Identifying Bubbles in Latin American Equity Markets: Phillips-Perron-based Tests and Linkages

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   - Detection of Bubbles
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   - Links between Bubbles across Equity Markets

5 Conclusion
Identification of Financial Bubbles

- Identification of financial bubbles can be critical:
  - The most recent financial crisis originated from a real estate prices bubble.
  - Dot-com bubble had effects on economic growth, employment, and the financial system.
  - A timely identification can provide a window for policies.
  - Particularly important in emerging economies that might be more fragile.
  - Contagion might be present.

- Focus on Latin American emerging markets:
  - Developing markets have increased their share in global GDP from 40% in 2000 to 49% in 2010.
  - LA has shown steady growth in the sizes of its equity markets in the last two decades.
Existence of Bubbles and Monetary Policy

- Eugene Fama and Robert Shiller on bubbles.
  - Fama: I don’t even know what a bubble means (The New Yorker, 2010)

- Alan Greenspan, Ben Bernarke and Nouriel Roubini on monetary policy and bubbles.
  - Greenspan and Bernarke: Various arguments against the use of monetary policy to target asset prices.
  - Roubini: Central banks should react to bubbles.
    - Optimal monetary policy rules imply targeting of asset prices.
    - Monetary policy should react to asset prices even under uncertainty on the existence of bubbles.
    - Monetary authorities should attempt to carefully ‘prick’ a bubble.
    - It is inconsistent to have monetary policy that reacts to bursting bubbles but not rising bubbles.
Detection of Bubbles

- Tests for bubble premiums (Hardouvelis, 1988; Rappoport and White, 1993).
- Tests for the cointegration of dividends and prices (Diba and Grossman, 1988).
- Duration dependence test (McQueen and Thorley, 1994).
- Parametric fits and non-parametric log-frequency analysis (Johansen and Sornette, 2001).
- As structural breaks (Escobari, Damianov and Bello, 2015).
- Recursive procedures (Phillips, Shi and and Yu, 2015).
Contribution

- Employ the recently developed methods of Phillips, Wu and Yu (2011) and Phillips, Shi and and Yu (2015)—real time bubble detection.
- Identify the beginning and end of bubble periods in six Latin American equity markets.
- PWY and PSY are based on the $ADF$ tests. Propose a similar recursive procedure based on $PP$ (uses an heterocedasticity- and autocorrelation-consistent covariance matrix).
- Estimate a DCC GARCH model to study the links between bubbles.
- Strong evidence of bubbles for Brazil, Chile, Colombia, Mexico, and Peru. No evidence for Argentina.
- The findings are consistent between the $ADF$-based and the $PP$-based tests.
- Clear overlap of bubbles across markets.
- Bubbles for Chile, Colombia and Peru match the months leading up to MILA in May 2011.
14 years with monthly observations from July 2000 through June 2014.
Inflation-adjusted stock indices for Argentina, Brazil, Chile, Colombia, Mexico, Peru, and the S&P 500.

Figure: Time series graphs for Brazil and Chile
The PWY and PSY methods as well as our proposed tests identify explosive behavior.

Explosive behavior is not necessarily empirical evidence of bubbles.

Let $B_t$ denote the bubble, i.e., $B_t = P_t - P_t^f$.

Asset pricing equation for the market fundamentals:

$$P_t^f = \sum_{i=0}^{\infty} \left( \frac{1}{1 + r_f} \right)^i E_t(D_{t+i} + U_{t+i})$$

- $D_t$: Dividend, $r_f$: Risk-free interest rate, $U_t$: Unobserved market fundamentals.
- If bubbles satisfy the property $E_t(B_{t+1}) = (1 + r_f)B_t$, then in the presence of bubbles $P_t$ will be explosive.
- If $D_t$ is $I(1)$ and $U_t$ is at most $I(1)$, then explosive behavior in $P_t$ can be interpreted as bubbles.
Identifying Explosive Behavior

Begin with the following Augmented Dickey-Fuller structure:

\[ \Delta P_t = \alpha_{r_1,r_2} + \beta_{r_1,r_2} P_{t-1} + \sum_{i=1}^{k} y^i_{r_1,r_2} \Delta P_{t-i} + \epsilon_t, \]

where \( \epsilon \sim iid N(0, \sigma^2_{r_1,r_2}) \), and \( r_1 \) and \( r_2 \) denote fractions of the total sample size.

