises from 0 to \( \infty \), \( \alpha \) rises monotonically from 0 to 1.
- As \( \psi \) rises from 0 to \( \infty \), \( D \) rises monotonically from \( 1 + \gamma \sigma^2 b \) to \( \infty \).
We will assume an AR(1) process for the relative interest rate:

\[ r_t^D = \rho r_{t-1}^D + \varepsilon_t \]

In that case (3) gives us

\[ q_t = \alpha q_{t-1} + \frac{1}{D - \rho} r_t^D \]
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In that case (3) gives us

\[ q_t = \alpha q_{t-1} + \frac{1}{D - \rho} r_t^D \]

We derive analytical expressions for the predictability coefficients \( \beta_k \) in:

\[ er_{t+k} = \alpha + \beta_k r_t^D + \varepsilon_{t+k}^{er} \]
1. Delayed Overshooting Puzzle

Proposition

Consider the impulse response of the real exchange rate to a positive shock to the relative Foreign interest rate $r^D_t$.

- if $\alpha < 1 - \rho$: the real exchange rate appreciates at the time of the shock and subsequently gradually depreciates back to the steady state.
- if $\alpha > 1 - \rho$: there is delayed overshooting. The real exchange rate appreciates at the time of the shock and keeps appreciating until time $t > \bar{t} > 1$. Then it gradually depreciates back to the steady state.
1. Delayed Overshooting Puzzle

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Consider the impulse response of the real exchange rate to a positive shock to the relative Foreign interest rate $r_t^D$.

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- If $\alpha > 1 - \rho$: there is delayed overshooting. The real exchange rate appreciates at the time of the shock and keeps appreciating until time $t > \bar{t} > 1$. Then it gradually depreciates back to the steady state.

- We show that $\bar{t}$ rises monotonically with $\psi$. 
Intuition Delayed Overshooting Puzzle

- A rise in the relative Foreign interest rate leads to an appreciation of the Foreign currency.

- After that there are two forces at work:

  1. $r_t^D$ gradually goes back to zero, which causes a gradual shift back to the Home currency and therefore a Foreign depreciation.

  2. If portfolios are slow to adjust, there is a continued shift to the Foreign bond, leading to a continued appreciation of Foreign currency for a period of time.

- When $\psi$ is large enough the second force dominates and there is delayed overshooting.
Numerical Illustration

- We use monthly data on real interest rates and real exchange rates for the 6 G7 countries relative to the United States to set $\rho = 0.9415$ and $\sigma = 0.0271$.

- We use data on external assets and liabilities for debt securities of these same countries to set the home bias parameter $h = 0.66$.

- We vary $\psi$ and $\gamma$ over a wide range, but in the benchmark set them $\psi = 15$ and $\gamma = 50$.
Figure 1 Impulse Response $q_t$ and Delayed Overshooting

A  Impulse Response $q_t$ in Percent  
($\psi=15, \gamma=50$)

B Overshooting: Time to Maximum Impact

γ=10  
γ=50  
γ=100
Delayed Overshooting

- Benchmark: exchange rate appreciates for 35 months

- Eichenbaum and Evans (1995): appreciation of currencies relative to dollar for 25-39 months after increase in the monetary policy interest rate

- With larger $\psi$ and smaller $\gamma$ more portfolio persistence: more gradual appreciation, which increases $\bar{t}$
2. Forward Discount Puzzle

\[ er_{t+1} = \alpha + \beta_1 r_t^D + \varepsilon_{t+1} \]

**Proposition**

The Fama predictability coefficient $\beta_1$ is positive, and larger when there is gradual portfolio adjustment ($\psi > 0$).
2. Forward Discount Puzzle

\[ e_{t+1} = \alpha + \beta_1 r_t^D + \varepsilon_{t+1} \]

**Proposition**

The Fama predictability coefficient \( \beta_1 \) is positive, and larger when there is gradual portfolio adjustment \((\psi > 0)\).

- **Intuition:** exchange rate continues to appreciate after the initial positive interest rate shock; positive excess return due to both the appreciation and the higher interest rate

- **Under the benchmark parameterization** \( \beta_1 = 3.26 \)

- **Even without delayed overshooting a higher \( \psi \) still raises \( \beta_1 \) as it weakens the depreciation subsequent to the shock**
Figure 2 Forward Discount Puzzle: Predictability Coefficient $\beta_1$

![Graph showing the predictability coefficient $\beta_1$ with different values of $\gamma$.](image-url)
- Low $\psi$: *portfolio persistence* is weak, less delayed overshooting and less excess return predictability.

