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Out-of-Sample Analysis of International Reserves for Emerging Economies with a Dynamic Panel Model

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Summary: Using data on 70 emerging countries for 1990-2011, we re-examine the validity of both traditional and recently proposed determinants of international reserves. The dynamic panel model considers panel unit root, endogeneity, and country heterogeneity and reveals that not only traditional determinants but also new financial variables - M2/GDP and foreign capital inflows through over-the-counter markets - have significant effects on reserves hoarding. More importantly, out-of-sample forecasts show that the dynamic model yields the best goodness-of-fit, and its predicted values successfully account for the recent patterns in reserve accumulations.

Key words: Foreign exchange reserves, Dynamic panel estimation, Out-of-sample analysis, Emerging economies, Over-the-counter markets.

JEL: C23, E44, E58, F21, F31.

This study investigates the determinants of reserves hoarding in a unified framework, using a sample of 70 emerging and developing economies from 1990 to 2011. The data clearly shows that the international reserves of many emerging and developing countries have grown persistently. However, many current studies employ static panel techniques without considering this persistent pattern of the reserves. Our study contributes to the literature by adopting various dynamic panel techniques that can correct misspecification errors in the conventional estimation methods.

Our results considering panel unit root, endogeneity, and country heterogeneity are consistent with previous findings that trade/financial openness and the terms of trade have significant effects on the reserves (Philip R. Lane and Dominic Burke 2001; Joshua Aizenman and Jaewoo Lee 2007). M2/GDP is shown to be positively associated with reserves, which indicates that financial stability motives may drive reserve hoarding (Maurice Obstfeld, Jay C. Shambaugh, and Alan M. Taylor 2010). Over-the-counter (OTC) capital inflows measured by foreign debt and foreign direct investment (FDI) inflows to GDP exhibit a positive correlation with international reserves (Kuk Mo Jung and Ju H. Pyun 2016). We also find that dynamic panel model performs best in terms of forecast accuracy. Our out-of-sample forecasts indicate that the current levels of international reserves of major emerging economies are neither in excess nor inexplicable, consistent with the studies of Yin-Wong Cheung and Hiro Ito (2009) and Obstfeld, Shambaugh, and Taylor (2010).

The remaining part of this study is organized as follows: Section 1 presents a literature review. Section 2 details the data set and model specifications. Section 3 presents the empirical results. Our concluding remarks appear in Section 4.

1. Literature Review

Since the turn of the millennium, monetary authorities in developing countries have begun to accumulate international reserves on an unprecedented scale. Over the last decade, China's international reserves alone have grown more than tenfold. Other oil-producing, emerging economies in Asia and Latin America (notably Russia) have experienced average reserve accumulation growth rates of more than 20% per year over the same period. Many scholars cite this phenomenal build-up of reserve stocks as the driving force behind many of the recent changes in the international monetary system.

Despite the importance of this phenomenon, the debate over its causes and how long it is likely to endure is ongoing. A plethora of studies have identified and tested various motives for holding international reserves. As Aizenman and Lee (2007) summarize, such motives can be broadly divided into two basic categories: precautionary and mercantilist motives. Precautionary motives reflect the desire to insure against external shock. Mercantilist motives, on the other hand, reflect the desire to promote exports or manipulate currency (see Michael Dooley, David Folkerts-Landau, and Peter Garber 2007 for a more detailed literature review on the mercantilist view. Also see Anton Korinek and Luis Servén 2016 and Woo Jin Choi and Taylor 2018 for the theoretical background for this motive). Cheung and Ito (2009) summarize various empirical studies on the effects of precautionary motives on reserve accumulation. The literature is divided on which motive has played a greater role in the accumulation of reserves. Note that some have even suggested that neither of the two motives is quantitatively consistent with the current level of reserves held by emerging economies, calling this build up a puzzle (Olivier Jeanne and RomainRanciére 2011).

Furthermore, subsequent studies propose additional determinants of reserve accumulation. For instance, Obstfeld, Shambaugh, and Taylor (2010) argue that many emerging countries rely on foreign exchange reserves as a tool for protecting domestic credit markets (i.e. the financial stability view). Their key idea, which can be traced back to Henry Thornton (1939), is that potential domestic capital outflows can place extraordinary demands on reserves. In other words, while previous studies (with precautionary views) primarily focused on external shock-driven sudden stops, they focus on domestic financial liabilities (proxied by M2/GDP), and empirically show the latter's significant and positive correlation with stocks of international reserves. Goncalo Pina (2015) offers an alternate theory, arguing that reserve accumulation can naturally follow from central bank policies while trying to smooth out inflation costs.

Jung and Pyun (2016) maintain that bilateral trading frictions in international capital markets might provide a fundamental reason behind a huge accumulation of reserves by emerging economies. Their argument is as follows. First, they point to the fact that emerging economies are in constant need of foreign investments. Thus, they always try to attract inward foreign investments through international capital markets.

Since international capital markets are inherently decentralized, the investment recipients, i.e. domestic firms, and foreign investors must trade bilaterally. In other words, FDI recipients must search for foreign investors, and after finding a match, the terms of trade are negotiated and eventually implemented by both parties.

Bilateral trade suffers from limited commitment problems, which hinders both parties from reaching an agreement on terms of trade. This is where US government bonds or international reserve assets come in as a facilitator for decentralized trade in international capital markets. In other words, reserve assets held by developing countries effectively act as a medium of exchange or as a collateral for foreign capital inflows. Then, a reduction in trading frictions in international capital markets through measures such as deregulation and technological advancement (widely observed over the last few decades worldwide) must enhance the reserve assets' value or liquidity value as a "trade facilitator". This in turn should induce (emerging) economies in need of foreign investments to accumulate the reserve asset in equilibrium. Therefore, one can intuitively predict a positive correlation between capital inflows through OTC markets (e.g. private equity funds, emerging market debts, financial FDI through mergers and acquisitions - M&A, and wholesale funding for multinational banks) and international reserves held by emerging economies, which is what this study is primarily trying to test.

Empirical studies on international reserves show that the abovementioned attributes play an important role in reserve hoardings. However, most studies employ a static panel regression approach and neglect the inertia of reserve accumulation. Notable exceptions are the studies of Diego Bastourre, Jorge Carrera, and Javier Ibarlucia (2009), Andreas Steiner (2011), and Xingwang Qian and Steiner (2014). These studies examine the determinants of the international reserves in a dynamic panel framework.