We are interested in the following test statistic:

\[ ADF_{r_1}^{r_2} = \frac{\hat{\beta}_{r_1,r_2}}{\text{s.e.}(\hat{\beta}_{r_1,r_2})}. \]
Single Episodes of Explosive Behavior

PWY propose using the following (forward recursive) Supremum $ADF$ statistic:

$$SADF(r_0) = \sup_{r_2 \in [r_0,1]} ADF^r_0.$$ 

There is explosive behavior when the $SADF$ statistic is greater than the right tailed critical values.

The limit distribution of the $SADF$ statistic given by:

$$\sup_{r_2 \in [r_0,1]} \frac{\int_0^1 WdW}{\int_0^1 W^2}.$$ 

The null hypothesis is that there are no explosive versus the alternative of explosive behavior.
Multiple Episodes of Explosive Behavior

PSY propose using the following (double recursive) Generalized SADF statistic:

$$GSADF(r_0) = \sup_{r_2 \in [r_0, 1]} \sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_2}^{r_1}.$$  

There is explosive behavior when the SADF statistic is greater than the right tailed critical values.

Once we identify that a series has an explosive behavior, we use a backward sup ADF (BSADF) series to identify the windows where this price exuberance exists. The BSADF statistic is defined as:

$$BSADF_{r_2}(r_0) = \sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_2}^{r_1}.$$
The beginning and the end of bubble periods are given by:

\[
\hat{r}_e = \inf_{r_2 \in [r_0, 1]} \left\{ r_2 : BSADF_{r_2}(r_0) > scv_{r_2}^\alpha \right\}
\]

and

\[
\hat{r}_f = \inf_{r_2 \in [\hat{r}_e + 1/T, 1]} \left\{ r_2 : BSADF_{r_2}(r_0) < scv_{r_2}^\alpha \right\}
\]

where \( scv_{r_2}^\alpha \) denotes the \( 100(1 - \alpha)\% \) critical value of the SADF statistic based on \( \lfloor r_2 T \rfloor \).
Phillips-Perron-based Tests

Phillips-Perron (PP) can be viewed as an ADF that is robust to serial correlation by using the Newey-West heteroscedasticity- and autocorrelation-consistent covariance matrix estimator. We use the following PP statistic:

$$PP^{r_2}_{r_1} = \sqrt{\frac{\hat{\gamma}_{0,T}}{\hat{\lambda}^2_T}} \frac{\hat{\beta}_{r_1,r_2}}{\text{s.e.}(\hat{\beta}_{r_1,r_2})} - \frac{1}{2} \left( \frac{\hat{\lambda}^2_T - \hat{\gamma}_{0,T}}{\hat{\lambda}_T} \right) \frac{1}{\text{s.e.}(\hat{\beta}_{r_1,r_2})}$$

That has the corresponding SPP, GSPP, and BSPP statistics:

$$SPP(r_0) = \sup_{r_2 \in [r_0,1]} PP^{r_2}_{0}, \quad GSPP(r_0) = \sup_{r_2 \in [r_0,1]} PP^{r_2}_{r_1}, \quad BSPP_{r_2}(r_0) = \sup_{r_1 \in [0,r_2-r_0]} PP^{r_2}_{r_1}$$

The limit distributions of each test are calculated via Monte Carlo simulations.
### ADF-based and PP-based Test Statistics