- High $\psi$: *return sensitivity* is weak, weakens excess return predictability

- $\beta_1$ larger when $\gamma$ is smaller: both *portfolio persistence* and *return sensitivity* are larger
3. Predictability Reversal Puzzle

\[ \text{er}_{t+k} = \alpha + \beta_k r_t^D + \varepsilon_{t+k} \]

- In our (2010) paper we show that \( \beta_k \) changes sign when \( k \) increases. Confirmed by Engel (2016)
3. Predictability Reversal Puzzle

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- Define \( \bar{\psi} = \rho \gamma \sigma^2 / (1 - \rho) \)
3. Predictability Reversal Puzzle

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- Define $\bar{\psi} = \rho \gamma \sigma^2 / (1 - \rho)$

**Proposition**

*The following holds for $\beta_k$:*

- if $\psi \leq \bar{\psi}$: $\beta_k$ is positive for all $k$ and drops monotonically to zero as $k \to \infty$

- if $\psi > \bar{\psi}$: there is a $\bar{k} > 1$ such that $\beta_k$ is positive for $k < \bar{k}$ and negative for $k \geq \bar{k}$. It converges to zero as $k \to \infty$. 
Intuition Predictability Reversal

- Consider delayed overshooting (although not a necessary condition for predictability reversal)

- Initially, high interest rate currency has a positive expected excess return, both due to the higher interest rate and the appreciation subsequent to the shock

- The real exchange rate appreciates until $\bar{t}$

- When $\bar{t}$ is large, by the time the real exchange rate starts to depreciate, the real interest differential is small (AR(1) process)

- The real depreciation then causes a negative excess return
Reversal occurs after 30 months. Not too far from the reversal after 5-10 quarters reported in Bacchetta and van Wincoop (2010).

$k$ rises with a higher $\psi$ and a lower $\gamma$. Both enhance the *portfolio persistence*, which delays the predictability reversal.
4. Engel Puzzle

- The Engel puzzle says that high interest rate currencies tend to be strong relative to what the exchange rate would be under UIP, where the expected excess return is zero:

\[ \text{cov}(q_t - q_t^{IP}, r_t^D) > 0 \quad \text{where} \quad q_t^{IP} = \sum_{i=0}^{\infty} E_t r_{t+i}^D \]

- This is the case when

\[ \sum_{k=1}^{\infty} \beta_k < 0 \]
4. Engel Puzzle

- Define \((\psi_1^E, \psi_2^E)\), with \(\psi_1^E < \psi_2^E\), where \(\text{cov}(q_t - q_t^{IP}, r_t^D) = 0\)
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**Proposition**

**Necessary and sufficient conditions for the Engel condition to hold are**

1. \(\psi_1^E < \psi < \psi_2^E\).
2. \(\gamma \sigma^2 b < \frac{1-\rho}{\rho} (1 - \sqrt{1-\rho})^2\).
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1. \(\psi_1^E < \psi < \psi_2^E\).
2. \(\gamma \sigma^2 b < \frac{1-\rho}{\rho} (1 - \sqrt{1-\rho})^2\).

- Holds for intermediate values of \(\psi\), where both _portfolio persistence_ and _return sensitivity_ matter

- Similarly \(\gamma\) not too large
Figure 4 Engel Puzzle: $\sum_{k=1}^{\infty} \beta_k$
5. Forward Guidance Exchange Rate Puzzle

\[ q_t = \alpha q_{t-1} + E_t \sum_{i=0}^{\infty} \frac{1}{D_{i+1}} r_{t+i} \]  

Proposition

The current real exchange rate \( q_t \) discounts expected interest differentials in the distant future more than in the near future. The higher the gradual portfolio adjustment parameter \( \psi \), the more future expected interest differentials are discounted.

By contrast, when \( \psi = 0 \), \( D = 1.0031 \).

Under UIP, \( D = 1 \).
5. Forward Guidance Exchange Rate Puzzle

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**Proposition**

The current real exchange rate \( q_t \) discounts expected interest differentials in the distant future more than in the near future. The higher the gradual portfolio adjustment parameter \( \psi \), the more future expected interest differentials are discounted.

- The discount rate \( D \) is equal to 1.29 in the benchmark parameterization.
- By contrast, when \( \psi = 0 \), \( D = 1.0031 \).
- Under UIP, \( D = 1 \).
Intuition Forward Guidance Exchange Rate Puzzle

- Consider a one-period expected increase in $r_{t+k}$

- Exchange rates prior to $t+k$ appreciate because of an anticipated subsequent appreciation

- The portfolio response at $t+k-1$ to the higher expected $q_{t+k}$ is reduced as portfolios are less responsive to expected returns

- This diminishes the response of $q_{t+k-1}$. The same argument can be repeated for time $t+k-2$, all the way to time $t$

- Multiple rounds of discounting as each period portfolios respond less to an expected return the next period as a result of $\psi > 0$
6. Lack of Predictability with Long-Term Bonds

