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Banking Crises in OECD Countries: Investigating the Role of Nonperforming Loans, the Equity Multiplier, Banking Concentration and Stock Market Capitalisation

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BANKING CRISES IN OECD COUNTRIES: INVESTIGATING THE ROLE OF NONPERFORMING LOANS, THE EQUITY MULTIPLIER, BANKING CONCENTRATION AND STOCK MARKET CAPITALISATION

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Abstract

Early warning systems (EWS) for banking crises traditionally have omitted bank capital, bank liquidity and property prices, with the notable exception being Barrell et al (2010a) . This dissertation expands from that paper using a sample of 25 OECD countries and data from 1987-2017. We develop a baseline model, finding strong effects for M2/Reserves, liquidity and property price growth while bank capital adequacy is insignificant, unlike Barrell et al (2010a). We then add four variables one by one to the baseline to end up at our final specification. Our final specification suggests that alongside external vulnerability (M2/Reserves) and property price growth, stock market capitalisation has a marked effect on the likelihood of a systemic banking crisis. Interestingly, other additional variables tested including nonperforming loans, the equity multiplier ratio and banking concentration are not significant early warning indicators. As a result, it is essential that regulators consider vulnerabilities within markets, stock and real estate alike and control their contributions to systemic episodes.

1 Introduction

The global financial crisis (GFC) experienced at the start of 2007 has had a long-lasting impact on global economies and led to the development of various regulations aiming to tackle and overcome the pitfalls experienced. Systemic banking crises lead to sustained declines in public confidence, output, employment, financial intermediation, and further fiscal costs due to bailouts. Such effects can have a sustained impact on the economy, for example, output fell sharply after the crisis and since 2009, growth has been slow. The Basel II accord, which was in place during the GFC, was not only found to be flawed but also not always actively followed, further exposed the failures in bank supervision. Meanwhile, macroprudential regulation was absent in most OECD countries prior to the GFC. As a result of the GFC, there has been an ever increasing attention on analysis of factors that predict a banking crisis, which regulatory measures should be implemented and how strict such measures should be. Notably there has been both a tightening of microprudential policy (Basel III) and widespread introduction of macroprudential measures.

This paper extends upon the work of Barrell et al. (2010a) – itself an input to Basel III - by using a more extensive dataset that encompasses 25 OECD Countries instead of 14. We also adopt a more up to date sample period of 30 years from 1987 to 2017 instead of 1980-2007, and make use of the up to date systemic banking crisis database (see Laeven and Valencia (2018)). Whereas Barrell et al. (2010a) focused both on systemic and non-systemic crises, this research focuses solely on crisis episodes that are systemic. As in the earlier paper, we are concerned with the prediction of a systemic crisis and therefore, we estimate determinants of crisis onset, even though they are expected to have a longer lasting duration. Once a baseline model is produced using “traditional” variables alongside bank capital, liquidity and property prices, four additional variables are tested, which have been largely absent from the existing litearature. These variables are nonperforming loans, the equity multiplier, banking concentration and stock market capitalisation.

The remainder of this paper is organised as follows: The second section will review the existing literature on the determinants of banking crises. The third section will discuss methodologies, our choice of methodology, data and the additional explanatory variables in detail. The fourth section will present and explain findings of the baseline model and final specification and discuss marginal implications. The fifth section will briefly discuss some policy implications. Lastly, the sixth section will conclude the study.

2 Literature Review

There is an extensive literature on banking crises models and in particular, early warning systems (EWSs) (for a survey, see Davis and Karim (2020)). However, findings vary, especially when considering a wide variety of variables traditionally grouped into macroeconomic, financial and banking sector variables. However, banking variables aggregated to a macro level have historically been widely neglected mainly due to a lack of data but are becoming more common over the last 10 years. The GFC has led many researchers to expand upon earlier work including use of bank-specific variables, discussion whether a crisis can be predicted with a reasonable level of precision and assessment what macroprudential policies should be in place to reduce the likelihood of such a widespread crisis as the GFC to recur.

Demirgüç-Kunt and Detragiache (1998) in one of the earliest papers adopted a multivariate logit model to study a variety of macroeconomic variables alongside structural characteristics of the general economy and financial sector that are associated with the emergence of systemic banking crises. Macroeconomic variables studied included real GDP growth, change in terms of trade, depreciation, real interest rates, inflation and the fiscal surplus/GDP. Financial variables included M2/reserves, credit to the private sector/GDP, bank cash plus reserves/bank assets and real domestic credit growth. Lastly, institutional variables included are a law and order index, GDP per capita and a dummy capturing the presence or absence of deposit insurance. Their dataset covered 45 to 65 (dependent upon specification) developed and developing countries over 1980-94 and encompassed 31 crises with the aim to identify factors that are common to all banking crises. For an episode of distress to be classified as a full-fledged crisis at least one of the following conditions had to hold: 1) ratio of nonperforming assets to total assets in the banking system exceeded 10 percent; 2) cost of the rescue operation was at least 2 percent of GDP; 3) banking sector problems resulted in a large scale nationalisation of banks; and 4) extensive bank runs took place or emergency measures such as deposit freezes, prolonged bank holidays, or generalised deposit guarantees were enacted by the government in response to the crisis.