2. Empirical Methodology

2.1 Data

Data are collected from World Development Indicators (WDI), the World Bank, International Financial Statistics (IFS), the International Monetary Fund (IMF), and updated and extended versions of Lane's and Gian Maria Milesi-Ferretti's (2007) external wealth dataset (see Table 2 for the definition of sources). Based on data availability, observations from 51 emerging and developing countries (with substantial reserve holdings) for the years 1990 to 2011 are arranged in an unbalanced panel dataset. Our sample includes only developing economies because Cheung and Ito (2009) show that international reserves and their determinants are significantly different between developed and developing economies. Note that Cheung and Ito (2009) take a positive approach to examine the determinants of international reserves between developed and developing countries. In our expanded sample, we cover a broader set of up to 70 countries (by excluding external debt variable). The sample countries are listed in the Appendix, Table A1.

The dependent variable is the ratio of official international reserves to GDP. Neither sovereign wealth funds nor official gold holdings are included in the measurement of reserves. We adopt explanatory variables, which are widely regarded as important determinants of international reserves (Aizenman and Lee 2007; Cheung and Ito 2009; Obstfeld, Shambaugh, and Taylor 2010; Steiner 2011). Table A2 in the Appendix summarizes the construction and sources of the explanatory variables. We include trade openness. According to Lane and Burke (2001), the reserves are financing option of last resort in covering import demand, so trade openness would be positively associated with the reserves. Crisis, exchange volatility, financial openness, and external debt variables may also capture precautionary motives. The terms of trade generate wealth shocks (especially for commodity trade), so the reserves are likely to be used to buffer those shocks (precautionary motive). In addition, the terms of trade can be considered as a proxy for mercantilist motive because emerging market policy makers would increase reserves in response to currency appreciation, driven by the improvement in terms of trade (see Aizenman and Lee 2007 for more mercantilist variables such as the export growth rate and real exchange misalignment). Note that Aizenman and Lee (2007) show that the precautionary motives tend to dominate over mercantilist motives, and most discussions in the literature focus on the former's effects on the management of reserves.

Since OTC foreign capital inflow is a new variable in the literature, no other benchmark variables exist. Furthermore, to the best of our knowledge, no aggregate data on these flows is available for emerging economies. Note that a few online databases, such as Hedge Fund Research (HFR), the Trading Advisor Selection System (TASS), and the Center for International Securities and Derivatives Markets (CISDM) provide data for hedge fund inflows by country. Additionally, the Emerging Market Private Equity Association (EMPEA) provides one of the most comprehensive datasets on private equity funds invested in emerging markets. However, not all this data is available to the public, let alone a dimension of the panel, which is narrow. For this reason, we must rely on indirect measures gathered from IFS. First, we exploit the fact that most emerging market debts are traded in OTC markets (Darrell Duffie, Nicolae Gârleanu, and Lasse Heje Pedersen 2005). As such, foreign debt liability flows are chosen as our baseline proxy for OTC foreign capital inflows. Furthermore, as FDI inflows into developing countries have increasingly been in the form of M&A (especially in financial FDI activities; Linda S. Goldberg 2007), and since a substantial portion of M&A activities are transacted outside the centralized market clearing system (e.g. the stock exchange), we choose to add FDI liabilities to the debt liabilities in order to calculate OTC foreign capital inflows. We admit that this methodology may produce measurement errors as the IFS does not offer segregated data on portfolio debt or FDI in terms of trading characteristics. Consequently, this limitation in the data forces us to conduct our study with the second-best measure. However, we can partially reduce any measurement errors by controlling for country fixed effects.

2.2 Empirical Specification

To examine the determinants of reserves to GDP, we introduce a dynamic specification because international reserves exhibit a high degree of autocorrelation in most countries.

$$y_{i,t} = \lambda\, y_{i,t-1} + X'_{i,t}\beta + \eta_i + \phi_t + \varepsilon_{i,t}, \tag{1}$$

where the subscripts i and t represent specific countries and time periods, respectively. $y_{i,t}$ is the ratio of official international reserves to GDP. We add the lagged dependent variable, $y_{i,t-1}$, as one of the regressors. $X_{i,t}$ represents a vector of explanatory variables (as described in the previous section) and η_i captures unobserved and time-invariant country-specific effects. This regression equation also includes a time dummy, ϕ_t, to control for the common effect of specific years (such as those with a global financial crisis). $\varepsilon_{i,t}$ is the error term. The coefficient β measures the impact of the regressors, $X_{i,t}$, on reserves at t.

We first conduct country fixed effects (henceforth FE) estimation to control for country heterogeneity because η_i can be correlated with $\varepsilon_{i,t}$. However, FE estimates may be biased due to the lagged dependent variable, $y_{i,t-1}$. For instance, the first difference of Equation (1) will eliminate the country-specific effects, η_i, and generate the following Equation (2):

$$y_{i,t} - y_{i,t-1} = \lambda(y_{i,t-1} - y_{i,t-2}) + (X'_{i,t} - X'_{i,t-1})\beta + (\varepsilon_{i,t} - \varepsilon_{i,t-1}). \quad (2)$$

The first-differencing process creates a correlation between $(y_{i,t-1} - y_{i,t-2})$ and $(\varepsilon_{i,t} - \varepsilon_{i,t-1})$ and causes a "Nickell" bias in the estimation of λ (Stephen Nickell 1981). To address this bias, we use Manuel Arellano's and Stephen Bond's (1991) difference-generalized method of moments (GMM). Arellano and Bond (1991) suggest a correction method that uses instruments to control for endogeneity (i.e. the correlation between $(y_{i,t-1} - y_{i,t-2})$ and $(\varepsilon_{i,t} - \varepsilon_{i,t-1})$) by specifying that all dependent variable lags (from $y_{i,t-2}$ to $y_{i,1}$) and the first-differences of the other regressors can be used as instruments. In this estimation, it is assumed that all the explanatory variables are strictly exogenous, that is, all their leads and lags are uncorrelated with the error term, $\varepsilon_{i,t}$. But when the set of explanatory variables (X) are weakly exogenous, the following moment conditions hold: $E[y_{i,t-k}(\varepsilon_{i,t} - \varepsilon_{i,t-1})] = 0$ for $k \geq 2$; $t = 3,\ldots, T$, and $E[X_{i,t-k}(\varepsilon_{i,t} - \varepsilon_{i,t-1})] = 0$ for $k \geq 2$; $t = 3,\ldots, T$.

