

Editorial note added on May 25, 2012

The authors have noted an error and therefore made the following request:

My co-author and I, have checked our paper again and found that, due to a programming error, Tables 1 and 2 do not contain the results described in the main body of the text. We have updated Tables 1 and 2 and would be happy if you could publish the attached corrigendum.

The updating of the tables does not change the main result. We find strong evidence of causality from Greece to the other countries. We also find that evidence of reverse causality is weak.

Please see the appendix which is included in the supplemental materials like for the correction.

1. Introduction

The international comovement of equity markets is a key manifestation of the globalization of financial markets. Recent economic and financial crises, however, have led to concerns among researchers and policymakers that the international comovement of equity markets may reflect contagious international linkages of equity markets. The Greek sovereign debt crisis of 2009/2010 is the most recent financial crisis that fostered widespread fears of contagion. Keeping track of potential contagious international linkages of equity markets thus is particularly important in times of financial crisis.

While there is no consensus on how exactly contagious international linkages of equity markets should be measured (Corsetti *et al.* 2005, Forbes and Rigobon 2001), the empirical framework we lay out in this paper makes it a natural choice to define contagion in terms of significant international linkages of speculative bubbles. Speculative bubbles in our research are defined as the extent to which equity market prices stochastically deviate from their fundamentals-based values. Our perspective of contagion is, in economic terms, in line with that proposed by Bekaert *et al.* (2005) who define “contagion as excess correlation, that is, correlation over and above what one would expect from economic fundamentals.” (Page 40).

In order to study international linkages of speculative bubbles, we estimated a version of the present-discounted value model of equity valuation extended to include a rational stochastic speculative bubble (Wu 1995, 1997). We estimated the model on data for the equity markets in Greece, Portugal, Ireland, Italy, and Spain. We then studied international linkages of speculative bubbles by testing for causal links between news to speculative bubbles. Our approach to study causal links of news resembles earlier approaches in the international finance literature that use news to study international comovement of equity markets (for example, Kizys and Pierdzioch 2009).

Our research contributes to the growing literature on the Greek sovereign debt crisis. This literature has focused on the role played by deteriorating fundamentals and shifts in expectations (Arghyrou and Tsoukalas 2011), the propagation of shocks via the bond market (Tamakoshi 2011), and the possibility of international contagion via a fragile banking sector (Bolton and Jeanne 2011). We contribute to this literature by studying whether there is evidence of contagion from the Greek equity market to the equity markets in Ireland, Italy, Portugal, and Spain. Our results indicate that news to speculative bubbles in the Greek equity market caused movements in speculative bubbles in other European stock markets. We did not find evidence of reversed causality, implying that news to speculative bubbles in the Greek equity market and the equity markets of the other European countries in our sample are unlikely to reflect responses to an unobserved common factor. Our results imply that, as far as equity markets are concerned, movements in speculative bubbles in the Greek equity market may in fact have the potential to spread in a contagious way to other European countries with high levels of sovereign debt.

We organize the remainder of this paper as follows. In Section 2, we describe the model that we used to estimate speculative bubbles. In Section 3, we summarize our empirical results. In Section 4, we offer some concluding remarks.

2. Speculative Bubbles in Equity Markets

Modeling speculative bubbles in equity markets is a delicate and controversial task. In the earlier literature, several empirical models have been developed that render it possible to test for speculative bubbles (for a survey, see Gurkaynak 2008). We used in our empirical analysis a model suggested by Wu (1995, 1997). This model is well-established in the literature on speculative bubbles, it is easy to implement, and it provides time-series estimates of speculative bubbles, which can be used to compute news to speculative bubbles. In addition, the estimated speculative bubbles are consistent with the absence of arbitrage opportunities and with rational expectations on the side of market participants. The estimated speculative bubbles follow an asymptotically explosive process, but also feature a stochastic disturbance term. The presence of the stochastic disturbance term implies that the model can be used to measure stochastic rational speculative bubbles. In contrast to the trajectories of explosive deterministic speculative bubbles, the trajectories of stochastic rational speculative bubbles feature phases of extensive growth, occasional eruptions, and periods of collapses. Another attractive feature of the model is that it renders it possible to apply the simple textbook present-discounted value model of equity valuation to estimate speculative bubbles.