<table>
<thead>
<tr>
<th></th>
<th>(1) Supremum</th>
<th>(2) Generalized Supremum</th>
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<tbody>
<tr>
<td></td>
<td>SADF</td>
<td>SPP</td>
</tr>
<tr>
<td>Argentina</td>
<td>0.198</td>
<td>0.762</td>
</tr>
<tr>
<td>Brazil</td>
<td>3.447*</td>
<td>3.778*</td>
</tr>
<tr>
<td>Chile</td>
<td>2.608*</td>
<td>3.675*</td>
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<tr>
<td>Colombia</td>
<td>11.334*</td>
<td>10.480*</td>
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<tr>
<td>Mexico</td>
<td>3.398*</td>
<td>3.530*</td>
</tr>
<tr>
<td>S&amp;P 500</td>
<td>0.521</td>
<td>0.752</td>
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### Panel B. Finite Sample Critical Values:

<table>
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<th></th>
<th>90%</th>
<th>95%</th>
<th>99%</th>
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<td></td>
<td>0.934</td>
<td>1.243</td>
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<td></td>
<td>1.540</td>
<td>1.882</td>
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</table>

Notes: The SADF and GSADF statistics follow PWY and PSY, while the SPP and GSPP are proposed in this article. The 95% critical values based on Monte Carlo simulations with 2,000 replications (sample size 156). * significant at 1%; † significant at 5%; ‡ significant at 10%.
GSADF Defined Bubble Periods

Figure: Time series graphs for Brazil and Chile

- Bubbles prior to the 2007 financial crisis.
- Brazil, no bubble around 2008.
**GSADF and GSPP Results for Mexico**

**Figure:** *GSADF and GSPP Results for Mexico*

- Implosion in March, 2009.
Bubbles prior to the 2007-2009 financial crisis are evident in all markets.
Common macroeconomic shocks across these countries.
Integrated Latin American Market (MILA).
## Testing for the Existence of Bubble Periods

### GSADF and GSPP Results

### Links between Bubbles across Equity Markets

### Table: Unconditional Correlations

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
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<tbody>
<tr>
<td>Brazil</td>
<td>0.902</td>
<td>0.788</td>
<td>0.972</td>
<td>0.899</td>
<td>0.957</td>
</tr>
<tr>
<td>Chile</td>
<td>0.499</td>
<td>1.000</td>
<td>0.648</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>0.577</td>
<td>0.583</td>
<td>0.708</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>0.811</td>
<td>0.541</td>
<td>0.673</td>
<td>0.436</td>
<td>1.000</td>
</tr>
<tr>
<td>Peru</td>
<td>0.282</td>
<td>0.541</td>
<td>0.673</td>
<td>0.436</td>
<td>1.000</td>
</tr>
</tbody>
</table>

### Notes:
- In Panel A, the correlation is between the BSADF and the BSPP sequences.
- In Panel B, bubble periods as defined by the GSADF at the 95% critical level.

- Some evidence of links between bubbles across equity markets.
Dynamic Conditional Correlation Model

Model the following mean equation:

\[ BU_t = \delta_0 + \delta_1 BU_{t}^{S&P500} + \varepsilon_t. \]

where \( BU_t = (BU_{t}^{Bra}, BU_{t}^{Chi}, BU_{t}^{Col}, BU_{t}^{Per}, BU_{t}^{Mex})' \),
\( \varepsilon_t = (\varepsilon_{t}^{Bra}, \varepsilon_{t}^{Chi}, \varepsilon_{t}^{Col}, \varepsilon_{t}^{Per}, \varepsilon_{t}^{Mex})' \), and \( \varepsilon_t | \Omega_{t-1} \sim N(0, H_t) \).

We model the time-variation of the variance-covariance matrix \( H_t \):

\[ H_t = G_t C_t G_t, \]

where \( G_t \) is a \((5 \times 5)\) diagonal matrix, and \( C_t \) is the \((5 \times 5)\) correlation matrix of interest.