However, César Alonso-Borrego and Arellano (1996) and Richard Blundell and Bond (1998) point out that the difference-GMM estimator cannot account for cross-country variations and that the regressors' lagged levels might be weak instruments for the first-differences if the regressors are persistent (close to a random walk) over time. Thus, the difference-GMM performs poorly when the past levels convey little information about future changes. To overcome this problem in the difference-GMM, we use the system-GMM estimator that combines the differences regression (2) with the levels regression (1) (Arellano and Olympia Bover 1995; Blundell and Bond 1998). Using Equation (1), level variables are instrumented with suitable lags of their own first differences. These differences are uncorrelated with the country fixed effects and error terms. The moment conditions of levels regression are $E[(y_{i,t-1} - y_{i,t-2})(\eta_{i,t} + \varepsilon_{i,t})] = 0$ and $E[(X_{i,t-1} - X_{i,t-2})(\eta_{i,t} + \varepsilon_{i,t})] = 0$.

In addition, we introduce the first-difference maximum likelihood (FDML) in dynamic panel in case of panel unit root (Chirok Han and Peter C. B. Phillips 2010). Lastly, we use the quasi-maximum likelihood (QML) estimation proposed by Kazuhiko Hayakawa and M. Hashem Pesaran (2015), which extends the transformed maximum likelihood approach for estimating the dynamic panel, in case the errors are cross-sectionally heteroskedastic.

3. Empirical Results

3.1 Panel Unit Root Tests and Cross-Sectional Independence

First, we display the descriptive statistics for the sample in Table A3 in the Appendix. The mean of reserves to GDP is 0.15 but its variations are from 0.002 to 1.083. The mean and standard deviation for other variables is reported (i.e. the mean of GDP *per capita* is 6,260 international dollars adjusted by purchasing power parity (PPP)). We report the correlations of reserves to GDP and other determinants in the last column. M2/GDP shows the highest positive correlation with the reserves to GDP (0.644) among all the variables. In addition, trade and financial openness and OTC flows also show a high positive correlation with the reserves, whereas crisis variables have a slightly negative correlation with the reserves.

Because we deal with large panels (N = 70 [or 51]; T = 22) of heterogeneous countries, we check the possibility of the panel unit root by using a test proposed by Kyung S. Im, Pesaran, and Yongcheol Shin (2003) for continuous variables in an unbalanced panel, as in our case. The baseline panel unit root test includes a time trend and allows for up to 3-year lags. One may argue that Im, Pesaran, and Shin (IPS) (2003) test has little power if a deterministic trend is included. To address this issue, we conduct Im, Pesaran, and Shin (2003) panel unit root test without a time trend as well. Additionally, we conduct a Fisher type panel unit root test to check robustness.

Table 1 shows the results of the panel unit root tests. The results of IPS test with a time trend show that for all variables including reserves to GDP, the null hypothesis that all panels contain a unit-root is rejected. However, when excluding a time trend or using Fisher type test, some variables such as population (in logs) and M2/GDP cannot reject the presence of the panel unit root. Thus, to consider the panel unit root, we use FDML.

Table 1 Panel Unit-Root Tests

	H_0: All panels contain a unit root (*p*-value is reported)		
	Im, Pesaran, and Shin (2003)		Fisher type test (w/trend)
	w/trend	w/o trend	
Reserves/GDP	0.000	0.458	0.001
Population (in logs)	0.000	1.000	0.921
GDP *per capita* (in logs)	0.005	1.000	0.006
Trade/GDP	0.006	0.064	0.001
Terms of trade	0.001	0.432	0.033
Financial openness (Lane, Milesi, and Ferretti 2007)	0.004	0.339	0.000
M2/GDP	0.002	0.999	0.231
Total external debt to GDP	0.007	0.006	0.000
Short-term external debt to GDP	0.000	0.001	0.000
Decentralized capital inflows/GDP	0.000	0.000	0.000

Notes: The null hypothesis of the panel unit root test is that all panels contain a unit root. All the tests include a panel mean. We allow for possible lags up to 3 years. For Fisher type unit root test, we use Phillips-Perron unit-root test. For Im, Pesaran, and Shin (2003) test, exchange rate volatility, peg, soft peg, and crisis variables fail to report the test statistics.

Source: Authors' calculations.

We conduct Pesaran's (2004) cross-sectional dependence test to check for cross sectional dependence in the panel. Pesaran's test of cross sectional independence for the error terms across panels in specification (1) does not reject the null hypothesis of cross-sectional independence (-1.553, *p*-value = 0.1204).

3.2 Comparison of Various Estimations

We begin by estimating Equation (1) with an array of variables that affect the reserves to GDP ratio. Column (1) of Table 1 shows the results with country fixed effects. As expected, the lagged reserves/GDP is significantly positive at the 1% level with a large magnitude (0.83). Since the fixed effects estimation may be biased because of the possible correlation between the lagged dependent variable and the error terms, difference-GMM estimators are presented in column (2).

As the reliability of the GMM estimator depends on the explanatory variables' lagged values are valid instruments, we conduct the weak instrument test (the null hypothesis that instruments are weak) and over-identification restriction tests (i.e. Hansen 1982 tests where failure to reject the null hypothesis gives support to the valid instruments). Note that if cross-country panel data has a longer sample period, the number of instruments tend to be greater than the number of countries. Clive G. Bowsher (2002) argues that instrument proliferation vitiates the Hansen test of over-identification and the test may implausibly return a perfect *p*-value of 1. Thus, we restrict the maximum lag on instruments to reduce the number of instruments to lower than or equal to the number of countries (see also David Roodman 2006, 2009).

In addition, for the specification test, it is necessary to check whether the error term, $\varepsilon_{i,t}$, is serially correlated; if it is not, then the first order differenced error terms ($\varepsilon_{i,t} - \varepsilon_{i,t-1}$) are expected to have serial correlation. As a result, it is expected that the second-order differenced error terms ($\varepsilon_{i,t} - \varepsilon_{i,t-2}$) will have no serial autocorrelation. So, the model is well specified if the null hypothesis of no first-order AR in the differences of the error terms is rejected and the second-order AR hypothesis is not.

Here, the difference-GMM results in column (2) present a misspecification problem. The specification tests in column (2) show that neither test is rejected at the 1% level. In addition, weak IV test shows that we cannot reject the null hypothesis.