- In order to address the LSV puzzle, we add long-term bonds
- The model is no longer analytically tractable and is solved numerically
- Agents hold both one-period short term bonds and long-term bonds
- Coupons of long term bonds slowly decline over time
Model with Long-Term Bonds

- Home agents maximize

\[ E_t \frac{C_{t+1}^{1-\gamma}}{1-\gamma} - \frac{1}{4} \psi \sum_{i=1}^{4} (z_{it} - z_{i,t-1})^2 \]

- \( z_{1t} \) = share invested in Foreign short-term bonds
- \( z_{2t} \) = share invested in Foreign long-term bonds
- \( z_{3t} \) = share invested in Home long-term bonds
- \( z_{4t} \) = share invested in Home short-term bonds
Model with Long-Term Bonds

- The model leads to three difference equations in $q_t$, $p^L_t$ and $p^L_{t,*}$
- We continue to assume that interest rates follow an AR process
- The solution can be used to compute coefficients of regressions on excess returns on the current interest differential
Model with Long-Term Bonds

- The model leads to three difference equations in $q_t$, $p_t^L$ and $p_t^{L,*}$

- We continue to assume that interest rates follow an AR process

- The solution can be used to compute coefficients of regressions on excess returns on the current interest differential

- Following LSV, we consider 3 excess returns

1. Short term bond excess return $q_{t+1} - q_t + r_t^* - r_t$
2. Long term bond excess return $q_{t+1} - q_t + r_{t+1}^{L,*} - r_{t+1}^L$
3. Foreign minus Home excess return of long term over short term bonds: $(r_{t+1}^{L,*} - r_t^*) - (r_{t+1}^L - r_t)$
## Predictability with Long-Term Bonds

### Regressions on $r_t^D$

<table>
<thead>
<tr>
<th></th>
<th>Currency Excess Return $q_{t+1} - q_t + r_t^* - r_t$</th>
<th>Bond Excess Return $q_{t+1} - q_t + r_{t+1}^{L,*} - r_{t+1}^L$</th>
<th>Bond local currency return diff. $(r_{t+1}^{L,<em>} - r_t^</em>) - (r_{t+1}^L - r_t)$</th>
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<td>LSV Panel Estimate</td>
<td>1.98</td>
<td>0.65</td>
<td>-1.34</td>
</tr>
</tbody>
</table>
Intuition Long-Term Bonds

- Foreign investors reallocate their portfolio from Foreign long-term to short-term bonds
  - Effect is stronger with home bias
  - Reverse for Home country

- Relative Home bond price $p_{t,D}^L$ rises: delayed overshooting (fig 5B)

- Relative term spread becomes negative, because of gradual adjustment (fig 6B)

- Offsets the Foreign currency appreciation: excess return on long-term bonds becomes negative
Figure 5 Impulse Response Real Exchange Rate and Relative Bond Price

A  Impulse Response Real Exchange Rate $q_t$ (Percent)

B  Impulse Response Relative Bond Price $p_t^{L,D}$ (Percent)
Figure 6 Impulse Response Excess Returns

A  Foreign minus Home
  Bond Excess Return (Percent)
  \( q_{t+1} - q_{t+1} + r_{t+1}^{L,*} - r_{t+1}^{L} \)

B  Foreign minus Home
  Local Excess Return (Percent)
  \( (r_{t+1}^{L,*} - r_t^*) - (r_{t+1}^{L} - r_t) \)
Conclusions

- We have introduced a simple model of gradual portfolio adjustment in the FX market.

- The model is able to account for 6 puzzles related to the connection between exchange rates and interest rates.

- Introducing a simple cost of portfolio adjustment has the advantage of analytic tractability by avoiding investor heterogeneity.

- Future research needs to verify these findings in the context of more complex models of gradual portfolio adjustment due to frictions that lead to infrequent portfolio decisions.
Comments on Engel (2016)

- Engel (2016) claims that models with gradual portfolio adjustment cannot account for the predictability reversal.

- Engel conjectures gradual catching up with UIP exchange rate:
  \[
  q_t - q_t^{IP} = \delta \left( q_{t-1} - q_{t-1}^{IP} \right) + \mu \varepsilon_t
  \]
  with $\delta$ between 0 and 1, $\mu$ negative and $\varepsilon_t$ the interest rate shock

- This would imply that the sum of expected excess future returns on the Foreign currency will remain positive indefinitely: no sign reversal

- But the conjecture is incorrect: initially $q_t < q_t^{IP}$ as a result of the weak initial portfolio adjustment, but not long after that $q_t > q_t^{IP}$: change in sign
Sign Reversal Predictability Coefficients $\beta_k$

A Impulse Response $q_t$ and $q_t^{IP}$ (percent, $\psi=15, \gamma=50$)

B Coefficients $\beta_k$ ($\psi=15, \gamma=50$)