Explanatory variables were not lagged, therefore specifications do not represent an early warning system (EWS). Results showed that banking crises have a tendency to emerge when the macroeconomic environment is weak, particularly in times of low growth and high inflation as was later supported by Kurcewicz (2000). Thus, crises are not solely driven by self-fulfilling expectations as suggested in Diamond and Dybvig (1983). The ratio of M2 to foreign exchange reserves significantly increased the probability of a banking crisis in most of the specifications, but lost significance when fiscal surplus to GDP was omitted. Another noteworthy finding is that a banking system with an explicit deposit insurance scheme will tend to make a crisis more likely through the incentives of excessive risk-taking by bank managers protected by depositor guarantees arising from moral hazard. Therefore, moral hazard seems to play a significant role in the emergence of systemic banking problems.

Hardy and Pazarbaşioğlu (1998) also using a multinomial logit model examined episodes of banking system distress for a sample of 50 countries in which 38 countries had suffered a total of 43 episodes consisting of 20 banking system crisis and 23 significant problems. Explanatory variables were grouped into the real sector, banking sector and potential shocks. Real sector variables included the capital/output ratio and growth rates of GDP, consumption and investment. Banking sector variables included deposit liabilities, credit to the private sector and foreign gross liabilities. Potential shock variables included inflation, the real interest rate, the real exchange rate, the real growth in imports and the terms of trade. Findings suggested that banking distress is associated with large contemporaneous falls in real GDP growth; boom-bust cycles in inflation, credit expansion and capital inflows; rising real interest rates and a declining incremental capital/output ratio. A sharp real exchange rate decline and an adverse trade shock were also significant. Furthermore, country-specific and regional circumstances have important roles to play in the likelihood of banking distress as evident in the Asian crises. Familiar characteristics of Asian episodes appear to be real appreciation followed by very harsh depreciation and the build-up followed by the collapse of banks' foreign borrowing.

Expanding upon their previous work, Demirgüç-Kunt and Detragiache (2005), again using a multivariate logit model found that the crises in their sample of 94 countries including 77 crises over 1980-2002 were again correlated with macroeconomic, banking sector and

institutional indicators. Results supported their earlier study but also found the ratio of broad money to foreign exchange reserves, credit to the private sector/GDP ratio and the lagged credit growth to be significant. They suggested that in order to improve model performance, the definition of a crisis could be improved because some crises result from long-simmering problems being bought into the open, whilst others may be triggered by severe exogenous shocks. Distinguishing between such crises could aid in identifying clearer and more robust relationships.

Whereas the above papers adopted the multivariate logit approach, various papers have adopted signal extraction models as EWSs an approach, which was originally used to identify business cycle turning points. Kaminsky and Reinhart (1999) pioneered work with such an approach to determine which 16 macroeconomic and financial factors were associated with the onset of banking crises. They specifically studied the "twin crises" phenomenon which suggests that a large number of banking crises are followed by currency crises or vice versa. Their sample consisted of 20 industrialised and developing countries for the period 1970-mid-1995 which incorporated 26 banking and 76 currency crises of which 19 were twin crises. Independent variables explored included the M2 multiplier, the ratio of lending-to-deposit interest rates, excess real M1 balances, real-commercial bank deposits, the value of exports and imports, domestic-foreign real interest-rate differential on deposit and industrial production. Banking sector problems were found to typically precede a currency crisis, and this deepens the banking crises. Therefore, it is suggested that crises occur as the economy enters a recession, following prolonged economic booms that are driven by credit, capital inflows and followed by an overvalued currency.

Another important paper that adopted the signal extraction approach is that of Borio and Lowe (2002). They examined whether the occurrences of a boom in asset prices, credit or investment provides a useful signal for an oncoming financial crisis for 34 countries over the 1960-1990 period. Along the lines of Kaminsky and Reinhart (1999), they found a threshold value for each indicator. If an indicator surpasses its threshold the situation is defined as a boom and a signal of an impending crisis. Instead of focusing on growth rates over one year as in Kaminsky and Reinhart (1999), a cumulative process was addressed, since vulnerabilities are built up over an extended period. Other differing aspects from Kaminsky and Reinhart (1999) included the use of only ex-ante information in determining the presence of booms, considering the combination of indicators rather than individually and studying multiple horizons via considering the usefulness of indicators in predicting crises within one, two and three years. Large increases in asset prices and sustained rapid credit growth seemed to increase the likelihood of an episode of financial instability. Furthermore, their results suggested that while low and stable inflation aids financial stability, it can also increase the risk that excess demand pressures will show up initially in credit aggregates and asset prices, instead of in goods and services prices. As a result, in some scenarios, a monetary response to credit and asset market booms is recommended for preserving both financial and monetary stability.

