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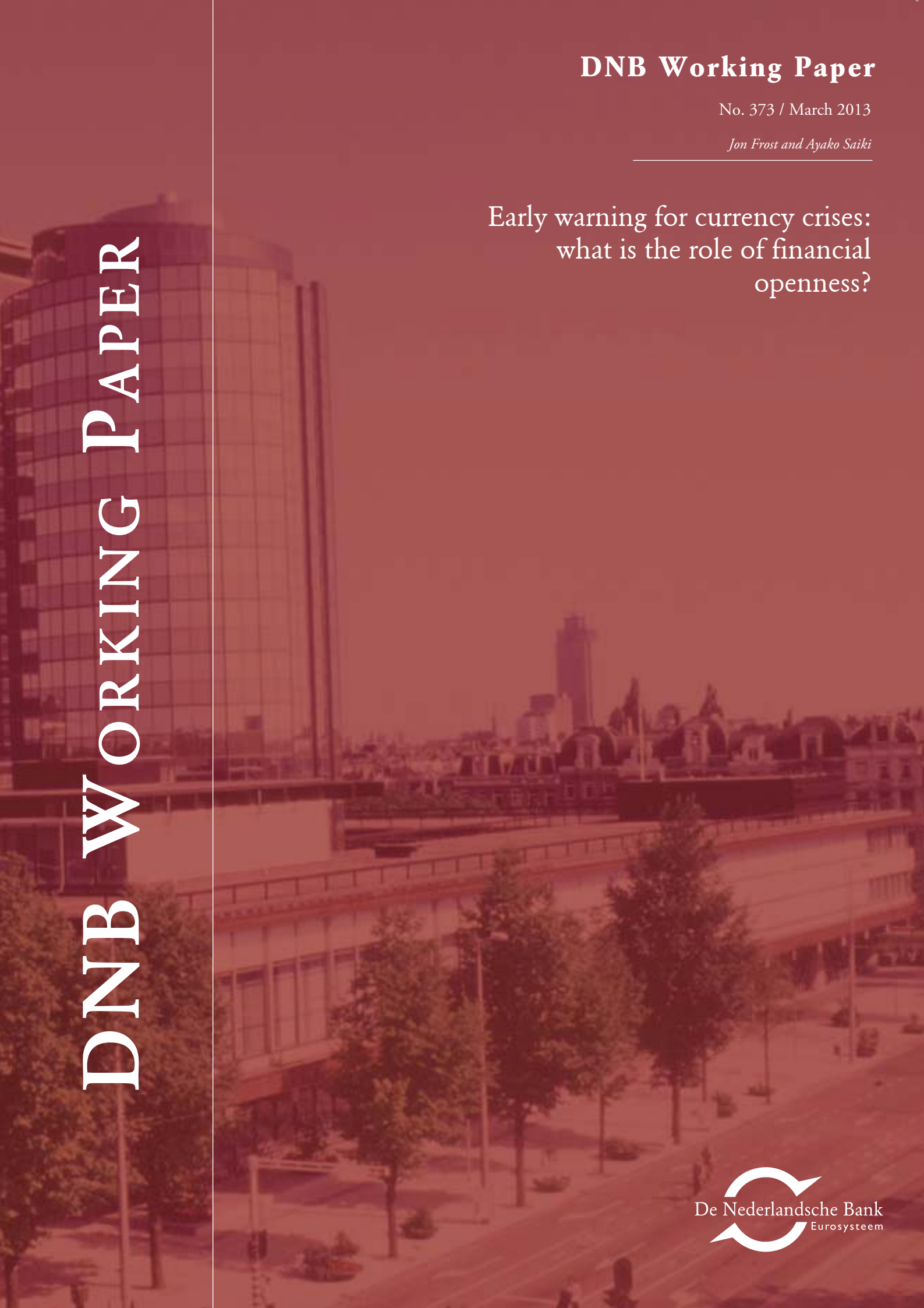

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Jon Frost and Ayako Saiki *

* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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De Nederlandsche Bank NV
P.O. Box 98
1000 AB AMSTERDAM
The Netherlands

Early warning for currency crises: what is the role of financial openness?

Jon Frost, Ayako Saiki[+]
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Abstract

We explore the role of financial openness – capital account openness and gross capital inflows – and a newly constructed gravity-based contagion index to assess the importance of these factors in the run-up to currency crises. Using a quarterly data set of 46 advanced and emerging market economies (EMEs) during the period 1975Q1-2011Q4, we estimate a multi-variable probit model including in the post-Lehman period. Our key findings are as follows. First, capital account openness is a robust indicator, reducing the probability of currency crisis for advanced economies, but less so for EMEs. Second, surges in gross (but not net) capital inflows in general increase the risk of a currency crisis, but looking at a disaggregated level, gross portfolio flows increase the risk of a currency crisis for advanced economies, whereas gross FDI inflows decrease the risk of a crisis for EMEs. Third, contagion has a very strong impact, consistent with the past literature, especially during the post-Lehman shock episode. Last, our model performs well out-of-sample, confirming that early warning models were helpful in judging relative vulnerability of countries during and since the Lehman crisis.

Keywords : Currency crisis, early warning, financial stability, capital account openness, capital flows, contagion, exchange rate regime.

JEL classification codes: F31, F32, F33, F41, G10, G15.

[+]Corresponding author: Ayako Saiki, Economist, Economic Research and Policy Division, De Nederlandsche Bank (Email: ayako@alumni.brandeis.edu), Jon Frost: Economist, Financial Stability Division, De Nederlandsche Bank.

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I. Introduction

Currency crises are both a very old and a very new challenge; they are of all times. Whereas currency crises became well-known during the emerging market crises of the 1980s and 1990s, the 2008 global financial crisis also involved a massive change in the relative value of the world's major reserve currencies, and a classic currency crisis in at least one advanced economy (Iceland). Given the weak growth outlook in advanced economies, persistent global imbalances and the wide-spread use of unconventional monetary policy, there is now renewed potential for disorderly currency movements. The European debt crisis has thrown a new wrench in the works, triggering a further round of global market volatility and sharp depreciation of a number of EME currencies in late 2011 – even as the euro largely maintained its value.

Currency crises are problematic for at least three reasons. First, they are generally the first and most visible sign of serious macroeconomic and balance of payments imbalances, often stemming from long-term macroeconomic imbalances, and are very often associated with banking and sovereign crises. Second, the sudden adjustment of relative prices often leads to significant losses on public and private balance sheets, i.e. by domestic actors with foreign currency liabilities and foreign investors with local currency assets. These losses can spread throughout the financial system, setting off a broader financial crisis. Finally, a currency crisis is typically followed by a substantial growth slow-down or a contraction. In each of these areas, there is potential for international spillovers. As the theoretical works of Krugman (1979) and Obstfeld (1994) show, currency crises can be self-fulfilling when investors begin to question the stability of a fixed exchange rate regime. Yet crises can also happen to countries with floating exchange rates or other regimes (Reinhart and Rogoff, 2004).

One weakness of EWI models is that they are often sensitive to data and model specifications, due in part to the fact that each currency crisis is unique. However, there are some variables that have turned out to be robust over time. In their meta-study, Frankel and Saravelos (2011) examine 83 contributions to the literature prior to 2008, and find that the level of reserves and movements of the exchange rate (i.e. real appreciation) in the run-up to the crisis are significant in more than half (around 60% and 50%, respectively) of the studies that they examined. Other factors, such as current account balance, money supply, external debt, etc., were significant in less than 30% of the studies. They apply these pre-2008 studies to their model, and find that including data through early 2009 significantly improves the results.

For policy-makers, EWI models are useful in the context of country risk monitoring – in which the relative vulnerability of countries is assessed and is compared with the exposures of financial

institutions. Yet they are also useful for understanding the drivers of currency crises, and thus for discussions in the international context on cooperative solutions for macro stability risks.

The purpose of this study is to find robust economic variables, qualitative and quantitative, to assess the risk of currency crisis up through the most recent period. In this, we add new variables from the more recent literature on financial openness, which we understand to comprise capital account openness (absence of capital controls) and actual financial integration defined by the level and composition of gross capital flows. We also add a newly-defined contagion variable. The remainder of this paper is structured as follows: the next session presents a theoretical overview of the literature on EWI, starting from the seminal work of Kaminsky, Lizondo and Reinhart (1998, henceforth KLR) and including the meta-study of Frankel and Saravelos (2011), from which several early warning indicators for currency stress are identified. Section III explains our model and data. Section IV presents results, while Section V offers robustness checks and out-of-sample performance. Section VI concludes =the paper with policy discussions.

II. Literature review

(a) Early warning indicators for currency crisis

The literature on EWI is vast, starting from the 1990s. It has been reviewed among others by Rose and Spiegel (2009) and Frankel and Saravelos (2011). The methodology of such models is diverse, ranging from OLS or probit models, as in Eichengreen, Rose and Wypslosz (1995) and Sachs, Tornell and Velasco (1996); to signal extraction models such as KLR (1998), Bruggeman and Linne (2000), and Edison (2003)[1]; to more sophisticated methods such as Markov switching models. Yet another strand of literature simply splits the sample into a crisis and non-crisis countries, and examines the differences in relevant variables (Kamin, 1988; Edwards, 1989; Edwards and Montiel, 1989).

The seminal works include KLR (1998) and Frankel and Rose (1996). KLR identify macro-economic variables that signal future currency crises when they cross a "critical threshold", defined by minimizing the noise-to-signal ratio. Frankel and Rose (1996) estimate a panel probit model, with economic variables chosen from widely-used economic models. Frankel and Saravelos (2011) select relevant indicators from past studies and find that, for the 2008-9 crisis, the level of reserves in 2007 appears as a consistent and statistically significant leading indicator of the current crisis, in line with the conclusions of the earlier literature. Also, long-run moves in the real effective exchange rate, domestic credit and GDP are confirmed to be statistically significant predictors of currency weakness.