The elements of \( G_t \) are \( \sqrt{g_{it}} \), with \( i = (\text{Bra}, \text{Chi}, \text{Col}, \text{Per}, \text{Mex}) \).
Engle (2002) suggest a two stage approach to estimate $H_t$:

1. Estimate $\sqrt{g_t^i}$ by fitting univariate volatility models.
2. Transform the residuals from the first stage using $u_t^i = \varepsilon_t^i / \sqrt{g_t^i}$, to use them when estimating the DCC.

The evolution of the correlations follows:

$$Q_t = (1 - \theta_1 - \theta_2) \bar{Q} + \theta_1 u_{t-1} u'_{t-1} + \theta_2 Q_{t-1},$$

where $\bar{Q} = E[u_t u'_t]$ is the unconditional variance-covariance matrix of $u_t$, and $Q_t$ is the time-varying conditional variance-covariance matrix of $u_t$.

To make sure $C_t$ contains ones in the main diagonal:

$$C_t = \text{diag}\left(\frac{1}{\sqrt{q_t^{\text{Bra}}}}, \cdots, \frac{1}{\sqrt{q_t^{\text{Mex}}}}\right) Q_t \text{diag}\left(\frac{1}{\sqrt{q_t^{\text{Bra}}}}, \cdots, \frac{1}{\sqrt{q_t^{\text{Mex}}}}\right),$$

where $q_t^i$ for $i = (\text{Bra, Chi, Col, Per, Mex})$ are the main diagonal elements of $Q_t$. 
### Dynamic Conditional Correlation Model Estimates

<table>
<thead>
<tr>
<th></th>
<th>(1) Brazil</th>
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<th>(4) Peru</th>
<th>(5) Mexico</th>
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<tr>
<td><strong>Panel A. Mean Equations:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$\delta_0$</td>
<td>0.0440*</td>
<td>0.161*</td>
<td>0.185*</td>
<td>0.0908‡</td>
<td>0.158*</td>
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<tr>
<td></td>
<td>(0.0109)</td>
<td>(0.0526)</td>
<td>(0.0505)</td>
<td>(0.0379)</td>
<td>(0.0582)</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>-0.0399</td>
<td>-0.135*</td>
<td>-0.148*</td>
<td>-0.0669</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>(0.0510)</td>
<td>(0.0789)</td>
<td>(0.0864)</td>
<td>(0.0591)</td>
<td>(0.113)</td>
</tr>
<tr>
<td><strong>Panel B. Variance Equations:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$c$</td>
<td>0.00364*</td>
<td>0.0606*</td>
<td>0.141*</td>
<td>0.0202*</td>
<td>0.0288‡</td>
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<tr>
<td></td>
<td>(0.000805)</td>
<td>(0.0192)</td>
<td>(0.0417)</td>
<td>(0.00539)</td>
<td>(0.0120)</td>
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<tr>
<td>$a$</td>
<td>0.500*</td>
<td>0.592*</td>
<td>0.890*</td>
<td>0.554*</td>
<td>0.256*</td>
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<tr>
<td></td>
<td>(0.110)</td>
<td>(0.150)</td>
<td>(0.192)</td>
<td>(0.112)</td>
<td>(0.0739)</td>
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<tr>
<td>$b$</td>
<td>0.578*</td>
<td>0.337‡</td>
<td>-0.0540</td>
<td>0.543*</td>
<td>0.728*</td>
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<tr>
<td></td>
<td>(0.0416)</td>
<td>(0.135)</td>
<td>(0.128)</td>
<td>(0.0532)</td>
<td>(0.0658)</td>
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<td><strong>Panel C. Multivariate DCC Equation:</strong></td>
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<tr>
<td>$\theta_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.494*</td>
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<td></td>
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<td></td>
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<td>(0.0570)</td>
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<tr>
<td>$\theta_2$</td>
<td></td>
<td></td>
<td></td>
<td>0.141*</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.0444)</td>
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<td>Observations</td>
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<td>156</td>
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<tr>
<td>$\chi^2$</td>
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<tr>
<td>$\chi^2$ (p-value)</td>
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<td>0.00559</td>
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Notes: The figures in parentheses are standard errors. * significant at 1%; † significant at 5%; ‡ significant at 10%. The mean bubble equation is: $BU_t = \delta_0 + \delta_1 BU_{S&P500} + \varepsilon_t$, with $BU_t = (BU_{Bra}^t, BU_{Chi}^t, BU_{Col}^t, BU_{Per}^t, BU_{Mex}^t')$, $\varepsilon_t = (\varepsilon_{t,Bra}, \varepsilon_{t,Chi}, \varepsilon_{t,Col}, \varepsilon_{t,Per}, \varepsilon_{t,Mex})'$, and $\varepsilon_t | \Omega_{t-1} \sim N(0, H_t)$. The variance equations: $h_i^t = c_i + a_i h_{i,t-1} + b_i (\varepsilon_{i,t-1})^2$ for $i = (Bra, Chi, Col, Per, Mex)$. 