A serious concern regarding work on EWSs is that whilst these leading indicators perform fairly well in hindsight, they might nor produce reliable signals for future crises. Developing upon Borio and Lowe (2002), Borio and Drehmann (2009) explored whether the GFC could have been anticipated by exploiting the historical relationship found in the 2002 paper, namely that unusually strong increases in credit and asset prices have tended to precede banking crises. They used a signal extraction model to analyse the combinations of two- and three- indicator variables to assess the out-of-sample performance of those indicators

covering the period 2004 to 2008 and also incorporate property prices. Results showed that they are fairly successful in providing a signal ahead of the GFC for several banking systems that were in distress, including the United States.

In recent years, researchers have attempted to explore new variables compared with these baseline studies. Beck et al. (2006) found that crises are less likely in economies with more concentrated banking systems using a sample of 70 countries which included a number of OECD countries for the period 1980 to 1997. Systemic episodes were also less likely in the presence of national institutions that promote competition and with fewer regulatory restrictions on bank competition and activities. As a result, they concluded that there is no evidence that greater competition enhances instability. This result is intuitive and seems to be in line with the theory that financial institutions are more efficient when they are larger due to their specialisation of information processing skills and greater ability to diversify their asset portfolio.

Since the GFC, researchers have more widely considered bank specific factors that have been neglected in the past. In particular, Barrell et al. (2010a) used not only standard indicators for EWSs for banking crises but also measures of bank capital and liquidity at the level of the banking sector and also real property price growth. Adopting a sample of 14 OECD countries consisting of 14 systemic and non-systemic crises over the 1980-2006 period, they found that such additional measures have an impact on the probability of a crisis occurring and excluded traditional variables such as GDP growth, inflation, measures of aggregate credit and real interest rates. Results were felt to underline the need for OECD countries to have high levels of capital and liquidity and show that house price growth affects crisis likelihood but credit growth, real GDP growth and other "traditional" variables did not. In further work, Barrell et al. (2010b) specifically suggested increasing capital and liquidity standards by 3.7 percentage points would reduce the annual average probability of a financial crisis occurring to around 1%.

Other work suggests that different predictive variables apply not only between advanced and developing countries but also between regions – although data availability may also play a role. Davis, Karim and Liadze (2012) showed that Real GDP growth is an extremely important leading indicator using a sample of 20 Asian and Latin American countries for 1981-2007 and is picked up by all model specifications – logit, signal extraction and binary recursive trees (BRTs). For alleviating financial instability, the ratio of fiscal surplus to GDP is important for both regions since the signal extraction model picks it up in the Asian, Latin American and combined models. Overall, findings appear to be influenced by the differing nature of crises in both regions with Asian crises being linked to financial and currency issues whilst Latin American crises are related to financial variables with inflationary and trade issues.

Schularick and Taylor (2012) focus on the behaviour of money, credit and macroeconomic indicators over a much longer historical dataset for 14 countries that are now all OECD members than other work, namely 1870-2008. Contrary to Barrell et al. (2010a), Bordo (2018) and Kiley (2018), credit growth was suggested to be a powerful predictor of financial crises and that history demonstrates that policymakers and researchers have ignored credit at their peril. Recurrent financial instability episodes are likely due to credit booms gone wrong arising in turn from failures in the operation and/or regulation of the financial system. As a result, policymakers should consider the growth in the scale and risks associated with the credit system.

Given the changes within the banking industry and landscape, researchers have attempted to adjust early warning systems to mimic the environment as accurately as possible. In a development from Barrell et al (2010a), Karim et al (2013) used a logit model to test for a consistent impact of off-balance sheet exposures on the likelihood of banking crises in OECD countries since 1980 using the share of non-interest income as a proxy. They found that the change in the off-balance sheet activity proxy is significant alongside bank capital adequacy, liquidity, changes in house prices and the current account balance to GDP ratio. Therefore, it is recommended that regulators should carefully consider the proxy to limit off-balance sheet exposures and their associated systemic risk.

Most studies treat the causes of banking crises to be homogenous, at least for countries at similar levels of financial development. However, Klomp (2010) examined to what extent there exists heterogeneity in the causes of banking crises via adopting a random coefficient logit model for 110 countries between 1970 and 2007. On average, credit growth, GDP growth rate and the real interest rate are the most key causes but none of them are significant in more than 60% of the crises. He concluded that there exists significant heterogeneity in the causes of banking crises. Furthermore, there is some evidence that an increase in globalization or the ratio between M2 and the foreign exchange reserves significantly increases banking crisis probabilities.