We report the system-GMM results in columns (3). Unlike the difference-GMM case, all tests including AR specification tests, weak IV tests, and the Hansen's over identification test confirm that the model is well specified, and the instruments are valid. The estimated coefficient on the lagged dependent variable is significantly positive at the 1% level (the magnitude is 0.956). This magnitude of coefficient implies that the long-term effect of individual regressors on reserves hoarding is about 23 (1/(1-0.956)) times greater than the short-term effect. Many independent variables are found to be statistically significant in this specification: (log) GDP *per capita* and total external debt/GDP are shown to have a negative effect on reserves to GDP, while financial openness and OTC inflow are shown to have positive effects. The estimated coefficients on financial openness is positive and significant at the 5% level, indicating that countries that have more open financial markets tend to hold more reserves. This result supports Aizenman and Lee's (2007) argument that reserve accumulation is fueled by precautionary motives. The results also show that the new variable, OTC capital inflows, contributes to this trend. This is consistent with the liquidity motive argument proposed by Jung and Pyun (2016). This implies that developing economies are motivated by a desire for liquidity in their accumulation of reserves. Furthermore, the goodness-of-fit, as measured by the correlation between the actual and the predicted reserves to GDP ratios, increases to 0.949. To summarize, the results in column (3) of Table 2 suggest that the key driving forces behind the recent surge in foreign exchange reserves are precautionary motives and reserves' role as an effective form of aggregate liquidity.

Column (4) shows the results with FDML in dynamic panel. Here, the positive coefficients of trade openness and the term of trade turn out to be significant, which is consistent with Lane and Burke (2001), and Aizenman and Lee (2007). In particular, the positive effect of the terms of trade may imply that: (i) emerging market policy makers would accumulate reserves to buffer the wealth shock driven by the terms of trade change; and/or (ii) the terms of trade improvement, associated with home currency appreciation, would induce central banks to actively purchase foreign reserve assets so that the currency appreciation forces are mitigated. While the coefficient of OTC variable loses significance, that of M2/GDP is positive and gains statistical significance at the 1% level. This finding supports financial stability motive arguments made by Obstfeld, Shambaugh, and Taylor (2010).

Column (5) reports the results with QML. Note that QML fails to retrieve the results for our baseline dynamic specification (1), owing to the failure of convergence of maximum likelihood function. So, we report the estimated results available using a sub-sample from 1990 to 2006, before the global financial crisis. Overall, the results are consistent with those in column (3), particularly for the lagged reserves to GDP and OTC capital flow variables.

Table 2 Dynamic Panel Model for Reserves/GDP

Dependent variable: reserves to GDP	Fixed effects model	Difference-GMM	System-GMM	FDML: Han and Philips (2010)	QML: Hayakawa and Pesaran (2015)
	(1)	(2)	(3)	(4)	(5)
Lagged reserves/GDP	0.8349***	-0.1080	0.9559***	1.3059***	0.8155***
	(0.0508)	(0.5653)	(0.0489)	(0.1000)	(0.0791)
Population (in logs)	0.0065	-0.0778	-0.0001	-0.1096	0.0597
	(0.0307)	(0.0871)	(0.0008)	(0.0691)	(0.0666)
GDP *per capita* (in logs)	-0.0161	-0.0692	-0.0039**	-0.0677***	0.0185
	(0.0180)	(0.0471)	(0.0015)	(0.0242)	(0.0195)
Trade/GDP	0.0060	0.0343	0.0016	0.0310**	0.0172
	(0.0122)	(0.0294)	(0.0058)	(0.0125)	(0.0110)
Terms of trade	0.0153	-0.0003	0.0025	0.0176*	0.0307*
	(0.0133)	(0.0161)	(0.0066)	(0.0100)	(0.0168)

Exchange rate volatility	-0.0376	-0.0018	-0.0565	-0.0136	-0.0550
	(0.0489)	(0.0317)	(0.0486)	(0.0131)	(0.0476)
Peg	0.0019	0.0147*	-0.0028	0.0180***	-0.0074
	(0.0042)	(0.0080)	(0.0030)	(0.0057)	(0.0057)
Soft peg	0.0009	0.0043	-0.0000	0.0071*	0.0002
	(0.0042)	(0.0044)	(0.0029)	(0.0037)	(0.0031)
De facto financial openness	0.0057	0.0203	0.0032**	0.0079***	-0.0038
	(0.0039)	(0.0217)	(0.0015)	(0.0029)	(0.0043)
M2/GDP	0.0290	0.1292*	0.0163	0.1384***	0.0377
	(0.0258)	(0.0756)	(0.0101)	(0.0241)	(0.0278)
Total external debt/GDP	-0.0087	-0.0352	-0.0072**	-0.0011	0.0113
	(0.0091)	(0.0450)	(0.0034)	(0.0040)	(0.0102)
OTC capital inflows/GDP	0.0452	-0.0048	0.0577*	0.0397	0.0865*
	(0.0394)	(0.0530)	(0.0323)	(0.0260)	(0.0488)
Currency crisis	0.0169	0.0001	0.0211	0.0016	
	(0.0114)	(0.0116)	(0.0137)	(0.0051)	
Banking crisis	0.0008	-0.0098**	0.0020	-0.0064	
	(0.0050)	(0.0048)	(0.0053)	(0.0046)	
Debt crisis	-0.0022	-0.0080	-0.0036	-0.0063	
	(0.0060)	(0.0060)	(0.0079)	(0.0067)	
AR(1) test (*p*-value)		0.802	0.000		
AR(2) test (*p*-value)		0.979	0.175		
Number of instruments		41	43		
Weak IV K-test (*p*-value)		0.347	0.000		
Hansen over-id (*p*-value)		0.240	0.185		
Observations	1,309	1,235	1,309	1,325	909
Number of countries	70	70	70	70	66
Corr(y,ŷ)^2	0.955	0.167	0.949	0.954	--

Notes: Clustered robust standard errors in parentheses but column (4) reports standard errors. *, **, and *** significant at 10%, 5%, and 1%, respectively. Two-step system GMM estimators are reported. Year fixed effects are included. For QML, the sample for 1990~2007 is used. We restrict maximum instruments lags (lagged reserves to GDP ratio) to seven years and use "collapse" to avoid an excess of instruments (Roodman 2009). Sebastian Kripfganz's (2016) code is used for Hayakawa and Pesaran (2015).

Source: Authors' calculations.