[1] The literature finds these models to be moderately successful in predicting financial crises. See for instance Berg and Patillo (1999), Bussiere and Mulder (1999) and Berg, Borensztein and Patillo (2004).

(b) Controversies

Despite the huge literature and applicability for policy, EWI models remain controversial. While there is a large body of work showing good *in-sample* performance, their *out-of-sample* performance has often been questioned. For example, Obstfeld, Shambaugh and Taylor (2009) find that while countries with large reserve war chests did not depreciate – and some even appreciated – during the global financial crisis, other variables, such as current account balance and short-term debt levels were not significant predictors of depreciation. Rose and Spiegel (2009) find that most of the commonly-cited causes of the crisis to its incidence across countries could not explain the financial crisis, though they do not explicitly examine currency crisis.

These doubts do not imply that EWI are without predictive power. Berg, Borensztein and Patillo (2004) look at the performance of various long- and short-term early warning models used by the IMF in the period 1999-2004, and find that the most widely accepted long-term model (based on KLR) was superior to pure guesswork and to ratings and private analysts' currency risk scores. Moreover, EWI models are generally better at identifying relative vulnerabilities across countries than identifying the exact timing of crises. Moreover, despite these controversies, there is a renewed interest in putting EWI into policy use, most recently in the IMF-FSB (Financial Stability Board) Early Warning Exercise, called for by the G20 at the height of the crisis in November 2008 "to provide early warning of macroeconomic and financial risks and the actions needed to address them".[2]

There are various explanations for these difficulties in model performance. One potential reason is the Lucas critique, i.e. countries may have successfully taken measures to avoid crises as the warning signals for vulnerability were identified. Cumperayot and Kouwenberg (2010) show that models based on extreme events ("fat tails") may miss the slower build-up of vulnerabilities; this is particularly problematic for signal extraction models based on movements in one variable. All in all, the apparent lack of conclusive evidence or robustness of EWI could be evidence that each currency crisis is unique, and commonly used variables may not be able to fully capture the underlying cause of each crisis.

(c) Capital account openness and currency crisis

The benefits and costs of liberalizing capital markets have also spawned a large body of literature. While neoclassical theory stresses the benefits of liberalizing capital flows from the viewpoint of a more efficient allocation of capital, the empirical literature is not as compelling. Analyses suggest that the causal effect of capital account liberalization on growth has been weak, especially for the poorest countries. Because the shallow financial sectors of many EMEs cannot channel foreign investment as efficiently as those of advanced economies, the risks of liberalization

[2] http://www.g20.utoronto.ca/2009/2009communique0402.html

may outweigh the benefits. Moreover, the benefits may be primarily indirect, by promoting financial sector development and good macroeconomic policies – precisely those elements necessary to reap the benefits of open capital accounts (Kose, Prasad and Taylor, 2011). Another view is that capital account openness will necessarily attract inflows, cause exchange rate appreciation and undermine long-run growth rates, meaning "*the appropriate role of policy will be as often to stem the tide of capital flows as to encourage them*" (Rodrik and Subramanian, 2009). On the other hand, capital account liberalization has been a key feature of macroeconomic policy in most advanced economies and many post-Communist transition economies, and is part of the Treaty on the Functioning of the European Union, a number of bilateral investment treaties, and the Codes of Liberalization of the OECD (Thiel, 2003). The IMF (2012) recently adopted a new institutional view on capital account liberalization, in which the Fund recognizes that "*capital flow liberalization is generally more beneficial and less risky if countries have reached certain levels or 'thresholds' of financial and institutional development*". When countries are less financially developed, financial openness can be disruptive and some capital controls may be warranted. More developed countries may see larger benefits of openness. In this context, it is of interest to test how and if capital account openness affects the likelihood of currency crisis.

(d) Gross vs. net capital flows

Another aspect of openness is the actual developments in financial transactions with the rest of the world. Previous studies have looked mainly at net capital flows which, by netting the inflow of investment by foreigners and outflow of investment by residents, represent the (change in) external indebtedness of the country. Although abrupt changes in capital flows are often associated with crises, EWI studies often fail to find net capital inflows to be significant. Yet recently, there has also been criticism that net capital flows may reveal little because by definition they net out the underlying changes in gross flows. Meanwhile, the importance of gross capital flows as a measure of global financing patterns has received more attention in the literature (Borio and Disyatat, 2011; Bruno and Shin, 2012; Broner, Didier, Erce and Schmukler, 2013). In the early and mid-1990s, net capital flows roughly mirrored gross inflows, but more recently, the size and volatility of gross flows have increased in line with increasing global financial integration and financial globalization. Forbes and Warnock (2011) were among the first to analyze the behavior of gross capital flows around so-called sudden-stop episodes: they find that factors outside the control of policymakers in most countries – such as changes in global risk sentiment, global growth, and contagion – create extreme capital flows. They also stress the importance of disaggregating capital flows by foreign investors (gross inflows) and domestic investors (gross outflows). Broner, Didier, Erce and Schmukler (2013) confirm the importance of disaggregation, and also find evidence that the behavior of both foreign

and domestic investors during the global financial crisis was consistent with previous crisis episodes. Against this backdrop, we include gross capital inflows and their components in our data.

(e) Contagion

There is a consensus in the literature that currency crises are contagious, and often regional. Kaminsky and Reinhart (2000) stress that it is important to differentiate a common adverse shock, such as a rise in world interest rates, from contagion; after controlling for the former, they find strong evidence of contagion. Studies of EWI incorporate the contagion channel into their models in various ways. Kaminsky and Reinhart (2000) as well as Licchetta (2011) use regional dummies which are equal to 1 when a country in the same region experiences a crisis, and 0 otherwise, and find that the regional effect is significant. Eichengreen, Rose and Wyplosz (1997) use an international trade-weighted index, which is higher when important trading partners of a country are in crisis. They find that this measure of contagion is much more significant in measuring joint shocks than similarity in macroeconomic factors.

It may be worthwhile to note that the criticism that the contagion effect itself is often loosely defined. Pesaran and Pick (2007) attempt to disentangle contagion – which they define as a largely unpredictable, higher correlation of countries during crisis times – from inter-dependence, i.e. correlations in macroeconomic variables or cross-border spillovers. They find that ignoring the endogeneity of contagion, which can run both from country A to country B and back again, can lead to overestimations of its effect. More recently, Mink and de Haan (2012) use high-frequency (daily) data to test contagion of sovereign debt crisis in the euro area. Their study highlights the importance of extracting a "pure contagion" effect after controlling for other factors such as related fundamentals, spill-overs, and a "wake-up call" factor. The results on the strength of contagion thus depend in large part on its exact definition. For the purpose of this paper, we take a broad view of contagion as an increased marginal likelihood of crisis on top of what could be predicted by macroeconomic fundamentals. Importantly, all studies agree that contagion is generally a very short-term explanatory factor, and is hence unable to provide early warning at the same time spans as other variables in the literature. In what follows, we take these differences between contagion and domestic and external "fundamentals" explicitly into account.

III. Data and model

In this paper, we present a multivariate probit model. This choice of method is based on the existing literature (Frankel and Rose, 1996; Licchetta, 2011) and on the advantage that the most effective indicators can be taken into account simultaneously – rather than one at a time, as in signal extraction models. Probit models' results, which take the form of a number between 0 and 1

("percentage chance of crisis") are easy to interpret and hence well-suited for policy purposes. Our data covers 46 advanced and emerging economies, with quarterly frequency between 1975Q1 and 2011Q4, enabling us to apply the model to the 2008-2009 crisis. –Except where otherwise mentioned, our data comes from the IMF International Financial Statistics or the BIS.

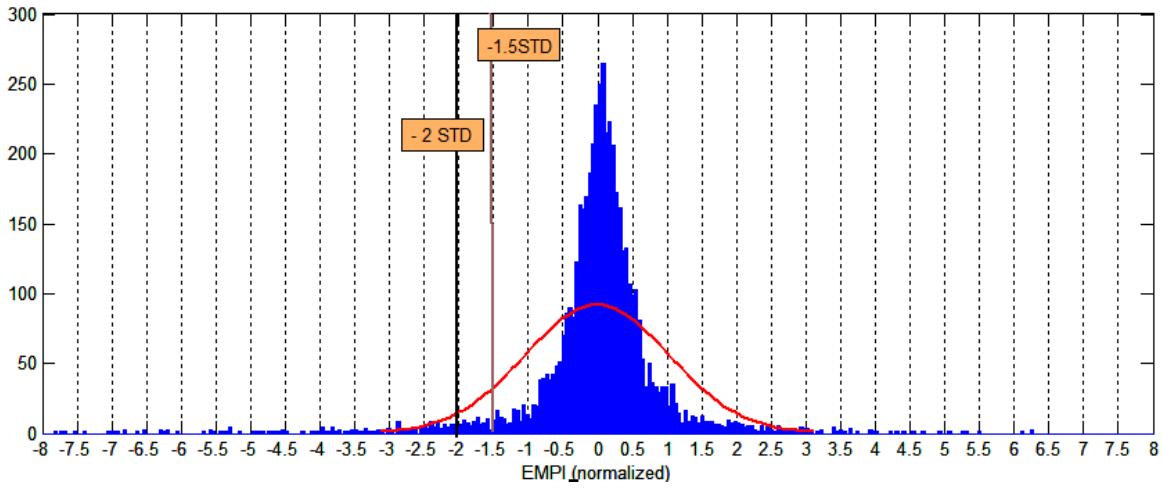
(a) Definition of dependent variable

We define currency crisis using an exchange market pressure index (EMPI), as used by Eichengreen, Rose and Wyplosz (1994) and KLR (1998). The EMPI is popular in the literature because it captures both major exchange rate depreciations (successful speculative attacks on currencies) as well as major reductions in reserves (unsuccessful attacks). While there are variations of EMPI which include other variables, such as interest rates, due to data restrictions, we define EMPI with a formula used by Arduini et al. (2011):