On another note, Roy and Kemme (2012) using a multivariate logit model examined similarities in the run-up to banking crises using two predictability criteria: i) the percentage of a specified number of years before a crisis is correctly called and ii) the percentage of true alarms of total alarms for a crisis. They found that a collapse of a real asset bubble will spark a banking crisis and that such bubbles would occur even in the absence of sustained surges of capital inflow, accumulation of public debt, low interest rate policies, or structural shocks. Further findings show that the increase in income inequality inflated the most recent housing bubble.

Using a multivariate logit model and adopting a sample of 100 developed and developing countries for the period 1994-2007, Čihák and Schaeck (2010) analysed use of a range of aggregate prudential ratios to predict banking problems. Alongside typical variables, prudential ratios explored and tested include regulatory capital to risk-weighted assets, nonperforming loans to total gross loans, capital to total assets and total debt to equity. Bank return on equity and (non-bank) corporate leverage were found to be good indicators for the accumulation of systemic banking problems. There is also some evidence that the contemporaneous ratio of NPLs to total loans and the contemporaneous capital adequacy ratio have a significant effect. However, lagging the two variables by one period renders them insignificant.

Replicating Demirgüç-Kunt and Detragiache (1998) work for a sample of 75 developed and emerging economies covering the period 1998-2011 and spanning 36 systemic banking crisis episodes, Wosser(2015) showed that sectoral variables like the bank Z-Score, private credit to GDP ratio, bank credit to deposit ratio and non-performing loan levels enable an improved model fit compared to one with solely macroeconomic variables. Results supported increased capital and/or reserves-based regulatory charges as when countries significantly raise Tier-1 capital levels over a 3-year period, systemic banking crises are significantly less likely. Restrictions in banks' trading activities also make banking sectors more stable. However, Tier-1 capital levels and the Basel III Net Stable Funding Ratio are not a determinant of systemic banking crises and deviations from such minimum levels do not seem to matter.

Definitions of systemic banking crises were revised by Laeven and Valencia in 2008 and 2013 with their latest update being Laeven and Valencia (2018). Now identifying 151 systemic banking crises from 1970-2017, they provided new evidence that crises in high-income countries tend to last longer and are associated with higher output losses, lower fiscal costs, and more extensive use of bank guarantees and expansionary macro policies than crises in low and middle income countries. Furthermore, sovereign debt and currency crises are found to have a tendency to coincide or follow banking crises and thus seeming to support Kaminsky and Reinhart (1999) claims of twin crises.

Barrell and Karim (2019) adopted a logit model to analyse the determinants of financial crises in OECD countries from 1980 to 2017 with an emphasis on the role of bank capital, book liquidity availability, property prices, current account deficits and credit growth. Results were supportive of Barrell et al (2010a) with aggregate bank capital ratios, liquidity measures and property prices driving variations in crisis probabilities. They also found that the current account also has a significant effect but there was no role for any lending or crisis indicators unlike Schularick and Taylor (2012) – who did not include banking sector variables due to lack of data. Barrell and Karim (2019) concluded that policymakers need to contain banking excesses, not constrain the macroeconomy.

Along the same lines, De Haan, Fang and Jing (2020) investigated the relation between bank balance sheet structure variables and banking crises for a sample of 147 developing countries from 1980 to 2016. Results suggested that low levels of bank liquid assets and domestic financial liabilities, and high levels of foreign liabilities and financial leverage increases the likelihood of a banking crisis. Interestingly, such indicators have the best predictive power for banking crises about 3 and a half years ahead.

Finally, Davis et al. (2020) in a study of the impact of competition and capital on bank risk, found both the Lerner Index as a measure of banking sector competition, and both risk adjusted and unadjusted capital ratios help explain banking crises in 112 global countries. The deposit/asset and the loan/asset ratios were also significant control variables.

In this paper, we develop from Barrell et al (2010a) by adopting a wider sample of countries, using data up till 2017, with the Laeven and Valencia (2018) definition of systemic crises and testing further variables by adding them one by one to a baseline model. These additional variables were nonperforming loans, another leverage measure, banking concentration and a stock market measure.

3 Data and Methodology

As previously discussed, logit models are commonly used in determining the causes of banking crises (see for example Demirguc Kunt and Detragiache (1998, 2005), and Barrell et al (2010a)). However, the signal univariate extraction model has also been adopted on numerous occasions (See Kaminsky and Reinhart (1999), Borio and Lowe (2002) and Borio and Drehmann (2009)). This non-parametric approach assesses the behaviour of single variables prior to and after banking crisis episodes and attempts to identify the variables that best signal those episodes. Furthermore, binary recursive trees (see Duttagupta and Cashin (2008), Davis and Karim (2008a) and Davis, Karim and Liadze (2012)) can also be used which creates two nodes which attempts to identify a single variable that is deemed to be the most important in deriving whether an episode is a crisis or non-crisis. Based on the splitter

variables' non-linear interactions with previous splitter variables, sub-nodes are created which creates crisis probability and splitter threshold figures.