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Identifying Bubbles in Latin American Equity Markets
Links between Bubbles across Equity Markets

Table: Unconditional and Conditional Correlations

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<th>(5) Peru</th>
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<tbody>
<tr>
<td><strong>Panel A. BSADF versus BSPP Correlations:</strong></td>
<td></td>
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<tr>
<td>ADF vs. PP</td>
<td>0.902</td>
<td>0.788</td>
<td>0.972</td>
<td>0.899</td>
<td>0.957</td>
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<tr>
<td><strong>Panel B. Unconditional Correlations:</strong></td>
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</tr>
<tr>
<td>Brazil</td>
<td>1.000</td>
<td></td>
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<tr>
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<td>0.499</td>
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<td>0.436</td>
<td>1.000</td>
</tr>
<tr>
<td><strong>Panel C. Conditional Correlations:</strong></td>
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<td></td>
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</tr>
<tr>
<td>Brazil</td>
<td>1.000</td>
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<td>Chile</td>
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<td>0.607</td>
<td>0.659</td>
<td>0.813</td>
<td>0.646</td>
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</tbody>
</table>

Notes: In Panel A, the correlation is between the BSADF and the BSPP sequences. In Panels B and C, bubble periods as defined by the GSADF at the 95% critical level. In Panel C, correlations are conditional on bubbles in the S&P 500, estimated with the methods in Engle (2002).
Strong evidence of interdependence between bubble periods across these equity markets.
Summary of Contribution

- Employ the recently developed methods of PWY (2011) and PSY (2015).
- Identify the beginning and end of bubble periods in six Latin American equity markets.
- PWY and PSY are based on the ADF test. Propose a similar recursive procedure based on PP (uses an heterocedasticity- and autocorrelation-consistent covariance matrix).
- Estimate a DCC GARCH model to study the links between bubbles.
- Strong evidence of bubbles for Brazil, Chile, Colombia, Mexico, and Peru. No evidence for Argentina.
- The findings are consistent between the ADF-based and the PP-based tests.
- Clear overlap of bubbles across markets prior to the 2007 financial crisis.
- Bubbles for Chile, Colombia and Peru match the months leading up to MILA in May 2011.
Conclusion

- *ADF*-based and *PP*-based tests coincide in 92.9% of the times when labeling bubble periods.
- Consistent across the *ADF*-based and *PP*-based tests, LA bubbles appear earlier and last longer than bubbles in the S&P 500.
- Additional research topics after identifying bubble periods, for example:
  - Regime changes.
  - Differentiated effects of monetary policy (bubble vs. no bubble).
  - More light on:
    - Should central banks respond to movements in asset prices? (Bernarke and Gertler, 2001 AER)
    - Why central banks should burst bubbles (Roubini, 2006)