3.3 Robustness of the Results

This section employs two selective estimations of the system-GMM and FDML and reinforces the robustness of our results with different sub-samples and alternative measures for external debt, financial, and trade openness. Tables 3 and 4 report the results with the system GMM and FDML, respectively. First, in Table 3 we show the results that include alternative measures of external debt to GDP (both total and short-term debt), financial openness (the Chinn-Ito index) (Menzie D. Chinn and Ito 2008), and trade openness (imports over GDP). Column (4) of Table 3 uses a different identification approach by considering not only lagged reserves to GDP but also trade openness and exchange rate volatility as endogenous variables. In column (5), we do a sub-sample regression by excluding the global financial crisis period.

The coefficients on the lagged reserves to GDP are significant and positive in all columns of Table 3. This result shows that many developing countries' international reserves grew in a highly persistent manner, thereby emphasizing the validity of a dynamic panel framework. The results in Table 3 provide empirical evidence that precautionary, financial stability, and liquidity motives drive reserve accumulation, which is consistent with previous studies. The terms of trade have positive effects on reserves to GDP in columns (1), (2) and (3). Peg dummies lower the level of reserves in column (1). Although this is contrary to our expectations, it is in accordance with the previous findings (Lane and Burke 2001; Steiner 2011). An explanation for this finding is that the precautionary motive - prevalent under flexible exchange rate systems - might be a stronger driving force than the intervention motive for the reserve accumulation.

The estimated coefficients on M2/GDP are positive in all columns and significant except for column (4). Total external debt to GDP and short-term debt to GDP show positive and negative signs respectively, which is consistent with Steiner (2011), but their coefficients become insignificant. This significant positive coefficient on external debt to GDP in column (2) may support the hypothesis that reserves are considered to protect the economy from negative repercussions associated with a sudden stop of foreign capital inflow. OTC capital inflows show significant and positive signs in all columns. Lastly, the coefficients of currency crisis are significant and positive in all columns except for column (4), indicating that the precautionary motive of reserve accumulation in response to the currency crisis prevails.

Table 4 shows estimation results with FDML. Column (1) includes both total and short-term external debts. Columns (2) and (3) introduce the alternative measures of openness. Columns (4) and (5) show sub-sample regressions. Overall, the results in Table 4 are consistent with those in Table 3: financial openness, trade openness, M2/GDP, and OTC capital flows show significant and positive signs (while they lose significance in some specifications). In this FDML estimation, peg dummy becomes significantly positive in all specifications. Additionally, total external debt to GDP shows negative signs, while short-term external debt to GDP shows positive signs.

Table 3 Robustness Tests with System GMM

	Alternative debt measure	Financial openness (Chinn and Ito)	Trade openness (IM/GDP)	Alternative identification	Excluding the GFC
	(1)	(2)	(3)	(4)	(5)
Lagged reserves/GDP	0.9100***	0.9148***	0.9111***	0.9467***	0.8687***
	(0.0439)	(0.0385)	(0.0437)	(0.0479)	(0.0769)
Population (in logs)	0.0006	-0.0001	-0.0005	0.0049**	0.0003
	(0.0011)	(0.0011)	(0.0012)	(0.0021)	(0.0015)
GDP *per capita* (in logs)	-0.0046**	-0.0014	-0.0050**	-0.0019	-0.0023
	(0.0021)	(0.0022)	(0.0021)	(0.0043)	(0.0022)
Trade openness	0.0020	0.0027	-0.0129	0.0541***	0.0080
	(0.0038)	(0.0037)	(0.0086)	(0.0201)	(0.0050)

Terms of trade	0.0114*	0.0114*	0.0102*	0.0114	0.0140
	(0.0057)	(0.0062)	(0.0058)	(0.0070)	(0.0131)
Exchange rate volatility	-0.0313	-0.0508	-0.0293	-0.0633	-0.0418
	(0.0549)	(0.0617)	(0.0562)	(0.0640)	(0.0910)
Peg	-0.0067*	-0.0054	-0.0060	-0.0102	-0.0040
	(0.0038)	(0.0035)	(0.0037)	(0.0068)	(0.0054)
Soft peg	-0.0043	-0.0037	-0.0041	-0.0075**	-0.0043
	(0.0029)	(0.0029)	(0.0030)	(0.0038)	(0.0036)
Financial openness	0.0087	-0.0012	0.0096	-0.0042	0.0027
	(0.0067)	(0.0012)	(0.0066)	(0.0120)	(0.0102)
M2/GDP	0.0246**	0.0312***	0.0259**	0.0204	0.0356***
	(0.0117)	(0.0113)	(0.0115)	(0.0164)	(0.0126)
Total external debt/GDP	0.0024	0.0153**	0.0014	0.0216	0.0178
	(0.0102)	(0.0073)	(0.0103)	(0.0161)	(0.0138)
Short-term external debt/GDP	-0.0162	-0.0156	-0.0089	-0.0708	-0.0323
	(0.0160)	(0.0193)	(0.0168)	(0.0440)	(0.0300)
OTC capital inflows/GDP	0.0992**	0.1133**	0.1038**	0.0873*	0.1774*
	(0.0464)	(0.0493)	(0.0464)	(0.0487)	(0.0941)
Currency crisis	0.0234*	0.0252*	0.0234*	0.0167	0.0273**
	(0.0128)	(0.0131)	(0.0129)	(0.0110)	(0.0131)
Banking crisis	-0.0003	-0.0015	0.0000	-0.0043	0.0012
	(0.0050)	(0.0055)	(0.0050)	(0.0062)	(0.0038)
Debt crisis	-0.0036	-0.0001	-0.0037	-0.0068	-0.0072
	(0.0088)	(0.0090)	(0.0088)	(0.0079)	(0.0102)
AR(1) test in first diff. (*p*-value)	0.000	0.000	0.000	0.000	0.000
AR(2) test in first diff. (*p*-value)	0.713	0.653	0.713	0.691	0.863
Number of instruments	39	39	39	49	40
Weak IV K-test (*p*-value)	0.03	0.02	0.03	0.002	0.004
Hansen test of over ID (*p*-value)	0.846	0.859	0.847	0.636	0.173
Observations	953	939	953	953	707
Number of countries	51	51	51	51	51
Corr(y,ŷ)^2	0.925	0.926	0.925	0.912	0.912

Notes: Two-step system GMM estimators are reported. Clustered robust standard errors are in parentheses, *, **, and *** significant at 10%, 5%, and 1%, respectively. Year fixed effects are included. Column (4) considers lagged reserve to GDP, trade openness and exchange rate volatility as endogenous variables.