Davis and Karim (2008b) assessed and compared logit and signal extraction early warning systems (EWS) for banking crises on a comprehensive common dataset. They found that the choice of estimation techniques makes a difference in indicator performance and crisis prediction, thereby suggesting the multinomial logit model may be better suited to a global EWS. Transformations that take into account cross-country heterogeneity may, however, improve model specification as fixed effects estimation is not feasible with logit. Along the same lines, Berg and Pattillo (1999) agreed that logit and probit models have greater success in cross-country data. In addition, Demirgüç-Kunt and Detragiache (2000) showed that logit outperforms signal extraction in terms of type I and type II errors. As a result, it seems that logit models are more accurate as an EWS.

To test the significance of the factors contributing to a systemic banking crisis, we accordingly make use of a multivariate logit model due to the numerous advantages discussed above. As in the principal results of Barrell et al (2010a), the dependent variable, Yit takes the form of a dummy for country i with a value one if a systemic crisis begins in year t and zero otherwise. Logit estimates the likelihood of a crisis in a given country with a vector of independent variables, Xit and takes the form of equation (1):

$$\mathrm{Prob}(Y_{it}) = F(\beta X_{it}) = \frac{e^{\beta' X_{it}}}{1 + e^{\beta' X_{it}}} \qquad (1)$$

In equation (1): Yit is the systemic banking crisis dummy for country i at time t; β is the vector of coefficients; and F(βXit) is the cumulative logistic distribution.

To obtain actual parameter estimates, the log likelihood function is adopted and takes the form of equation (2):

$$\log_e L = \sum_{i=1}^{n} \sum_{t=1}^{T} [(Y_{it} \log_e F(\beta' X_{it})) + (1 - Y_{it}) \log_e (1 - (F(\beta' X_{it}))] \qquad (2)$$

In contrast to a standard OLS regression, the estimated coefficients for a logit model are not marginal effects and therefore do not imply an increase or decrease in crisis likelihood given a one-unit change in a given explanatory variable. However, coefficients signs can be easily interpreted as either representing an increase or decrease in crisis likelihood.

Regression results will have implications for macroprudential policy and provide a basis for future regulation to tackle the everchanging environment and activities of the banking industry. Results will show how the significance of the explanatory variables have changed over time, which factors are more or less influential and therefore scale of risk being reduced via the use of financial derivatives and off-balance sheet activities.

An important aspect of our study is the construction of the banking crisis dummy variable. Banking crisis definitions have varied across the literature with notable identifications obtained from Demirguc-Kunt and Detragiache (2005), Caprio and Klingebiel (2003) and Laeven and Valencia (2008, 2018). For example, Caprio et al (2005) defined a financial crisis as being present when at least one of following conditions hold; the proportion of non-performing loans to total banking system assets was greater than 10and; the public bailout cost exceeded 2 percent of GDP; a systemic crisis caused large scale bank nationalisation, and if not, emergency government intervention was sustained. We choose to adopt Laeven and Valencia (2018) as they stress the public sector intervention role and adopt a more restrictive criterion. They define a banking crisis as an event satisfying two conditions:

1) Significant signs of financial distress in the banking system (as indicated by significant bank runs, losses in the banking system, and/or bank liquidations).
2) Significant banking policy intervention measures in response to significant losses in the banking system

To ensure that the crisis is correctly dated, Laeven and Valencia consider the first year that the conditions are met to be the year that the crisis becomes systemic. As we are concerned with predicting a crisis and therefore the switching between a non-crisis to a crisis period, we assume the duration of a crisis to be one year.

The dataset is made up of 25 OECD countries including all 14 countries used in Barrell et al. (2010a) and contains 25 systemic crisis episodes according to Laeven and Valencia (2018) listed in Table 1. To align our study with previous literature, we include all of the explanatory variables used in Barrell et al. (2010a). However, instead of measuring liquidity via the ratio of the sum of cash and balances with central banks and securities for all banks over the end of year total assets, the ratio of bank liquid reserves to total assets is used (as the OECD income statement and balance sheet database used by the earlier work has been discontinued). Australia, Canada, and New Zealand have not experienced a crisis episode during the sample period and can be used as controls. Hungary, Sweden and United States suffered more than one crisis during the sample period possibly suggesting that there was an underlying weakness within the banking sectors that was not adequately addressed.

This paper starts using a general to specific approach by using all the Barrel et al. (2010a) variables and at each stage omitting the variable that was the least significant in order to be left with a baseline model. Omitting insignificant variables has the advantage of reducing over-specification bias and thus reduces the biases in the coefficients of the relevant variables that remain. Variables are all lagged by one period except for house price growth which has three lags as in Barrell et al. (2010a), due to it being an indication of potential lending problems arising because of a house price bubble. We also follow them in excluding measures of development such as GDP per capita as they are irrelevant to such OECD countries. All OECD countries also have some form of deposit insurance thus a deposit dummy is unnecessary.