$$I_{i,t} = \frac{\Delta E_{i,t}}{E_{i,t-1}} - \frac{\sigma_{E,i}}{\sigma_{R,i}} \frac{\Delta R_{i,t}}{R_{i,t-1}} \qquad [1]$$

where $E_{i,t}$ is the exchange rate of the currency of country i against the dollar at time t (local currency per US dollar), $R_{i,t}$ represents a measure of international reserves (minus gold) for country i at time t, $\sigma_{E,i}$ and $\sigma_{R,I}$ are the country-specific standard deviation of the quarterly percentage change, respectively, in the exchange rate and reserves. As is clear from Figure 1 below, the EMPI variable has high kurtosis and fat tails, and the null hypothesis (H_0) that data are normally distributed is rejected at 1% level. This indicates that there are more "tranquil times" than would be expected by a normal distribution, but also more "extreme events". In addition, a large depreciation is more likely than a large appreciation. This non-normality has no problematic implications for our regression, as our explanatory variables are binary – equal to 1 when this normalized EMPI exceeds critical thresholds (-1.5 or below).

Figure 1: Distribution of EMPI values, normalized



Note: The red line denotes normal distribution. Properties of the distribution are as follows: Kurtosis=23.92, Skewness=-1.89, Test statistics for fat tails= 0.79, Test for Leptokurtosis -= -3.41.

In determining the threshold above which a crisis is counted, KLR (1998) propose three standard deviations below the mean. Following Eichengreen et al (1996), we use a minus 1.5 standard deviation threshold. This threshold captures 130 currency crisis episodes within our sample, or 2.4% of all observations ("broad definition"). As a robustness check, we also have defined crises with a 2 standard deviation threshold, yielding 88 crisis episodes (1.6% of the sample; "narrow definition"), and we obtained more or less similar results. Further, in order to avoid double-counting, we remove "recurrent" currency crises from the sample with a one-quarter exclusion window. Annex II shows a full list of crisis episodes by country. Of the 46 countries in our sample, 26 have had a crisis since 1975, including 11 advanced economies. With 20 crisis episodes in the sample period, Brazil has been the most crisis-hit country, followed by Venezuela with 13. Argentina (for which reserve data is not available prior to 1994) holds the record for deepest crisis, as measured by the EMPI, with the collapse of its currency board arrangement in 2002. Sweden and the UK have crises around the break-up of the European Monetary System (EMS) in 1992-3. After the Lehman shock, there were 13 crises in the immediate post-Lehman quarters (Q4 2008 and Q1 2009). Since then there have been deep crises in Venezuela and much milder crises in 2011 in Taiwan and Poland.

(b) Explanatory variables

For the explanatory variables, we have first selected those "basic" indicators that have had a relatively strong track record in the past literature, as compiled by Frankel and Saravelos (2011). Next, we have added our measures of financial openness: capital account openness, gross capital flows, and contagion. In parentheses is the expected sign ("+" , "-", or, when uncertain, " +/-").

External

1. **Real exchange rate deviation from 10-year average (+)**: measured by the IMF estimations of the real effective exchange rate (REER). Where the REER has risen rapidly or deviated from its long-term average, there is more likelihood of a sudden correction is larger (Goldfajn and Valdes, 1997). In line with Frank and Saravelos (2010) we have tried a rate of appreciation over a set time period (1, 2 or 5 years) and a deviation from a 5- or 10-year average, with the argument that the REER should exhibit mean reversion. We confirm that the deviation from the 10-year average has the most significant effect.
2. **Reserve adequacy (-):** defined as official reserves to short-term debt ("Greenspan-Guidotti ratio"). A ratio above 1 – i.e. reserves sufficient to cover all external debt maturing in the coming

year – is considered the minimum level of reserves for EMEs in particular. Data on short-term external debt is taken from the BIS.[3]

3. **Gross/net flows and their components (+/-):** Surges in capital inflows can make countries vulnerable, but the composition of flows also matters. Gross FDI flows could reduce vulnerability to a crisis, as this is a more stable form of financing which should remain even as external pressures build. Portfolio and other flows, meanwhile, tend to be more short-term and less stable. We divide the gross flows by a permanent component of GDP growth, de-trended using a Hodrick-Prescott (HP) filter (lambda=1600). In order to capture surges in capital inflows, we take the deviation of this ratio from its 5-year average, comparable with the methodology for the REER. As a robustness check, we compare these to net inflows, and confirm that surges in gross flows are superior to predict crisis vulnerability.

Domestic

4. **Credit growth (+):** defined as the change in total credit/GDP over 5 years. This measure relates closely with the work on early warning of credit bubbles and banking crises (c.f. Borio and Drehmann, 2009). As an alternative, we have tried the credit gap, a variable defined as the deviation of credit to GDP from a slow-moving trend, as defined by an HP filter with very long-term smoothing parameter (lambda=400,000 for quarterly data). Each appear to have explanatory power, but we use the simpler methodology of 5-year growth.
5. **Average annual GDP growth (+):** Countries with high growth rates in the recent past have sometimes been found to be more vulnerable to sudden corrections. This may reflect the build-up of asset bubbles, overheating and other variables not fully captured by the other variables[4]. We try 1-, 2- and 5-year growth, and find that the 5-year growth rate has the most significant effect.
6. **External debt growth (+):** Strong growth in external debt to GDP can be a sign of growing vulnerabilities in the balance of payments. Like the other variables, these tend to build over a long period of time, hence the use of 5-year growth.

Institutional factors

7. **EME dummy (+)**: EMEs display a number of features that may diverge from AEs, including the depth of financial markets, the level of financial development and the scale of local currency

[3] Advanced economies with floating exchange rates generally have much lower levels of reserve coverage – reflecting large financial sectors and lower levels of currency mismatch. The necessity of implementing dollar swap lines due to dollar liquidity shortages in the post-Lehman and recent crisis nevertheless show that foreign currency funding problems can also materialize in these countries.

[4] Frankel and Saravelos (2011) note that this result is somewhat counterintuitive, yet confirm that GDP growth prior to the global financial crisis is a significant predictor not only of the chance and severity of currency crises, but also the depth of recessions and recourse to IMF resources.

financing. This dummy is 1 if a country is an EME in the most recent IMF World Economic Outlook classification, which is consistent over time for each country in the sample, and 0 otherwise – even where countries have previously been defined as EMEs.

Openness and contagion

8. **Capital account openness (+/-)**: we use the financial openness index developed by Chinn and Ito (2007)[5]. This index, named "KAOPEN", is based on binary dummy variables that codify the tabulation of restrictions on cross-border financial transactions reported in the IMF's *Annual Report on Exchange Arrangements and Exchange Restrictions*. One advantage of this variable is that it combines capital restrictions with other restrictions on international financial transactions. The coverage is extensive (182 countries, between 1970 and 2010, updated annually). To attain data for 2011, we extrapolate 2010 values to the end of our sample. Where relevant to examine the specific characteristics of AEs versus EMEs, we interact the variable with our EME term. Given that the index is generally very slow-moving, it is most valuable in the cross-sectional dimension, though changes in KAOPEN, meant to capture episodes liberalization or reversal in liberalization, have also used as a robustness check.[6]
9. **Contagion indicators (+):** to measure the scale of crises in nearby countries, we construct a new gravity-weighted contagion index, which is defined as:

$$\sum_{\substack{i=1 \\ i\neq H}}^{45} \frac{D_t^i}{dist_{H,i}} * GDP_{i,t} \qquad [1]$$

where D is our dummy representing a crisis in country i at time t, *dist* denotes the Great Circle distance between the capital cities of crisis-hit "source" country i and receiving "home" country H, and GDP_s is the source country's GDP.[7] The intuition is that a country is more vulnerable to contagion-driven currency crisis when the crisis-hit source country is closer and larger.[8] As an alternative, we construct an index similar to Eichengreen, Rose and Wyplosz (1997), as:

$$\sum_{\substack{i=1 \\ i\neq H}}^{45} D_t^i * weight_{i,H} \qquad [2]$$

[5] Chinn and Ito (2008). The data is downloadable from http://web.pdx.edu/~ito/Chinn-Ito_website.htm.
[6] Most countries in the sample see either a gradual or more sudden opening of capital accounts during the sample period, yet Venezuela since 2002 and Iceland since the 2008 currency crisis are notable exceptions.
[7] We thank Prof. Jeffrey Frankel for providing the idea for this variable.
[8] An alternative model used the GDP of the source country divided by GDP of the receiving country, with the argument that larger countries should be less affected by contagion than smaller countries. The results were similar, but less significant. The same holds for regional dummies, as in Kaminsky and Reinhart (2000) and a trade-weighted index as in Eichengreen, Rose and Wyplosz (1997).

where *weight* is the trade weight for source country *i* and receiving country *H* in the NEER index, as defined by the BIS.

(c) Estimation

We estimate a multivariate probit model with random effects, which can be specified as:

$$P = P(Y = 1 | X) = P(I_i^* \leq I_i) = P(Z_i \leq \beta X) \quad [3]$$

where X is a set of explanatory variables mentioned above, and

$$F(I_i) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Ii} e^{-Z^2/2} dz \quad [4]$$

where F is the standard normal CDF, and z is the standard normal variable.