The present-discounted value model implies that the real equity price, P_t , can be expressed as the expected present value of next period's real equity price and real dividends, D_t . The model gives rise to the following valuation equation:

$$P_t = \mathbb{E}_t (P_{t+1} + D_t) / (1 + R), \quad (1)$$

where \mathbb{E}_t denotes the conditional expectations operator and R denotes the required real rate of return, assumed to be time invariant. Upon letting lowercase letters denote the natural logarithm of a variable, a loglinearized version of Equation (1) is given by (Campbell *et al.* 1997):

$$p_t = \kappa - r + \phi \mathbb{E}_t (p_{t+1}) + (1 - \phi) d_t, \quad (2)$$

where $\kappa = -\log(\phi) - (1 - \phi) \log(1/\phi - 1)$ and $\phi = 1 / (1 + \exp(\overline{d - p}))$. The term $\overline{d - p}$ denotes the steady-state log dividend-price ratio. The current real equity price thus is a weighted average of the expected next-period real equity price and real dividends, plus a constant.

The fundamental rational expectation equity price, p_t^f , can be derived upon invoking a transversality condition. Forward-iteration of Equation (2) then yields the following solution:

$$p_t^f = (\kappa - r)/(1 - \phi) + (1 - \phi)\mathbb{E}_t \sum_{j=0}^{\infty} \phi^j d_{t+j}, \quad (3)$$

The fundamental rational expectations equity price is determined in terms of the present-discounted value of the expected stream of real dividends, plus a constant. In the remainder of this paper, we use the term “fundamentals” to denote the fundamental rational expectations equity price. Fundamentals increase when expected real dividends increase, and they decrease when the required rate of return increases. For example, the recent Moody’s downgrade of the Greek credit rating (Financial Times 2011) may imply an increase in the required rate of return, giving rise to a decrease in fundamentals.

Computation of the expected future stream of real dividends is made possible by assuming an autoregressive model for the dynamics of demeaned real dividends:

$$\Delta d_t = \sum_{j=1}^n \varphi_j \Delta d_{t-j} + u_t, \quad (4)$$

where $n = 1, 2, \dots$, and the normally distributed mean-zero stochastic disturbance term, u_t , has variance σ_u^2 . We used the first-difference operator, Δ , to express the model in first differences because real equity prices and real dividends are nonstationary. Therefore, Δd_t can be interpreted as the demeaned growth rate of real dividends, and the stochastic disturbance term, u_t , can be interpreted to capture news about the growth rate of real dividends. In our empirical research, we used a parsimonious AR(2) model to capture the main elements of the dynamics of real dividends.

The actual real equity price can differ from fundamentals in case the transversality condition does not hold. If the transversality condition does not hold, a rational speculative bubble, b_t , can arise. The resulting equilibrium real equity price then can be expressed as the sum of fundamentals and the speculative bubble, $p_t = p_t^f + b_t$. This log-linear identity requires that an increase in the equity price should be matched by a commensurate increase in fundamentals, or an increase in the speculative bubble, or both. For example, when the equity price increases and, at the same time, the expected stream of real dividends remains constant, the rise in the equity price reflects a rise in the speculative bubble. The speculative bubble is consistent with rational expectations and the absence of arbitrage opportunities provided it satisfies the condition $\mathbb{E}_t b_{t+j} = (1/\phi)^j b_t$. The following standard parameterization of a stochastic rational speculative bubble satisfies this condition:

$$b_t = (1/\phi) b_{t-1} + \epsilon_t, \quad (5)$$

where $0 < \phi = 1/(1 + \exp(-\mu)) < 1$, μ denotes a parameter to be estimated, and ϵ_t

denotes a normally distributed mean-zero stochastic disturbance term with variance σ_ϵ^2 . The stochastic disturbance terms, ϵ_t and u_t are mutually independent. The stochastic disturbance term, ϵ_t , measures news to speculative bubbles generated by variables that are either unobserved or not explicitly modeled. One source of news to speculative bubbles that we shall analyze in detail in Section 3 below is the news hitting speculative bubbles in other countries. Upon inserting Equation (5) into Equation (2) and noting that the actual real equity price is the sum of fundamentals and the speculative bubble, it is straightforward to show that the speculative bubble constitutes a rational-expectations solution to the present-discounted value model.