Table 1: Sample composition, crisis onset years and duration

Country (ID)	Crisis onset and end year(s)
Australia (AUS)	
Austria (AUT)	2008-2012
Belgium (BEL)	2008-2012
Canada (CAN)	
Denmark (DEN)	2008-2009
Finland (FIN)	1991-1995
France (FRA)	2008-2009
Germany (GER)	2008-2009
Greece (GRC)	2008-2012
Hungary (HUN)	1991-1995, 2008-2012
Iceland (ISL)	2008-2012
Ireland (IRE)	2008-2012
Italy (ITA)	2008-2009
Japan (JAP)	1997-2001
Mexico (MEX)	1994-1996
Netherlands (NET)	2008-2009
New Zealand (NZL)	
Norway (NOR)	1991-1993
Poland (POL)	1992-1994
Portugal (POR)	2008-2012
Spain (SPA)	2008-2012
Sweden (SWE)	1991-1995, 2008-2009
Switzerland (CHE)	2008-2009
United Kingdom (UK)	2007-2011
United States (USA)	1998-1998, 2007-2011

Source: Laeven and Valencia (2018)

As noted, bank-specific variables aggregated to a sectoral level such as unweighted capital adequacy and liquidity as well as real housing price growth were first tested by Barrell et al (2010a) alongside 6 "traditional" variables: real GDP growth; real interest rate; inflation; budget balance to GD; M2 to total reserves; and real domestic credit growth. We include these variables alongside additional macroeconomic and banking specific variables that have not been widely used in the literature to date. As shown in Appendix Table A.1.,data are sourced from the World Bank's World Development Indicators (WDIs) database including their archives and World Economic Outlook (WEO) database, IMFs International Financial Statistics (IFS) database and OECDs public data available on their website. Data construction for capital adequacy and liquidity is undertaken via the World Bank's Global Financial Development Database (GFDD) and WDI respectively. We obtain an unbalanced panel dataset for the sample period 1987-2017. Data gaps are filled out where possible via each country's respective national sources such as their Central Bank or Statistical Office.

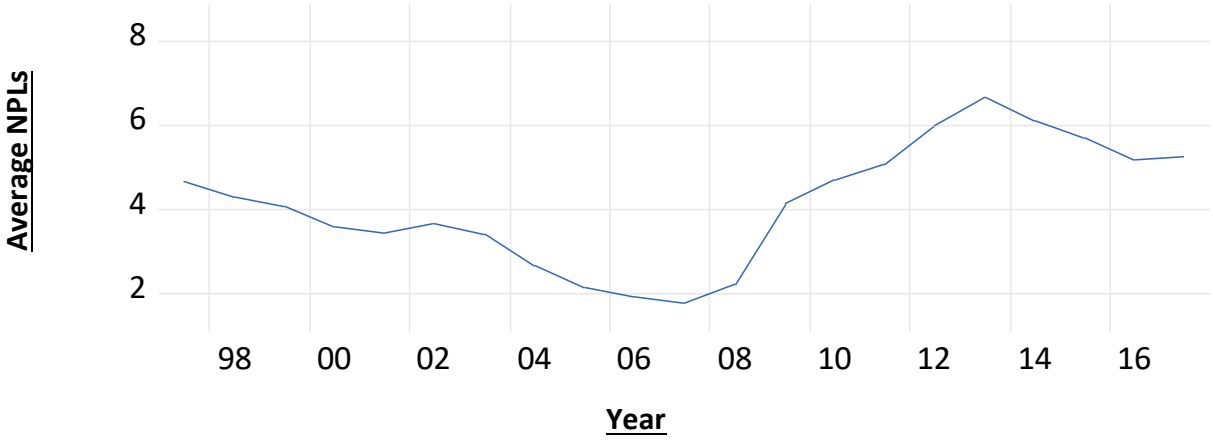
This paper then tests four explanatory variables that have either only recently entered the literature or have not been considered and therefore not extensively tested yet alongside typical variables including bank-specific factors. Each variable is added to the baseline model one by one to see its influence on the baseline model coefficients and their respective significance. If the additional variable is significant it is kept within the baseline model.

Adding a significant variable could potentially change the significance of the existing variables included in the baseline model and therefore may could be omitted if existing variables become insignificant in order to obtain a final specification. As noted, data sources with definitions for all variables are supplied within the Appendix Table A.1.