(d) Descriptive statistics of explanatory variables

Table 1 shows some key descriptive statistics of our independent variables. Reserve adequacy (Greenspan-Guidotti ratio) is expressed as a factor (where 1 corresponds to 100%), whereas other variables are often expressed as a simple change (where 0.01 is 1% growth). KAOPEN and the contagion indices are continuous variables with their own units.

In comparing the mean of variables through the whole sample and the mean measured over 4 quarters prior to and after a crisis episode, we can take a first look at the behavior of variables in the run-up to a currency crisis. Notable is that reserve adequacy is much lower 4 quarters ahead of a crisis than in the full sample. During a crisis, the average is even lower – reflecting that the crisis is often marked by a run-down in reserves – while reserve coverage recovers to some extent on average after the crisis episode. REER appreciation and the change in credit to GDP tend to be higher before a crisis, indicating their value as early warning indicators. While nominal depreciation tends to reverse real overvaluation during and after a crisis, the change in credit to GDP remains higher than average during and 4 quarters after the crisis episode, which could reflect either that credit contractions are slower than exchange rate adjustments, or the denominator effect of GDP. 5-year average GDP growth, meanwhile, is slightly lower before a crisis than in the general sample, but even lower during and after the crisis, indicating the output costs of crises, which slowly bring down the 5-year average (even as the one-year growth loss is much higher). All the components of gross capital flows are higher 4 quarters prior to a crisis than the general mean, indicating that a surge in gross capital inflows can indeed precede crisis. Consistent with other literature, portfolio inflows tend to be most volatile around the crisis episode. 5-year external debt growth is also higher 4 quarters prior to a crisis, as expected. Importantly, KAOPEN is lower prior to crises than in the general sample, meaning that in general, without considering any other factors, more closed economies have been more susceptible to crises in our sample. Our gravity-weighted contagion index, *Contagion EMPI*, is

much higher during a crisis episode than in the whole-sample average, but not 4 quarter before or after a crisis, confirming that contagion is generally a short-term ("fast-burning") phenomenon.

Table 2 describes the correlation among explanatory variables. The correlations are mostly low, with the notable exception of the components of gross capital flows – gross inflow and gross other inflow (0.83); gross inflow and gross portfolio inflow (0.65); and financial openness and the EME dummy (-0.72). However, the first two combinations will not be a problem as we will include them separately in the different regression specifications which we run. To control for the institutional determinants of financial openness and the trend that EMEs are generally less open, we explicitly distinguish between AEs and EMEs in the regressions.

Table 1: Descriptive statistics

	Entire sample					Around crisis episodes (only crisis-hit countries)		
	# of obs	Mean	Std. Dev.	Min	Max	Mean 4q before crisis	Mean during crisis	Mean 4q after crisis
Reserve adequacy (Greenspan-Guidotti ratio)	3939	**1.950**	2.550	0.000	22.382	**1.470**	**1.190**	**1.400**
REER Dev	4031	**-0.005**	0.130	-0.494	0.643	**0.069**	**-0.047**	**-0.017**
5 year change in credit	3232	**0.177**	0.354	-1.000	3.422	**0.258**	**0.346**	**0.322**
5 year average annual GDP change	4812	**0.033**	0.025	-0.142	0.119	**0.032**	**0.027**	**0.022**
Gross inflow deviation	3867	**-0.006**	0.347	-10.191	2.622	**0.050**	**-0.002**	**-0.032**
Gross FDI inflow deviation	3776	**0.003**	0.054	-0.889	1.405	**0.010**	**0.003**	**-0.003**
Gross portfolio inflow deviation	3657	**-0.007**	0.224	-6.773	1.372	**0.008**	**-0.017**	**-0.027**
Gross other flow deviation	3793	**-0.002**	0.156	-3.764	1.870	**0.033**	**0.010**	**-0.003**
5 year external debt growth	3066	**0.302**	0.808	-0.754	9.036	**0.410**	**-0.020**	**0.384**
KA open (Financial Openness)	6028	**0.771**	1.565	-1.856	2.456	**-0.520**	**-0.600**	**-0.566**
EME	6808	**0.413**	0.492	0.000	1.000	**0.738**	**0.738**	**0.729**
ContagionEMPI	3270	**0.014**	0.058	0.000	0.950	**0.007**	**0.066**	**0.004**

Table 2: Correlation among explanatory variables

	REER dev	Reserve adequacy	Gross inflow deviation	Gross portfolio deviation	Gross FDI deviation	Gross other deviation	GDP growth av 5 years	Credit growth 5 years	External debt growth 5 years	Financial openness	EME*Financial openness
REER dev	1										
Reserve adequacy	0.0141	1									
Gross inflow deviation	0.0842	0.023	1								
Gross portfolio deviation	0.0328	0.0025	0.6498	1							
Gross FDI deviation	0.0709	-0.0255	0.3312	-0.0105	1						
Gross other deviation	0.0697	0.0407	0.8344	0.2121	0.1015	1					
GDP growth avg over 5 years	0.1054	0.4197	0.2939	0.1503	0.1244	0.2643	1				
Credit growth 5 years	0.1503	-0.2689	0.0571	0.0224	0.0847	0.0333	-0.1864	1			
External debt growth 5 years	0.1151	-0.0815	0.0701	-0.017	0.091	0.0778	0.0474	0.4155	1		
Financial openness	0.0617	-0.4721	-0.0626	-0.0456	-0.0193	-0.0493	-0.4852	-0.0229	-0.1325	1	
EME	0.0313	0.4128	0.025	0.0003	0.0039	0.034	0.3066	-0.0371	0.0405	-0.7275	1.000
Contagion	0.0094	-0.0163	-0.1312	-0.1146	0.0047	-0.1066	-0.0348	0.0582	0.0536	0.0554	-0.0304

IV. Results

(a) Entire sample

This section describes our results, assessing the strength of the various indicators and their relative importance. Table 3(a), below, shows our main results. The sample is all 46 countries. Specifications (1) to (6) cover entire sample periods, while specifications (7) and (8) split the sample before and after the Lehman shock (cut-off point: 2007Q2). Notable is that many explanatory variables are significant and have the expected sign. The statistical significance of the coefficients of REER deviation from the 10-year average and reserve adequacy are strong, and those of 5-years average GDP growth and 5-year credit growth are not. These results are more or less in line with the findings of Frankel and Saravelos (2011).

We would like to highlight several points. First, regarding contagion, our initial baseline model (specification (1)) includes trade-weighted contagion index defined as Eichengreen et al (1996). It turns out to be positive and significant as expected. We then use newly-constructed gravity-based contagion index, which is also consistently positive and significant at the 1% level. These indicate the strength of contagion in a currency crisis, which is consistent with the past literature.

Second, regarding KAOPEN (capital account openness), there are three remarkable findings: (i) capital account openness (KAOPEN) is almost consistently negative and statistically significant, meaning that more open economies are less prone to exchange rate crisis; (ii) the coefficients of the cross-term of EMEs and KAOPEN are positive in each specification, indicating that for EMEs, the benefit of capital account openness in terms of reducing the probability of a currency crisis is partly offset; (iii) the fit is consistently negative through time, but statistically significant only after the Lehman shock (specification (8)), which may be an indication that openness matters more in the most recent period around the global financial crisis (the reason for this this needs further examination). While not shown here, a number of further tests have been tried, including regressing the *change* in KAOPEN, to determine whether capital account liberalization can trigger crises. The fact that the coefficients for the change in KAOPEN are not significant confirms that liberalization itself does not appear to be driving crisis vulnerability across the whole sample.[9]

Third, gross capital flows are in many cases significant and have the expected sign. The fit of the model is better with gross capital flows than net capital flows (as measured by the Chi-square statistics) in general and the coefficients of capital flows are significant only for gross flows (see Table 3(a) and Annex IV). This indicates that surges in overall gross capital flows increase the chance of a currency crisis, but not net capital flows.

[9] This does not preclude openness or liberalization having an effect on other variables in the model, such as real appreciation or credit growth, which do lead to crisis vulnerability. Moreover, the endogeneity associated with capital account liberalization is not explicitly considered here, but would be an avenue of future research.

Fourth, looking into the composition of gross capital inflows (specifications (4)-(6)) gives us another interesting insight: among gross capital flows, it is only portfolio inflows that significantly increase the probability of a currency crisis. The sign on FDI flow indicate that FDI surges reduce the probability of a currency crisis, but it is not statistically significant; later we use only EME data, and find the effect to be statistically significant.