Source: Authors' calculations.

Table 4 Robustness Tests with FDML

	Alternative debt measure	Financial openness (Chinn and Ito)	Trade openness (IM/GDP)	Excluding the GFC	Sub-sample (East Asia, Latin America, Middle East & Africa)
	(1)	(2)	(3)	(4)	(5)
Lagged reserves/GDP	1.1423***	1.2800***	1.1900***	1.0475***	1.3613***
	(0.1031)	(0.1017)	(0.1039)	(0.1187)	(0.1310)
Population (in logs)	-0.1286	-0.0707	-0.1282	-0.0875	-0.3173
	(0.1262)	(0.0950)	(0.1072)	(0.2280)	(0.2595)
GDP *per capita* (in logs)	-0.0480*	-0.0722***	-0.0441	-0.0614*	-0.0552
	(0.0288)	(0.0273)	(0.0277)	(0.0327)	(0.0439)
Trade openness	0.0295**	0.0508***	-0.0148	0.0223	0.0496**
	(0.0143)	(0.0156)	(0.0238)	(0.0151)	(0.0218)
Terms of trade	0.0051	0.0062	0.0030	0.0213	-0.0109
	(0.0114)	(0.0121)	(0.0117)	(0.0144)	(0.0149)
Exchange rate volatility	-0.0058	-0.0102	-0.0044	-0.0061	-0.0116
	(0.0118)	(0.0127)	(0.0118)	(0.0113)	(0.0141)
Peg	0.0157***	0.0171***	0.0163***	0.0151***	0.0202***
	(0.0053)	(0.0057)	(0.0053)	(0.0049)	(0.0074)
Soft peg	0.0062*	0.0060	0.0064*	0.0063*	0.0119**
	(0.0037)	(0.0039)	(0.0037)	(0.0034)	(0.0051)
Financial openness	0.0650***	-0.0019	0.0680***	0.0559***	0.0603***
	(0.0081)	(0.0026)	(0.0080)	(0.0090)	(0.0101)
M2/GDP	0.0431	0.0893***	0.0499*	0.0045	0.0986***
	(0.0281)	(0.0279)	(0.0277)	(0.0306)	(0.0362)
Total external debt/GDP	-0.0597***	0.0065	-0.0604***	-0.0431***	-0.0645***
	(0.0133)	(0.0097)	(0.0131)	(0.0145)	(0.0172)
Short-term external debt/GDP	0.0133	0.0170	0.0035	-0.0174	0.0490
	(0.0397)	(0.0405)	(0.0391)	(0.0411)	(0.0559)
OTC capital inflows/GDP	0.0246	0.0670**	0.0367	0.0750*	0.0903*
	(0.0287)	(0.0302)	(0.0291)	(0.0386)	(0.0526)
Currency crisis	-0.0007	0.0015	-0.0006	0.0006	0.0023
	(0.0046)	(0.0050)	(0.0047)	(0.0043)	(0.0060)
Banking crisis	-0.0026	-0.0038	-0.0019	-0.0010	-0.0024
	(0.0048)	(0.0051)	(0.0048)	(0.0045)	(0.0059)
Debt crisis	-0.0014	-0.0018	-0.0021	-0.0019	-0.0041
	(0.0068)	(0.0071)	(0.0068)	(0.0063)	(0.0080)
Observations	957	957	957	702	790
Number of countries	51	51	51	51	40
R-square	0.952	0.936	0.943	0.947	0.935

Notes: Han and Phillps (2010)'s FDML is used. Standard errors are in parentheses, * significant at 10%, ** significant at 5%, *** significant at 1%. Year fixed effects are included.

Source: Authors' calculations.

3.4 Out-of-Sample Analysis

This section focuses on model fit and quantitative significance associated with the out-of-sample prediction. We estimate the pooled OLS, fixed effect, system-GMM, and FDML models with data from 1990 to 2001. The estimates are then used to forecast the reserves to GDP ratio through 2011.

Table 5 reports the root-mean-squared-errors (RMSE) of the four models' predicted values for time horizons over 2001-2011. This statistic is our principal means of comparing the prediction power of the four models:

$$RMSE = \left\{ \sum_{s=0}^{N_k - 1} \frac{\left(F(t+s+k) - A(t+s+k) \right)^2}{N_k} \right\}^{1/2}, \quad (3)$$

where the forecast begins at t = 2001, and the forecast horizon is denoted by k = 1, 3, 6, and 10. N_k is the total number of forecasts in the projection period when the actual reserves to GDP ratio $A(t)$ is known, and $F(t)$ is the forecasted value of reserves to GDP. A lower RMSE indicates that the model has fewer prediction errors. At all horizons, the system-GMM model produces the most accurate predictions with the lowest RMSE, and the FDML follows the next.