The set of parameters to be estimated contains the autoregressive parameters in Equation (4), the autoregressive parameter that governs the dynamics of the speculative bubble, and the variances of the disturbance terms in Equations (4) and (5). The parameters can be estimated by writing the model in state-space form (for details, see Wu 1995, 1997, Bhar and Hamori 2005, Chapter 12). Kim and Nelson (2000, Chapter 3) describe how the parameters of a model written in state-space form can be estimated by means of the Kalman-filter model. We estimated this model and all other empirical models that we studied in our empirical analysis using the software R (R Development Core Team 2010).

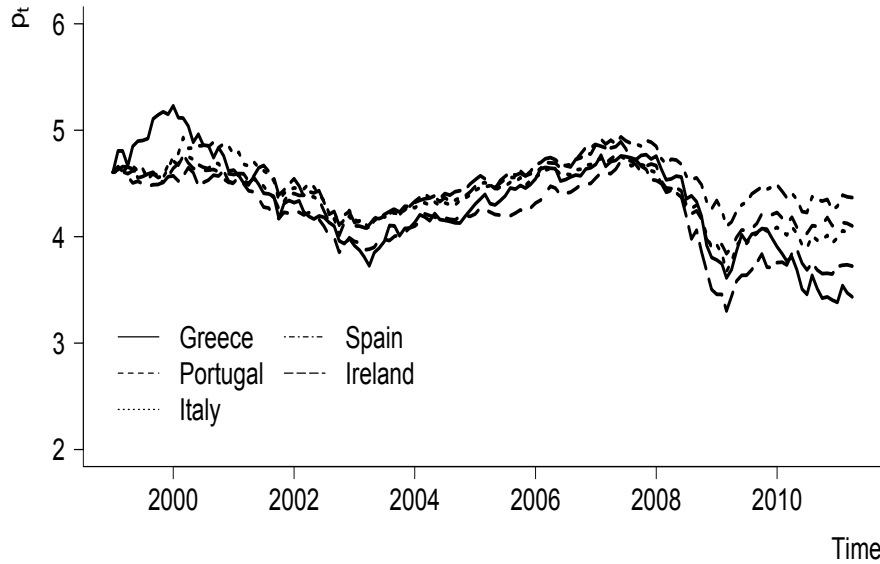
3. Empirical Results

In order to estimate the parameters of the model of speculative bubbles, we retrieved from Thompson Financial Datastream monthly data on equity market indexes and dividend yields for the sample period from 1999/1 to 2011/4. In addition to the Greek equity market, we studied the equity markets of Portugal, Ireland, Italy, and Spain. We computed dividends by multiplying the Datastream-estimated dividend yield with the lagged equity market index. We computed real equity market indexes and real dividends by using the consumer price index as a deflator. In order to make cross-country comparisons possible, we scaled the equity market indexes to assume the value 100 at the beginning of the sample period.

Figure 1 shows the equity market indexes (logarithmic scale). The equity market indexes collapsed in 2007 following the U.S. subprime mortgage crisis. It is also evident that the Greek sovereign debt crisis has had a substantial negative effect on the Greek equity market index. The Greek sovereign debt crisis, however, is less visible in the dynamics of the equity market indexes of the other countries in our sample. It is, therefore, interesting to inspect whether news to speculative bubble gave rise to contagious international linkages of the Greek and the other equity markets in our sample.