[The results are shown in the next page]

Table 3(a): Regression results, all countries

Dependent variable: EMPI 1.5 st dev crisis dummy

All countries															
	(1)		(2)		(3)		(4)		(5)		(6)		(7) Before Q2-2007		(8) After Q2-2007	
Period+	All		All		ALL		ALL		ALL		All					
*All variables are lagged by 4 quarters, except for EME, KAOPEN, KAOPEN*EME, and contagion*																
Financial openness																
KAOPEN	-0.57	***	-0.76	***	-0.47	***	-0.76	***	-0.86	***	-0.73	***	-0.28		-1.26	***
	(0.14)		(0.19)		(0.13)		(0.18)		(0.21)		(0.18)		(0.29)		(0.42)	
KAOPEN*EME	0.26		0.38	*	0.21		0.43	**	0.50	**	0.39	**	-0.18		1.09	***
	(0.18)		(0.21)		(0.17)		(0.22)		(0.22)		(0.21)		(0.38)		(0.42)	
EME	0.19		0.27		0.25		0.18		0.30		0.24		1.04	**	-0.82	
	(0.24)		(0.28)		(0.23)		(0.27)		(0.28)		(0.28)		(0.51)		(0.57)	
Contagion																
Contagion (gravity-based)			4.06	***			4.15	***	4.50	***	3.97	***	34.43	***	4.51	***
			(0.78)				(0.81)		(0.85)		(0.77)		(9.31)		(1.08)	
Contagion (trade-weigh based)	0.13	***														
	(0.02)															
Externals																
REER (deviation from 10 yrs avg)	2.30	***	1.63	**	1.79	**	1.82	**	1.66	**	1.67	**	0.64		1.79	
	(0.79)		(0.77)		(0.72)		(0.78)		(0.78)		(0.77)		(1.18)		(1.23)	
Reserve adequacy	-0.24	***	-0.24	***	-0.22	***	-0.27	***	-0.24	***	-0.24	***	-0.45	***	-0.17	
	(0.08)		(0.09)		(0.08)		(0.09)		(0.09)		(0.09)		(0.16)		(0.14)	
External debt growth (5 years)	0.053		-0.15		-0.01		-0.13		-0.13		-0.15		-0.30		-0.11	
	(0.08)		(0.09)		(0.08)		(0.09)		(0.09)		(0.09)		(0.35)		(0.14)	
Financial																
1 year gross inflow++	1.26	**	1.21	*	1.13	*							2.04	**	-0.77	
	(0.65)		(0.69)		(0.60)								(0.96)		(1.25)	
1 year gross FDI++							-1.17									
							(2.19)									
1 year gross inflow portfolio++									3.00	**						
									(1.25)							
1 year gross inflow other++											1.57					
											(1.40)					
Domestic																
5 years GDP growth	-0.86		0.71		6.71		2.29		-0.23		1.12		15.23		3.91	
	(6.69)		(7.04)		(6.04)		(6.83)		(7.09)		(6.98)		(11.63)		(13.83)	
5 years credit growth	-0.16		0.03		-0.06		0.14		0.02		0.08		-0.18		0.12	
	(0.23)		(0.22)		(0.21)		(0.19)		(0.21)		(0.20)		(0.32)		(0.61)	
# of observations	1382		1315		1382		1306		1303		1295		683		632	
# of crisis episodes							130						112		15	
Log likelihood	-101		-93		-115		-94		-91		-93		-47		-37	
Wald chi-square	56.01		46.48		37.30		45.89		45.44		45.97		27.55		30.2	
Prob > chi2	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	

Constants are not reported, in parentheses are standard deviation

+sample period is 1975Q1 - 2011Q4, but due to missing observations, most data starts from the second half of 1980s.

++gross capital flows are measured as deviation from 5 years average

***, **, * denotes significance at 1, 5, and 10% level, respectively.

Finally, while it is not reported here, the interaction of KAOPEN and gross capital inflow is negative – indicating that the risk from the surge in gross capital inflow would be mitigated when the capital account is more open. However, since both KAOPEN and gross capital inflow are continuous variables, so the model will be prone to inferential errors. . Therefore, further analysis of these effects for different values of KAOPEN, as in the multiplicative interaction models by Brambor et al. (2006) should be employed. This would be a future extension for this research.

(b) EMEs and advanced economies

We have performed a Chow test between the two samples and we reject the null that the cross-term of all the variables and EME, including EME itself, is jointly insignificant at the 1% level. This confirms a structural difference between EMEs and advanced economies. Therefore we run separate regressions to test for any systematic difference. The results are presented in Table 3(b).

There are some key findings. First, for both advanced economies and EMEs, while the coefficient KAOPEN is negative, its size is less for EMEs, as shown by the smaller coefficients (about one-third of the coefficient for AEs). This is consistent with the negative cross-term of EMEs and KAOPEN in the pooled regression, indicating that the benefit of capital account openness to ward off a currency crisis is smaller for EMEs. Second, reserve adequacy is significant only for EMEs. This reflects the higher need for EMEs to hold foreign currencies, because – for example – EMEs have to use foreign currencies to settle trade, and because financial liabilities are often in foreign currencies ("original sin"). In addition, for EMEs other means of support – including international central bank swap lines, as used during the Lehman crisis – are traditionally less available than to advanced economies[1].

[1] The 2008 central bank cooperation on swap lines may have marked the beginning of a turning point, however, as the Fed granted swap lines to large EMEs including Brazil, Mexico and Singapore.

Table 3(b): Regression coefficients, for EMEs and advanced economies

EMEs						
	(9)	(10)	(12)	(13)	(14) Before Q2-2007	(15) After Q2-2007
Period+	All	All	ALL	ALL		
Financial openness						
KAOPEN	-0.34 **	-0.33 **	-0.33 **	-0.35 **	-0.45 **	-0.06
	(0.14)	(.013)	(0.14)	(0.15)	(0.23)	(0.29)
Contagion						
Contagion (gravity-based)	5.32	5.49 ***	4.80 ***	4.77 ***	29.63 **	4.85 ***
	(1.25)	(1.22)	(1.09)	(1.18)	(13.54)	(1.33)
Externals						
REER (deviation from 10 yrs avg)	1.34	1.27	1.12	1.19	0.7	1.79
	(0.85)	(0.83)	(0.82)	(0.84)	(1.32)	(1.37)
Reserve adequacy	-0.32 ***	-0.33 ***	-0.30 **	-0.29 **	-0.46 *	-0.13
	(0.12)	(0.12)	(0.11)	(0.12)	(0.24)	(0.14)
External debt growth (5 years)	-0.19	-0.21 *	-0.17	-0.18 *	-0.29	-0.14
	(0.11)	(0.11)	(0.11)	(0.11)	(0.36)	(0.18)
Financial						
1 year gross inflow++	-2.19				-1.76	-2.52
	(2.13)				(5.43)	(2.19)
1 year gross FDI++		-4.19 *				
		(2.37)				
1 year gross inflow portfolio++			4.97			
			(5.45)			
1 year gross inflow other++				-0.41		
				(5.72)		
Domestic						
5 years GDP growth	8.25	7.50	5.83	6.62	21.09	12.2
	(8.15)	(8.15)	(8.22)	(8.42)	(14.66)	(17.10)
5 years credit growth	0.09	0.09	0.08	0.09	-0.10	0.49
	(0.22)	(0.22)	(0.22)	(0.22)	(0.31)	(0.90)
# of observations	525	516	513	505	293	390
# of crisis episodes			96		84	12
Log likelihood	-67.8	-67	-67.8	-68.2	-37.5	-25.9
Wald chi-square	31.61	31.82	32.16	31.23	17.17	20.74
Prob > chi2	0.00	0.00	0.00	0.00	0.03	0.01

Advanced economies						
Constants are not reported	(16)	(17)	(18)	(19)	(20) Before Q2-2007	(21) After Q2-2007
Period+	All	All	ALL	ALL		
Financial openness						
KAOPEN	-1.47 **	-1.11 **	-1.74 **	-1.11 **	-2.88	-3.56 *
	(0.60)	(0.47)	(0.73)	(0.43)	(2.51)	(1.93)
Contagion						
Contagion (gravity-based)	4.87 ***	4.44 ***	5.95 ***	4.37 ***	180.1	7.15 **
	(1.74)	(1.66)	(2.13)	(1.48)	(115.74)	(3.39)
Externals						
REER (deviation from 10 yrs avg)	5.16 *	4.35 *	5.02 *	4.36 *	9.7	6.23
	(3.09)	(2.31)	(2.83)	(2.36)	(15.25)	(7.78)
Reserve adequacy	-0.36 *	-0.28	-0.37 *	-0.29	-4.74	-2.88
	(0.21)	(0.18)	(0.22)	(0.18)	(3.98)	(1.82)
External debt growth (5 years)	-0.18	-0.32	-0.02	-0.38	-7.26	0.55
	(0.61)	(0.53)	(0.63)	(0.55)	(8.88)	(1.21)
Financial						
1 year gross inflow++	3.23 **				6.82	2.98
	(1.62)				(6.96)	(3.45)
1 year gross FDI++		0.85				
		(6.17)				
1 year gross inflow portfolio++			4.38 **			
1 year gross inflow other++				1.42		
				(2.22)		
Domestic						
5 years GDP growth	-46	-23.2	-55.3	-24.9	-79.6	90.23
	(32.78)	(24.20)	(35.97)	(23.81)	(131.19)	(65.10)
5 years credit growth	-1.29	0.35	-0.66	0.19	0.55	-6.64
	(1.15)	(0.74)	(0.84)	(0.66)	(5.77)	(4.06)
# of observations	790	790	790	790	390	400
# of crisis episodes			34		28	6
Log likelihood	-20.7	-23.1	-20.5	-22.9	-4.39	-7.66
Wald chi-square	12.37	14.86	11.82	14.52	3.94	6.5
Prob > chi2	0.14	0.06	0.16	0.07	0.86	0.59

Second, looking at gross flows for EMEs, it is apparent that FDI helps to reduce the probability of a currency crisis, as shown by its negative and significant (at the 10% level) coefficient. On the other hand, for advanced economies, surges in gross capital inflows, and especially gross portfolio inflows, tend to increase the risk of a currency crisis. This indicates that EMEs will be prone to a crisis when FDI declines, but for advanced economies, portfolio flows matters more, probably due to the higher transaction volumes of advanced economies' financial markets and the channeling of such investment into bank credit, e.g. through international wholesale funding.