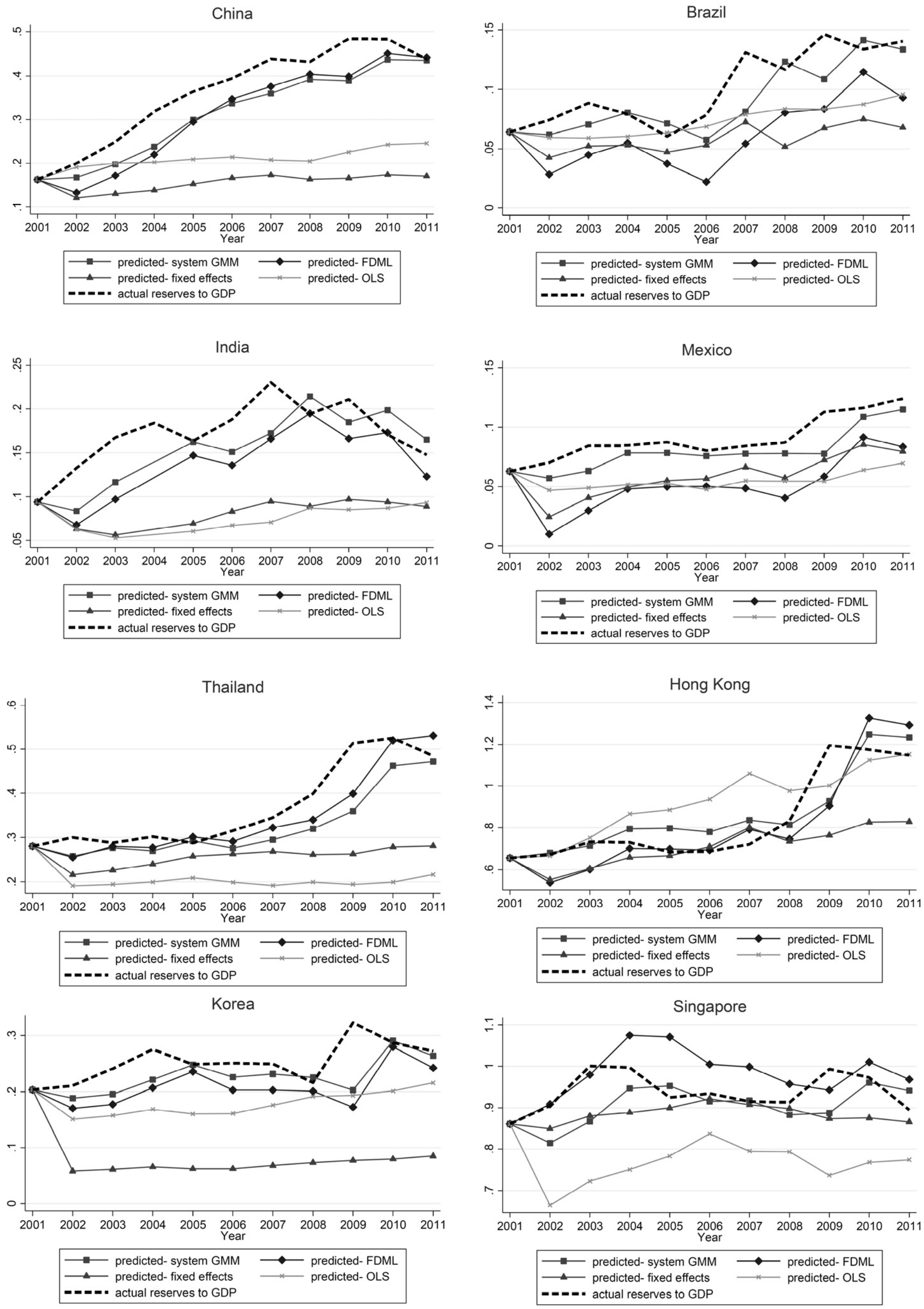
Table 5 Out-of-Sample Analysis: Comparing Four Models

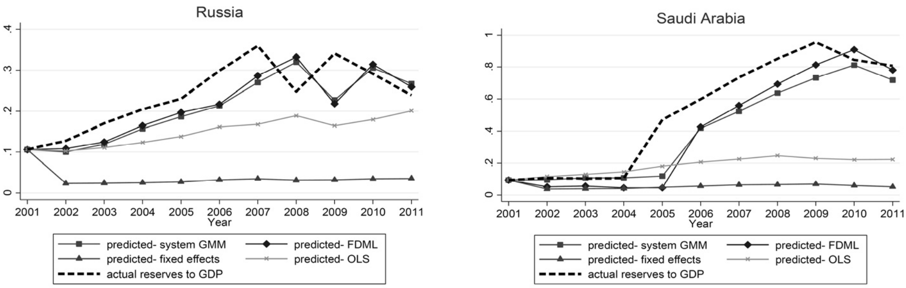
Model	RMSE (Root-Mean-Squared-Error)			
	Horizon			
	1	3	6	10
OLS	7.42	9.11	11.36	14.43
Fixed effects	6.13	7.15	8.09	9.17
Dynamic panel (S-GMM)	3.01	4.07	4.35	4.92
Dynamic panel (FDML)	5.47	5.57	5.93	6.24

Notes: RMSE are reported in terms of percentages. Forecasts are compared from 2002 to 2011.

Source: Authors' calculations.

Figure 1 compares the four models' out-of-sample predictions for a selection of 10 important reserve holders. From the graph of the actual reserves to GDP ratios against the out-of-sample predictions, one can see that the dynamic panel model's specification outperforms the other models. In fact, it not only predicts the magnitude of the ratios effectively but also predicts their movements better than the other models. It should be noted that reserve accumulation in these countries over the last decade is in no way inexplicable. In fact, the actual reserves to GDP for many countries are quite close to the values predicted by the system-GMM specification. Interestingly, China, Korea, Hong-Kong, and Singapore, who in many studies have been identified as excessive reserves hoarders, (Obstfeld, Shambaugh, and Taylor 2010; Jeanne and Ranciére 2011) are not shown to be an over-saver in 2011 according to this model's specification. Chinese and Russian reserve accumulation before the global financial crisis is still greater than what the model would predict. Yet, as Obstfeld, Shambaugh, and Taylor (2010) suggest, China's reserves holdings (the biggest in the world) may be affected by a variety of factors. Note that China may require a larger amount of international reserves to recapitalize domestic banks and many non-performing Chinese bank loans may require greater holdings as well.





Notes: Total external debt and short-term debt data in WDI are not available for Korea, Singapore, Hong Kong, Russia and Saudi Arabia. Thus, total foreign debt liability variable from Lane and Milesi-Ferretti (2007) is included to derive out-of-sample forecasts for these countries.

Source: Authors' calculations.

Figure 1 Out-of-Sample Prediction over Time: 10 Selected Countries

4. Conclusion

The phenomenal build-up of reserves in emerging economies (especially in China) has attracted considerable scrutiny. Consequently, the century old international macroeconomic theory regarding reserve determinants has been revived. Among the topics addressed in the recent literature, the question of whether the determinants of international reserves change over time has drawn considerable attention. This is because of the widely held belief that traditional determinants, such as the short-term debt to GDP ratios or trade openness, cannot explain the recent rapid accumulation of reserves. In response, many scholars have proposed a variety of new factors to explain this surge in demand (e.g. Obstfeld, Shambaugh, and Taylor 2010 and Jung and Pyun 2016).

We empirically test both new and traditional determinants of the reserves using dynamic panel model specifications. This approach allows us to dissect the dynamics of international reserves. Our results confirm that the traditional determinants specified in the previous studies and the new factors including M2/GDP and OTC foreign capital inflows significantly influence cross-country variations in the reserves. More importantly, we conduct an out-of-sample analysis to shed light on the current reserves adequacy debate. The dynamic panel specification appears to accurately predict reserve accumulation.