Table I summarizes the estimation results for the state-space model. The parameters of the autoregressive process that captures the dynamics of real dividends are in general statistically significant. The estimation results further show that the parameter ϕ is always close to unity, a result that is consistent with results reported in earlier literature. We

Figure 1: Equity Market Indexes



Note: This figure plots monthly real equity market indexes (logarithmic scale, 1999/1=100). Deflator: consumer price index. Datasource: Thompson Financial Datastream.

used the speculative bubbles implied by the state-space model and the estimates of the parameter ϕ to compute a series of estimated news, $\hat{\epsilon}_t$, to study contagious international linkages of speculative bubbles. It should be noted that the news have the advantage that they do not share the explosive dynamics of speculative bubbles, implying that we can use standard econometric techniques to study their international linkages.

We inspected potential causal international linkages of the news by means of tests for Granger noncausality, which require estimating vector autoregressive (VAR) models for every pair of countries. For recent applications, see Glezakos *et al.* (2007) and Gklezakou and Mylonakis (2009). The VAR models contain as endogenous variables the news to speculative bubbles. In order to assess the robustness of our results, we used one to six lags to estimate VAR models for every pair of countries. Table II (Panel A) summarizes the test results for the full sample of data. Different VAR specifications are organized in columns, and country pairs are organized in rows. The cells in the table document the p-values of the Granger noncausality tests. The boldface results indicate the optimal lag length selected according to the Schwarz Bayesian information criterion. This information criterion suggest that the optimal lag length is between 1 and 3.

The test results strongly indicate that news to speculative bubbles in the Greek equity market caused movements in the equity markets of the other countries. In contrast, there is no strong evidence of a reversed causality. News to speculative bubbles in, for example, the Spanish equity market did not cause movements in the Greek equity market. The

Table I: Estimation Results for the State-Space Model

| Row | Country | φ_1 | φ_2 | μ | ϕ | σ_u | σ_ϵ |
|-----|-----------------|-------------|-------------|-------|--------|------------|-------------------|
| 1 | Greece | | | | | | |
| 2 | Coefficient | -0.246 | -0.212 | 3.907 | 0.980 | 132.949 | 140.574 |
| 3 | p-value | 0.004 | 0.001 | 0.000 | | 0.000 | 0.000 |
| 4 | Portugal | | | | | | |
| 5 | Coefficient | -0.114 | -0.365 | 2.377 | 0.915 | 103.663 | 97.886 |
| 6 | p-value | 0.157 | 0.000 | 0.000 | | 0.000 | 0.000 |
| 7 | Italy | | | | | | |
| 8 | Coefficient | -0.168 | -0.202 | 3.659 | 0.975 | 110.476 | 111.930 |
| 9 | p-value | 0.052 | 0.001 | 0.000 | | 0.000 | 0.000 |
| 10 | Spain | | | | | | |
| 11 | Coefficient | -0.308 | -0.446 | 2.343 | 0.912 | 96.833 | 95.991 |
| 12 | p-value | 0.000 | 0.000 | 0.000 | | 0.000 | 0.000 |
| 13 | Ireland | | | | | | |
| 14 | Coefficient | -0.171 | -0.185 | 3.623 | 0.974 | 135.569 | 133.742 |
| 15 | p-value | 0.053 | 0.002 | 0.000 | | 0.000 | 0.000 |

Note: The parameters φ_1 and φ_2 denote the autoregressive parameters of the model that describes the dynamics of real (demeaned) dividends. The parameters ϕ and μ capture the dynamics of speculative bubbles. The parameter σ_u denotes the standard deviation of the error term of the model that describes the dynamics of real (demeaned) dividends. The parameter σ_ϵ denotes the standard deviation of the error term of the model that describes the dynamics of speculative bubbles.

pattern of causal linkages of news to speculative bubbles thus is unlikely to reflect responses to an unobserved common factor. As a robustness check, we dropped data for the Greek sovereign debt crisis (Table II, Panel B). Again, we found strong evidence of a causal effect of news to speculative bubbles in the Greek equity market on news to speculative bubbles in the other European countries. Interestingly, a comparison of the results in Panel A for Italy with the results in Panel B reveals that the causal effect of news to the Greek equity market on the Italian equity market may have strengthened following the Greek sovereign debt crisis (that is, from 2009/10 on). There is hardly evidence of reversed causality.