The first additional variable we include is non-performing loans (NPLs) to total gross loans as NPLs ultimately can lead to bank insolvency and banking crises are more severe when such insolvency occurs, particularly if it occurs for systemically important banks. A high ratio of NPLs to total loans is a particular problem within the banking industry as banks tend to be highly leveraged, i.e. debt to equity is high as banks tend to finance their activities via debt as it is relatively cheaper to hold compared to equity, i.e. bank capital. However, such high leverage leads to an enhanced risk of insolvency as capital is used as a cushion against loan losses. If the NPLs losses cannot be absorbed by the capital held, then the bank is insolvent. NPLs are expected to rise prior to a crisis and therefore can be used to foreshadow a systemic episode. Therefore, it's expected that the sign of the coefficient will be positive as higher NPLs to total loans will increase the likelihood of a crisis.

However, NPL data shown in figure 1 shows a different pattern. Contrary to data collected in Čihák and Schaeck (2010), nonperforming loans to total gross loans do not behave intuitively. Prior to a crisis, it is expected that nonperforming loans will rise implying a deterioration in bank loan quality. However, before the GFC that started in 2007, nonperforming loans actually showed a decrease. Nonperforming loans then rose substantially after the 2007 onset and is more than three times higher in 2013 compared to 2007. It is therefore evident that nonperforming loans appear slow to react to the onset of a crisis and then fully recognised with a time lag as in Čihák and Schaeck (2010). Interestingly enough, 10 years after the GFC onset, average nonperforming loans remained high and relatively stable around the 5and mark. The crisis onset data is heavily influenced by the recent GFC data and therefore, it seems that a negative correlation might be expected between the probability of a systemic crisis and the ratio of nonperforming loans to total gross loans.

Figure 1: Average nonperforming loans to total gross loans for 25 OECD countries (1997-2017)



Secondly, we not only test for inclusion of unweighted capital adequacy (LEV1) which is usually called the leverage ratio as in Barrell et al (2010a) but also another form of leverage known as LEV2. LEV1 is measured via the ratio of bank capital and reserves to total assets,

whereas LEV2 is the ratio between selected banking sector assets and their total equity and is also known as the bank equity multiplier ratio (Hagino and Cavieres (2013), OECD (2021)). The selected assets cover currency and deposits, debt securities and loans. Higher capital adequacy or equity multiplier means lower leverage in the traditional economic sense of debt-to-equity.

Financial institutions traditionally have had low capital levels relative to their total assets held but after the GFC, more attention has been given to highly leveraged balance sheets and their role in the build-up of systemic issues. The equity multiplier directly measures the value of assets being financed by bank equity and conversely, also represents the level of debt that is financing assets. It may better capture "shadow banking" activities than the traditional leverage measure (Hagino and Cavieres 2013). Debt is more attractive to hold than equity capital as debt is a tax-deductible expense unlike dividends paid to shareholders. In addition, bank debt is normally in the form of deposits where depositors are willing to accept lower interest yields due to the instant liquidity achieved from deposits. Furthermore, all OECD countries have some form of deposit insurance which is beneficial for depositors but can encourage excess risk-taking strategies and indeed moral hazard as banks are not liable for deposit losses. Such features of debt have led to highly leveraged balance sheets, i.e. debt to equity being too high and capital to assets being too low. Therefore, banks determine their likelihood of insolvency depending on the leverage they choose to operate at according to private calculations of profit and loss and may ignore the wider social costs of their failure, which may be sizeable for systemically large and important banks. This is a key justification for banking regulation.

The reasoning for assessing LEV2 as well as LEV1 is that given an alternative definition of leverage, we need to assess whether such differences alter its importance to crisis likelihood. As a result, results will show which leverage measure is more appropriate to be used upon determining which macroprudential regulations should be adopted to tackle issues arising from highly leveraged balance sheets. If LEV2 is more significant then LEV1, this suggests that macroprudential policy is likely to be more effective in reducing future crises if requirements were measured via the equity multiplier ratio instead of bank capital and reserves to total assets ratio.

Note that the Basel III macroprudential accord has used capital requirements which include calculating risk weighted assets (RWAs) as well as a leverage ratio which uses non risk weighted assets similar to our LEV1. Even though it is expected that RWAs are a useful indicator of systemic issues, such risk weighting measures have been subject to major criticism as to whether risk weights are appropriately assigned. In addition, data restrictions on such a measure have led to its exclusion.

Thirdly, bank concentration is included as another specific bank variable to be tested as in Beck et al. (2006). Bank concentration is defined as the assets of the three largest commercial banks as a share of total commercial banking assets. The inclusion of bank concentration is influenced by the concentration-stability view argument which suggests that banking systems with a few large banks are more stable than less concentrated systems.

A final additional variable to be tested is stock market capitalisation (SMC) which measures the total value of listed shares on the stock market as a percentage of GDP. Such a measure is potentially useful as a leading indicator of systemic issues especially when an asset price bubble is about to burst. It seems that bank failures may not be due to exposure to other

bank failures but rather due to exposure to the same common shock either through economic downturns or downturns within the stock and real estate markets.