Our findings have important implications for the study of reserve accumulation. First, they indicate that more nuanced theories regarding precautionary motives are needed. For instance, a model of reserves demand may be developed in which the openness in financial markets does not directly determine reserve accumulation (though frictions in the financial market that react to currency crises would need to be included in this, as they would fundamentally alter the demand for reserves). Note that a growing number of studies distinguish between insurance motives of the precautionary approach, including Obstfeld, Shambaugh, and Taylor (2010). Gong Cheng (2015) shows the insurance effect of public assets (the reserves) that can mitigate private risks (private foreign liabilities), for example, through the prism of balance sheet effects. Sewon Hur and Illenin O. Kondo (2016) and Javier Bianchi, Juan Carlos Hatchondo, and Leonardo Martinez (2018) explain the accumulation of international reserves as a hedge against (liquidity) roll-over risk, because maintaining reserves allows the government to have liquid assets that are available during a financial crisis. Sang Seok Lee and Paul Luk (2018) shed light on the precautionary demand for reserves, which is driven by policy maker's model uncertainty after a financial crisis.

Both academics and policy makers may draw important implications from our findings. First, the influence of OTC foreign capital inflows on changes in reserves demonstrates that using a frictionless Walrasian model to examine recent patterns in reserve accumulation would result in a certain loss of generality. Second, international capital market risks should be considered to account for the interaction between fundamental market risk aversion and crises rather than only its interaction with variations in financial stability or openness. Lastly, our out-of-sample results imply that policy makers should carefully consider highly persistent reserves dynamics when engaging in debates over reserve adequacy or forecasting changes in reserves.

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Appendix

Table A1 List of 70 (51) Countries in the Sample

Asia (20)		
East	Singapore*	Sri Lanka
Cambodia	Thailand	
China, P.R.: Mainland	Vietnam	*Central*
China: Hong Kong*		Kazakhstan
Indonesia	*South*	Kyrgyz Republic
Korea, Rep.*	Bangladesh	Mongolia
Lao People's Dem. Rep.	India	Tajikistan
Malaysia	Nepal	
Philippines	Pakistan	
Middle East & Africa (13)		
Algeria	Morocco	
Bahrain*	Oman*	
Jordan	Saudi Arabia*	
Egypt	South Africa	
Israel*	Tunisia	
Kuwait*	Turkey	
Lebanon		
Latin America (16)		
Bolivia	Honduras	
Brazil	Mexico	
Chile	Nicaragua	
Colombia	Panama	
Costa Rica	Paraguay	
Dominican Republic	Peru	
El Salvador	Uruguay*	
Guatemala	Venezuela, Rep. Bol.	
Caucasus & Eastern Europe (21)		
Caucasus	*Eastern Europe*	Latvia*
Azerbaijan	Albania	Lithuania*
Armenia	Belarus	Macedonia
Georgia	Bosnia and Herzegovina	Moldova
Russia*	Bulgaria	Poland*
	Czech Republic*	Romania
	Croatia*	Slovak Republic*
	Estonia*	Slovenia*
	Hungary	Ukraine

Notes: * indicates countries that are included in only the 70 expanded sample.

Source: Authors' calculations.

Table A2 Definitions and Sources for Regressors

Regressors	Definitions	Sources
Population	Population (billions)	World Development Indicator (WDI)
GDP *per capita*	GDP *per capita* (PPP converted, to current international dollars, thousands)	WDI
Trade/GDP	A ratio of total trade (export + import) to GDP	WDI
Terms of trade	The terms of trade in goods and services	World Economic Outlook (WEO), IMF
Exchange rate volatility	Annual standard deviation in monthly exchange rate changes	International Financial Statistics (IFS), IMF
Peg	A pegged exchange rate dummy	Obstfeld, Shambaugh, and Taylor (2010)
Soft peg	A soft-peg exchange rate dummy	Obstfeld, Shambaugh, and Taylor (2010)

Financial openness	Lane and Milesi-Ferretti's *de facto* measure[1] and Chinn and Ito's *de jure* measure[2]	Lane and Milesi-Ferretti (2007) Chinn and Ito (2008)
M2/GDP	A ratio of M2 to GDP	WDI and the OECD economic outlook
External debt to GDP	A ratio of total external debt to GDP or debt liabilities stock to GDP	WDI and Lane and Milesi-Ferretti (2007)
Short-term debt to GDP	A ratio of short-term external debt to GDP	WDI
Decentralized capital flows	(Debt liabilities + FDI liabilities)/GDP	IFS
Currency crisis	A currency crisis dummy at *t*	Luc Laeven and Fabian Valencia (2012)
Banking crisis	A banking crisis dummy at *t*	Laeven and Valencia (2012)
Debt crisis	A debt crisis dummy at *t*	Laeven and Valencia (2012)

Source: Authors' calculations.

Table A3 Summary Statistics for 51 countries

Variables	Obs.	Mean	Standard deviation	Min.	Max.	Corr. w/ reserves/GDP
Reserves/GDP	970	0.153	0.125	0.002	1.083	1
Population (billions)	970	0.086	0.237	0.002	1.344	0.0202
GDP *per capita* (thousands)	970	6.260	4.067	0.691	22.413	0.3692
Trade/GDP	970	0.790	0.384	0.149	2.204	0.3468
Terms of trade	970	103.393	22.988	46.600	259.514	0.1915
Exchange rate volatility	970	0.027	0.089	0	1.944	-0.0895
Peg	970	0.265	0.442	0	1	0.241
Soft peg	970	0.354	0.478	0	1	-0.0684
Financial openness (Lane and Milesi-Ferretti 2007)	970	1.261	1.024	0.225	21.695	0.3362
M2/GDP	970	0.473	0.335	0.065	2.284	0.644
Total external debt to GDP	970	0.543	0.743	0.030	20.837	0.0416
Short-term external debt to GDP	970	0.079	0.170	0	4.695	0.1344
Decentralized capital inflows/GDP	970	0.042	0.055	-0.158	0.560	0.2114
Currency crisis	970	0.031	0.173	0	1	-0.0745
Banking crisis	970	0.096	0.295	0	1	-0.0471
Debt crisis	970	0.067	0.250	0	1	-0.1443

Source: Authors' calculations.

[1] **External Wealth of Nations Dataset.** 2017. http://www.philiplane.org/EWN.html (accessed january 10, 2017).
[2] **The Chinn-Ito Index**: **A de jure Measure of Financial Openness.** 2017. http://web.pdx.edu/~ito/Chinn-Ito_website.htm (accessed january 10, 2017).

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