Third, contagion is strong in all specifications, using both the trade-based and gravity-based contagion index, and statistically significant either at the 1% or, in one case, 5% level. Its importance is not noticeably different between advanced and emerging economies. While the impact of "pure contagion" could be overstated by two-way spillovers and interdependence between countries, our inclusive definition of contagion – as an explanatory factor above and beyond macroeconomic fundamentals – shows contagion to be a consistently strong driver or trigger of crises both in and out of sample. The extreme values of contagion during the Lehman shock do affect the level of coefficients, which are higher in sample.

Finally, the fit of the model overall is better for EMEs, as indicated by the Wald Chi-square test. This could be an indication that EWI models are better-suited to predict currency crises in EMEs, upon which much of the existing literature is focused. However, advanced economies are clearly not immune to crisis – and appear to be impacted by many of the same macroeconomic factors. While the smaller number of crisis episodes in advanced economies may hamper statistical analysis, we confirm that when taking the structural differences into account, similar models can be used to examine vulnerability across both groups.

V. Performance and Robustness checks

(a) Was the model able to predict currency crises around the Lehman shock?

This section examines whether the model was able to predict the currency crises in 2008Q4, using out-of-sample tests (in-sample data up to 2007Q2) when the bankruptcy of Lehman Brothers caused a massive and contemporaneous shock to the global financial system. Using our model in sample (Table 3(a), specification (7)), we calculate the fitted values for the probability of a currency crisis. In addition, to see how strong the contagion effect is, we also calculate the fitted value without including contagion in the model specification. This is important, given the question of whether the ensuing crises were driven primarily by fundamentals, or primarily by contagion.

Table 4 (a) shows the results. The fitted values of the model with contagion are universally close to 1, which demonstrates the extreme multiplicative impact of a number of currency crises across the world during the Lehman crisis period. Thus, we should interpret this result as a very exceptional and unique case. Contagion was in this case better at signaling the timing of crises than countries' relative vulnerability (cross-sectional dimension). Yet the model without contagion also signals vulnerabilities, and the differentiation allows for a "ranking" of crisis probability. Of the top 10 countries in our list, ranked here by the fitted value in the model without contagion (Table 4(a)), 5 countries actually had a currency crisis according to our definition. On the other hand, the model does give a low value for Sweden – a country which did experience a crisis, in large part due to foreign currency needs of its internationally operating banking sector, a phenomenon which we have not been able to capture with our data.

In Table 4(b), we present the same results, yet now for 2011Q3. Again, countries are ranked according to the probability of a currency crisis without contagion effect. When escalation of the euro area crisis led to a rise in global risk aversion and the sudden depreciation of a number of EME currencies, including the South African rand, the Indian rupee and the Polish zloty. The results here are somewhat weaker. Of the 5 countries judged mostly vulnerable by the model, only Poland experienced an actual currency crisis; shocks in South Africa and India were milder, as defined by the EMPI. Yet the results do show each of these countries to have been vulnerable. In this case, a measure of judgment would also have been necessary to interpret the model's results, based e.g. on the financial links between Poland and the euro area.

Table 4(a): Predicted and actual crisis, 2008Q4

Sorted by the fitted probability without contagion effect

	1	2	3	4
Country	Predicted probability (%) with contagion effect	Predicted probability without contagion effect	Actual crisis (=1 if there was a crisis)	Normalized EMPI, if <-1.5, a crisis is called
Turkey	100.00	6.76	1	-2.2283
India	100.00	5.18	0	-0.3792
South Africa	100.00	4.45	1	-1.7126
Argentina	100.00	4.21	0	0.3161
Philippines	100.00	3.62	0	-0.2988
Poland	100.00	3.26	1	-3.7947
Russia	100.00	2.02	0	-1.1913
Indonesia	100.00	1.82	1	-3.1038
Hungary	100.00	1.73	0	-0.3998
Brazil	100.00	1.65	1	-3.4211
Colombia	100.00	1.39	0	-1.3628
Hong Kong	100.00	0.69	0	1.3032
Australia	98.61	0.59	1	-2.0176
Ukraine	100.00	0.46	0	-1.3868
Korea	99.65	0.42	1	-2.6938
Ireland	100.00	0.32	0	-0.2147
Mexico	99.84	0.27	1	-2.3982
Singapore	100.00	0.24	0	0.1006
Malaysia	100.00	0.24	0	-0.6687
Switzerland	100.00	0.24	0	0.2718

Table 4(b): Predicted and actual crisis, 2011Q3

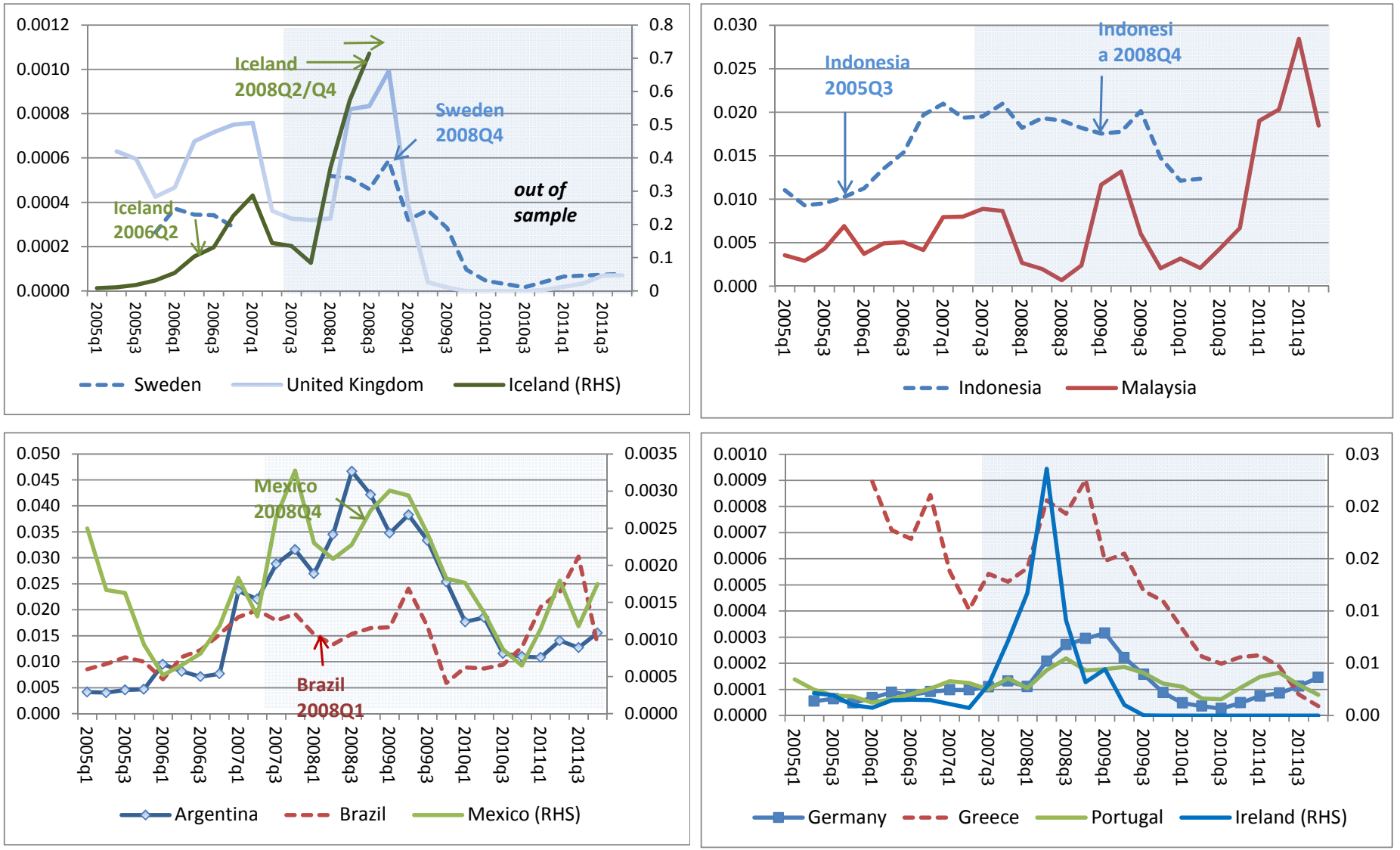
Sorted by the fitted probability without contagion effect

	5	6	7	8
Country	Predicted probability (%) with contagion effect	Predicted probability without contagion effect	Actual crisis (=1 if there was a crisis)	Normalized EMPI, if <-1.5, a crisis is called
India	9.32	10.36	0	-0.5737
Brazil	1.03	3.02	0	0.3832
Malaysia	0.85	2.84	0	-0.1360
South Africa	0.72	1.88	0	-0.5473
Poland	0.43	1.64	1	-1.7242
Argentina	0.46	1.27	0	-0.0048
Australia	0.17	0.45	0	-0.2026
Ukraine	0.01	0.41	0	0.3104
Korea	0.02	0.17	0	-0.4160
Mexico	0.01	0.12	0	-0.2616
Singapore	0.03	0.03	0	-0.0812
Switzerland	0.02	0.01	0	1.6229
Netherlands	0.02	0.01	0	-0.1028
Portugal	0.01	0.01	0	-0.2534
Finland	0.02	0.01	0	-0.0952
Germany	0.03	0.01	0	-0.0701
United States	0.01	0.01	0	0.0946
Greece	0.01	0.01	0	-0.0370
Sweden	0.01	0.01	0	-0.3180
United Kingdom	0.01	0.01	0	-0.0234

Aside from these tables, figure 2 shows the development of the fitted (predicted) values for selected countries, in and out-of-sample, with arrows indicating the actual occurrence of a currency crisis. Note that this, again, is based on the model without contagion. This fitted value did indeed give some warning of crises in Iceland (in 2008Q2 and Q4) and Indonesia (2008Q4) crisis (out-of-sample), as indicated by the elevated predicted value preceding the quarter of the crises. Notable is that while the timing of crises is difficult to predict, peaks sometimes correspond roughly with actual crisis. For Iceland, the fitted values do peak just before the crises of Q2 2006 and Q4 2008, at levels much higher than the UK and Sweden (Iceland is on the right-hand axis). Brazil and Malaysia both see fitted values peak just before the large depreciations (just short of our crisis definition) in Q3 2011.