When we studied Granger causality between the equity market indexes, we found less clear-cut evidence of causality from Greek to the other countries, and in some cases evidence of reverse causality (results not reported). It, thus, is our strategy of accounting for news to speculative bubbles that allows contagious linkages of the equity markets in our sample to be recovered.

Table II: Results of Tests for Granger Noncausality (p-values)

| Panel A: Full sample | | | | | | | |
|----------------------|--------------------|-------|--------------|--------------|-------|-------|-------|
| Row | Lags | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | Greece to Portugal | 0.011 | 0.004 | 0.000 | 0.001 | 0.001 | 0.001 |
| 2 | Greece to Italy | 0.190 | 0.014 | 0.030 | 0.075 | 0.052 | 0.088 |
| 3 | Greece to Spain | 0.009 | 0.052 | 0.022 | 0.037 | 0.050 | 0.094 |
| 4 | Greece to Ireland | 0.147 | 0.108 | 0.050 | 0.044 | 0.065 | 0.074 |
| 5 | Portugal to Greece | 0.096 | 0.370 | 0.750 | 0.338 | 0.031 | 0.049 |
| 6 | Italy to Greece | 0.089 | 0.311 | 0.339 | 0.321 | 0.332 | 0.432 |
| 7 | Spain to Greece | 0.088 | 0.640 | 0.763 | 0.860 | 0.807 | 0.666 |
| 8 | Ireland to Greece | 0.667 | 0.722 | 0.814 | 0.939 | 0.455 | 0.571 |

| Panel B: Before the Greek sovereign debt crisis | | | | | | | |
|---|--------------------|--------------|-------|--------------|-------|-------|-------|
| Row | Lags | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | Greece to Portugal | 0.010 | 0.004 | 0.000 | 0.001 | 0.000 | 0.000 |
| 2 | Greece to Italy | 0.153 | 0.074 | 0.174 | 0.314 | 0.213 | 0.329 |
| 3 | Greece to Spain | 0.002 | 0.018 | 0.011 | 0.027 | 0.029 | 0.069 |
| 4 | Greece to Ireland | 0.042 | 0.031 | 0.028 | 0.058 | 0.032 | 0.057 |
| 5 | Portugal to Greece | 0.213 | 0.604 | 0.862 | 0.433 | 0.037 | 0.064 |
| 6 | Italy to Greece | 0.251 | 0.592 | 0.192 | 0.166 | 0.173 | 0.273 |
| 7 | Spain to Greece | 0.123 | 0.805 | 0.601 | 0.734 | 0.356 | 0.274 |
| 8 | Ireland to Greece | 0.667 | 0.751 | 0.866 | 0.985 | 0.172 | 0.335 |

Note: This table summarizes the p-values of tests for noncausality between the news to speculative bubbles. VAR specifications are organized in columns. Country pairs are organized in rows. The boldface p-values indicate the optimal lag length selected according to the Schwarz Bayesian information criterion. We computed the noncausality tests using the R package “lmtest” (Zeileis and Hothorn 2002) and the Schwarz Bayesian information criterion using the R package “msbvar” (Brandt 2011). The pre-crisis sample period ends in 2009/9.

4. Concluding Remarks

Our results may help to develop a better understanding of contagious international linkages of speculative bubbles in equity markets. While we have focused on the Greek sovereign debt crisis, the general modeling framework that we have laid out in this paper may be useful in future research to study contagious international linkages of speculative bubbles in countries and regions outside Europe. Our modeling framework also lends itself to other extensions, including the modeling of contemporaneous causality and causality-in-variance (see Tamakoshi 2011) between speculative bubbles. Finally, it is important to note that we have studied one specific model of speculative bubbles. Before reaching policy conclusions

from our results, it is important to analyze alternative models of speculative bubbles and investor exuberance to shed light on contagious international linkages of equity markets.

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