Focusing in on the specific case of the euro area, it is notable that both Greece and Ireland experience rises in the vulnerability indicator around 2009. The higher prediction seems to relate to the deviation of the REER for both countries and the large scale of credit growth and capital inflows in Ireland in the period just prior to the crisis. Portugal does not show the same scale of vulnerability, with levels comparable to Germany, as its real appreciation may have been offset by weak growth, which lowers vulnerability in the regression estimation. These estimations are notable given the extreme pressure that the euro area underwent in 2010 and 2011, in which, alongside fiscal and financial sector problems, competitiveness relating to the real exchange rate played a central role, particularly because exchange rate adjustment within the euro area is not possible. This exercise illustrates that early warning models may be of use even in a context of a single currency. By predicting crisis vulnerability *as if* countries did have autonomous exchange rates, the model sheds light on the pressures which have be addressed through other policy means.

Figure 2: Predicted probability of a currency crisis (fitted value from model without contagion, shaded area denotes out-of-sample observations)



(b) Signal-to-noise ratio

Similar to signal extraction models, the output of a multivariate model can be translated into a framework which gives explicit binary signals for whether or not a crisis will occur. To extract signals, we define a critical threshold equal to the median predicted values during actual crisis in sample. We then extend this framework out of sample, and identify a crisis whenever the predicted value exceeds our critical threshold.

Ideally, an early warning model will try to issue reliable information in advance, avoiding both type I errors (false signal) and type II errors (unpredicted crises). We want the predictor to be able to call crises, but not be "noisy". Following Goldstein et al. (2000), we summarize the potential outcomes of our predictions as the following two-by-two matrix:

	Crisis occurs in the following 4 quarters	No crisis occurs in the following 4 quarters
Signal	A	B (Type I error)
No signal	C (Type II error)	D

Comparable with KLR, we subsequently define a Signal-to-Noise ratio, as[1]:

$$S/N = [A/(A+C)]/[B/(B+D)] \qquad [5]$$

Yet whereas KLR optimize this ratio based with different values of the critical threshold, we are more interested in the meaning of this ratio for the predictive power of our model. Specifically, a signal-to-noise ratio greater than one means that the model predicts currency crises better than random guesswork; higher values indicate stronger performance. Unlike the levels of Wald chi-squared and other estimations of model fit, these look explicitly at the power to foresee crises out of sample, and are not necessarily correlated with estimations of model fit. With this indicator, we can compare the power of our baseline estimation to alternative models without contagion (as shown in figure 2), without financial openness and without the deviation of gross inflows.

Table 5: Signal to Noise ratio of different specifications (all sample periods/countries)

(i) Baseline model (Model 1 in Table 3(a))	8.120
(ii) Without contagion ((i) without contagion effects)	5.984
(iii) Without contagion, capital account openness ((ii) without KAOPEN)	4.296
(iv) Without contagion, financial openness, and gross inflow deviation ((iii) without gross inflow deviation)	4.040

[1] KLR actually define a noise-to-signal ratio – the simple inverse of our function – which they then minimize. As our focus is on an indicator of the predictive power of our model, we choose a ratio that increases with the number of crises correctly called.

Table 5 shows the results of four different specifications. The signal-to-noise ratio shows that crisi prediction significantly improves when contagion is taken into account. Yet given that contagion is only available contemporaneously, this cannot truly offer "early" warning. Yet a model with only the other variables also has relatively strong predictive power. Moreover, a model with capital account openness significantly outperforms a model without (compare (ii) and (iii)). Including gross inflow deviations offers a positive, though more modest benefit in terms of predictive power (compare (iii) and (iv)).

VI. Conclusion and possible extensions

Our findings can be summarized as follows. First, capital account openness plays an important part in reducing the vulnerability of an economy to a currency crisis, but such a benefit is smaller for EMEs. There are a number of possible explanations for this. For example, countries with extensive capital controls may have poor institutional frameworks and hence greater vulnerability to domestic and external shocks.[2] While controls seek to prevent disorderly inflows and outflows, they are often distortive and can contribute to imbalances and risky circumvention practices. The thresholds of financial development, as described by Kose, Prasad and Taylor (2011), mean that countries with more developed financial systems are more likely to reap benefits from open capital accounts, largely through the associated improvements in institutional quality, and be able to respond to associated risks. This explains why advanced economies are more likely to see a reduction in vulnerability due to open capital accounts, and why the emerging economies in our sample, with less developed financial systems and foreign currency liabilities ("original sin"), are less likely to see benefits. Indeed, our preliminary rough test (not reported) indicates that when capital account openness is interacted with gross capital inflows, it reduces the chances of a currency crisis originating from surges in gross capital inflows. An alternative explanation is that surges in portfolio inflows, real appreciation, and strong credit growth, all of which are associated with greater probability of a currency crisis, can themselves become more likely when a country pursues greater openness. If a country has liberalized its capital account but then become subject to such factors, the net result of openness on crisis vulnerability may then be more ambiguous. The implication of this would be that even as open capital account openness in general can reduce vulnerability, it also places a higher burden on policy to effectively manage macroeconomic risks. Yet another explanation is that openness could interact with contagion and policy responses to it. While more open and developed economies are generally more exposed to external shocks in the balance of payments and exchange rates, they are also in some cases more able to respond through official mechanisms, such as central bank swap lines, as used during the recent crisis. A final explanation is that capital account

[2] We thank Prof. Menzie Chinn for providing us with this possible explanation.

openness stimulates financial development, promotes market discipline and is correlated with other economic reforms. The results of this paper do not support the argument for the effectiveness of capital flow management measures (including capital controls) to dampen the destabilizing financial effects of capital inflows. Instead, fiscal policy can be a more effective means to counteract such volatile flows than controls (Cardarelli, Elekdag and Kose, 2009). Excessive real appreciation, low reserve adequacy and rapid credit growth are confirmed to be further risk factors. Appropriate responses to these risks could include sterilized intervention and macroprudential tools.

Second, we find that surges in gross capital inflows increase the probability of a currency crisis, but not net capital inflows, as reflected by the significance of coefficients (gross capital flows are significant whereas net capital flows are not) and the overall fit of the model (the model with gross capital flow has a better fit). This is consistent with the recent literature which stresses the importance of gross capital inflow as a cause of bubbles and subsequent crashes (for example, Bruno and Shin, 2012). We should, however, pay attention to the disaggregated components of flows: for EMEs, surges in gross FDI inflows reduce the probability of a currency crisis, whereas gross portfolio inflows in advanced economies increase the chance of a currency crisis. This is understandable, given that FDI inflows are more stable and portfolio inflows are very volatile and associated with credit and asset price bubbles. The differences between advanced and emerging economies likely relate to structural factors in financial development and the depth of financial markets.

Third, the role that contagion plays is quite strong, especially during the Lehman crisis episodes. Explicitly modeling contagion also greatly improves model fit in our sample. However, with our quarterly-frequency data, it is difficult to detect the contagion effect *a priori*. Perhaps using higher frequency data (daily or weekly) would allow us to detect the actual speed and the transmission mechanism, but that is beyond the scope of this paper. For now, we note that our gravity-based index performs similarly compared with a trade-weighted index as in Eichengreen, Rose and Wyplosz (1996). Our broad definition of contagion is indeed an important contributor to crisis vulnerability.

It seems the fit and therefore the usefulness of "traditional" models with often-used variables can be greatly improved when they are augmented with financial openness and contagion. For policy-makers, this means greater usefulness of the EWI model, though outputs would call for some level of judgment. Still, given that the factors driving crises in the past appear to have remained consistent through the global crisis, there is evidence that the patterns preceding past crises can continue to give guidance for the future.

Finally, our paper has some interesting applications for the current euro area problems. While the euro area crisis is not a currency crisis per se, it is clear that, in the absence of the single currency, there would likely be pressure for adjustment of vulnerable euro area countries' exchange

rates[3]. These are currently suppressed, meaning that adjustment has to take place through other mechanisms, e.g. fiscal consolidation, structural adjustment and internal devaluation. For us, this is not a sign that early warning indicators are not relevant for members of a currency union; on the contrary, it may be even more important to monitor fundamental developments for currency union members given the lack of autonomous monetary and exchange rate policy (De Grauwe, 2012). By using economic indicators[4] to monitor risk, there may be room to take preventive action earlier so as to ensure the stability of the union as a whole.

[3] It is important to distinguish between pressure for adjustment and actual adjustment. If the currency union had not been in place, it could be that countries would resist adjustment through exchange rate intervention – e.g. due to worries about the effects on foreign exchange lending portfolios (as in CEE countries) or due to political will to maintain pegs (as in the EMS crisis in 1992). In any case, this is consistent with our use of exchange rate pressure, as defined by the EMPI.

[4] See for example, the Macro Imbalances Procedure of the European Commission, which includes monitoring of public, private and external debt levels as well as REER, current account balance and other fundamentals.

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Annex I: Sample Countries

Advanced economies (euro area) Austria Belgium Finland France Germany Greece Ireland Italy Luxembourg The Netherlands Portugal Spain **Advanced economies (other)** Australia Canada Czech Republic* Iceland Israel* Japan Norway Republic of Korea* Singapore* Sweden Switzerland United Kingdom United States of America	**Emerging market economies** Argentina Brazil China Chinese Taipei (Taiwan) Colombia Hong Kong, SAR Hungary India Indonesia Malaysia Mexico Peru Philippines Poland Russia Saudi Arabia South Africa Turkey Thailand Ukraine Venezuela

*These countries were previously defined by the IMF WEO as “emerging market economies” during the sample period. For the sake of consistency, they are defined throughout the sample based on the most recent classification.

Annex II: List of crisis episodes (normalized EMPI<-1.5)

Country	Time	EMPI (normalized)
United Kingdom	1976q4	-1.525
	1992q4	-1.750
Sweden	1993q1	-1.900
	2008q4	-1.816
Japan	1979q1	-1.600
	1979q4	**-2.523**
Greece	1983q1	**-2.144**
	1985q4	**-2.305**
Iceland	1978q1	-1.555
	1980q2	-1.565
	1982q1	**-2.244**
	1982q3	**-2.349**
	1983q3	-1.723
	2001q2	-1.707
	2006q2	**-2.041**
	2008q2	**-2.094**
	2008q4	**-3.327**
Portugal	1977q2	-1.851
Spain	1983q1	-1.567
Australia	1985q2	-1.745
	1986q3	**-2.493**
	2008q4	**-2.018**
Israel	1975q3	-1.867
	1977q4	**-2.443**
	1979q2	-1.968
	1979q4	-1.920
	1980q3	**-2.320**
	1983q1	-1.668
	1988q3	-1.632
	1992q3	**-2.326**
	1994q2	-1.722
Taiwan	2011q2	**-2.115**
Korea	1997q4	**-6.195**
	2008q4	**-2.694**
Turkey	1995q4	**-3.407**
	1996q4	-1.963
	1997q4	**-2.113**
	1998q3	-1.772
	1999q4	-1.592
	2001q1	**-4.676**
	2006q2	**-2.502**
	2008q4	**-2.228**
South Africa	1975q4	-1.780
	1981q3	-1.510
	1984q3	-1.948
	1985q3	**-2.953**
	1996q2	**-2.170**
	1998q3	**-2.223**
	2001q4	**-2.061**
	2008q4	-1.713
Argentina	1995q1	-1.626
	2002q1	**-7.727**

Country	Time	EMPI (normalized)
Brazil	1976q1	**-2.196**
	1977q1	**-2.111**
	1979q1	-1.887
	1981q1	-1.866
	1982q1	-1.876
	1985q1	**-3.798**
	1986q3	**-2.524**
	1987q4	**-2.286**
	1990q3	**-4.080**
	1991q3	**-6.908**
	1992q3	**-5.572**
	1995q1	**-2.114**
	1997q4	**-2.378**
	1998q3	**-5.325**
	1999q1	**-7.546**
	1999q4	**-2.328**
	2000q2	**-3.937**
	2001q4	-1.759
	2002q3	**-3.845**
	2008q4	**-3.421**
Colombia	1984q1	-1.699
	1985q2	-2.000
	1999q3	-1.723
	2002q3	-1.931
Mexico	1976q3	**-3.742**
	1982q1	**-4.125**
	1985q2	-1.577
	1987q4	**-2.649**
	1988q4	-1.736
	1990q1	-1.608
	1994q2	**-2.452**
	1994q4	**-3.510**
	1995q4	-1.686
	2008q4	**-2.398**

Country	Time	EMPI (normalized)
Indonesia	1997q3	-1.931
	1999q3	-1.734
	2000q2	-1.507
	2004q2	-1.781
	2005q3	**-2.061**
	2008q4	**-3.104**
Malaysia	1997q4	**-2.294**
Philippines	1983q1	-1.567
	1983q3	-1.608
	1984q3	**-2.385**
	1990q4	-1.686
	1997q4	-1.817
Thailand	1997q3	**-3.834**
Russia	1994q3	**-2.996**
	1998q3	**-3.472**
	2009q1	**-2.536**
China	1992q3	**-2.044**
Ukraine	1994q2	-1.735
	1995q3	**-2.874**
	1998q4	**-2.839**
	2009q1	**-2.225**
Poland	1985q3	**-5.691**
	1986q1	**-3.258**
	1986q3	**-3.190**
	1988q1	-1.635
	1989q2	**-3.536**
	1990q4	**-2.131**
	1991q4	**-2.388**
	1993q1	-1.978
	2008q4	**-3.795**
	2011q3	-1.724

Annex III: Regressions with EMPI 2 standard deviations (for all countries)

Dependent variable: EMPI 2 st dev crisis dummy

All samples									
Constants are not reported, in parenthesis are standard deviation	(1)		(2)		(3)		(4)		(5)
Period+	All		All		ALL		ALL		All
*All variables are lagged by 4 quarters, except for EME, KAOPEN, KAOPEN*EME, and contagion*									
Financial openness									
KAOPEN	-0.69	***	-0.79	***	-0.75	***	-0.91	***	-0.75	***
	(0.19)		(0.21)		(0.21)		(0.24)		(0.20)	
KAOPEN*EME	0.44	**	0.46	**	0.49	**	0.63	**	-0.47	**
	(0.22)		(0.23)		(0.24)		(0.25)		(0.22)	
EME	0.19		0.30		0.19		0.32		0.27	
	(0.28)		(0.32)		(0.30)		(0.33)		(0.32)	
Contagion									
Contagion (gravity-based)			3.49	***	3.47	***	4.00	***	3.38	***
			(0.85)		(0.87)		(0.89)		(0.84)	
Contagion (trade-weigh based)	0.12	***								
	(0.03)									
Externals									
REER (deviation from 10 yrs avg)	2.87	***	2.03	**	2.19	**	2.08	**	2.04	**
	(0.91)		(0.88)		(0.88)		(0.89)		(0.88)	
Reserve adequacy	-0.25	**	-0.27	***	-0.30	***	-0.28	***	-0.28	***
	(0.10)		(0.10)		(0.10)		(0.10)		(0.10)	
External debt growth (5 years)	0.13		-0.05		-0.04		-0.03		-0.05	
	(0.09)		(0.11)		(0.09)		(0.11)		(0.10)	
Financial									
1 year gross inflow++	1.73	**	1.78	**						
	(0.76)		(0.81)							
1 year gross FDI++					-0.2	*				
					(2.26)					
1 year gross inflow portfolio++							3.45	**		
							(1.40)			
1 year gross inflow other++									2.46	
									(1.55)	
Domestic									
5 years GDP growth	-3.74		-1.12		1.69		-1.57		-0.2	
	(7.80)		(8.25)		(7.77)		(8.21)		(8.04)	
5 years credit growth	-0.44		-0.38		-0.09		-0.27		-0.23	
	(0.32)		(0.36)		(0.24)		(0.29)		(0.29)	
# of observations	1393		1325		1316		1313		1305	
# of crisis episodes					88					
Log likelihood	-77		-73		-76		-73		-74	
Wald chi-square	40.48		37.16		35.73		35.92		36.38	
Prob > chi2	0.00		0.00		0.00		0.00		0.00	

+sample period is 1975Q1 - 2011Q4, but due to missing observations, most data starts from the second half of 1980s.

++gross capital flows are measured as deviation from 5 years average

***, **, * denotes significance at 1, 5, and 10% level, respectively.

Annex IV: Regressions with net capital inflows as explanatory variables (for all countries)

All samples								
Constants are not reported, in parenthesis are standard deviation	(1)		(2)		(3)		(4)	
Period[+]	All		All		ALL		ALL	
*All variables are lagged by 4 quarters, except for EME, KAOPEN, KAOPEN*EME, and contagion*								
Financial openness								
KAOPEN	-0.78	***	-0.81	***	-0.84	***	-0.74	***
	(0.19)		(0.19)		(0.21)		(0.19)	
KAOPEN*EME	0.45	**	0.34		0.37		0.39	*
	(0.22)		(0.22)		(0.23)		(0.21)	
EME	0.17		0.18		0.06		0.18	
	(0.27)		(0.30)		(0.28)		(0.26)	
Contagion								
Contagion (gravity-based)	4.05	***	4.40	***	4.31	***	4.02	***
	(0.77)		(0.85)		(0.83)		(0.78)	
Externals								
REER (deviation from 10 yrs avg)	1.68	**	1.87	**	2.03	**	1.77	**
	(0.78)		(0.86)		(0.83)		(0.78)	
Reserve adequacy	-0.26	***	-0.24	***	-0.24	***	-0.25	***
	(0.09)		(0.09)		(0.09)		(0.09)	
External debt growth (5 years)	-0.13		-0.11		-0.13		-0.14	
	(0.09)		(0.11)		(0.09)		(0.09)	
Financial								
1 year net inflow++	2674							
	(2530)							
1 year net FDI++			-7995	**				
			(3880)					
1 year net inflow portfolio++					1900			
					(1445)			
1 year net inflow other++							9.58	
							(2120)	
Domestic								
5 years GDP growth	0.32		-1.04		-0.89		2.25	
	(7.26)		(7.61)		(7.22)		(6.85)	
5 years credit growth	0.12		-0.02		0.15		0.13	
	(0.19)		(0.37)		(0.20)		(0.19)	
# of observations	1315		1241		1281		1284	
# of crisis episodes				130				
Log likelihood	-94		-81		-85		-94	
Wald chi-square	46.59		42.86		43.43		45.84	
Prob > chi2	0.00		0.00		0.00		0.00	

+sample period is 1975Q1 - 2011Q4, but due to missing observations, most data starts from the second half of 1980s.

++net capital flows are measured as deviation from 5 years average

***, **, * denotes significance at 1, 5, and 10% level, respectively.

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