Increases in the stock market capitalisation to GDP reflect that consumer optimism has risen as prices of stock will reflect investors collective assessment of a firms current performance and future performance as stated in Bodie, Kane and Marcus (2013). Stock prices play an integral role in the economy as a higher price encourages investments as its easier to raise capital for business as asset values may be used to support borrowing. In a rising stock market, economic activity grows and fills the economy with confidence. Businesses and consumers are therefore more likely to borrow for capital investment and consumer purchases. Banks are likely to drop their credit standards and be vulnerable to adverse selection of borrowers. James (1987) found that banking loans were special and that there is a positive and statistically significant stock price response to borrowers' bank loan approval. As a result, the credit expansion prior to the GFC probably enhanced stock market capitalisation as well as real estate prices.

The beginning of June 2007 saw stock prices fall considerably and such a depreciation of assets was triggered by falling real estate prices aggravated by the opaque structure of many mortgage bonds that had been issued and widely held by banks. In turn, this led to defaults and banks having to cover losses via capital. Interbank lending came to a halt as asymmetric information and shattered confidence led banks to be cautious and unwilling to take on the risk. To keep capital at a reasonable operating level, banks were forced to sell a large number of their assets causing asset price spirals as well as market liquidity crises as a large number of banks attempted to sell simultaneously.

Table 2: Summary statistics

	Mean	Median	Max	Min	Standard deviation	No. of observations
YG	**2.32**	**2.40**	**25.10**	**-11.90**	**2.67**	800
RIR	**4.46**	4.26	15.14	-58.85	4.32	781
INFL	**5.08**	2.34	567.88	-4.48	23.25	801
BB	**-2.49**	-2.62	18.63	-32.07	4.33	790
M2RES	**17.06**	9.20	293.76	1.22	26.39	734
RDCG	**1.20**	1.22	5.08	0.16	0.53	768
LIQ	**5.12**	2.31	63.77	0.18	6.91	750
LEV1	**6.70**	6.19	21.10	2.40	2.58	493
RHPG	**2.53**	2.15	45.52	-21.86	7.00	684
NPL	**4.51**	2.70	45.57	0.08	5.82	535
LEV2	**16.51**	13.33	103.36	3.96	11.86	495
SMC	**60.84**	48.93	263.75	0.18	45.97	727
CONC	**69.87**	69.85	100.00	20.19	19.11	560

Note: YG – real GDP growth, RIR – real interest rate, INFL – inflation, BB – budget balance to GDP ratio, M2RES – M2 to reserves ratio, RDCG – real domestic credit growth, LIQ – liquidity ratio, LEV1 – unweighted capital adequacy ratio, RHPG – real house price growth, NPL – Bank nonperforming loans to total gross loans, LEV2 – equity multiplier ratio, SMC – stock market capitalisation to GDP ratio, CONC – bank concentration ratio.

Table 2 shows summary statistics for our sample. The maximum inflation is very high due to hyperinflation within Poland during the early 1990s, but such extremes were not excluded as this research wants to gather the realistic nature of markets. Note that observations are markedly lower for both leverage measures compared to traditional macro variables. Also,

observations for nonperforming loans and stock market capitalisation are around the 550 mark. On average, liquidity and LEV1 measures are similar but liquidity has a much greater maximum value and a lower minimum value. The equity multiplier ratio as expected has a much higher maximum than the leverage ratio and a similar number of observations making a comparison rather interesting. We also note that OECD banking systems on average are rather concentrated and keep relatively low levels of liquidity and capital.

Table 3: Correlation matrix

	YG	RIR	INFL	BB	M2RES	RDCG	LIQ	LEV1	RHPG	NPL	LEV2	SMC	CONC
YG	1												
RIR	-0.17	1											
INFL	0.15	-0.06	1										
BB	0.35	-0.36	0.21	1									
M2RES	0.04	0.10	0.10	-0.20	1								
RDCG	-0.02	-0.23	-0.09	-0.02	0.20	1							
LIQ	-0.09	-0.01	0.05	-0.15	-0.20	-0.16	1						
LEV1	0.12	0.04	0.04	-0.05	-0.00	0.11	0.31	1					
RHPG	0.58	-0.24	0.04	0.44	-0.05	-0.04	-0.16	0.08	1				
NPL	-0.34	0.39	-0.18	-0.40	0.16	-0.22	0.06	0.15	-0.37	1			
LEV2	-0.36	-0.12	-0.27	-0.13	-0.04	0.14	0.12	-0.37	-0.25	0.08	1		
SMC	0.39	-0.19	0.01	0.23	0.04	0.38	-0.10	0.15	0.30	-0.41	-0.19	1	
CONC	0.05	-0.13	0.10	0.43	-0.10	-0.24	-0.28	-0.35	0.12	-0.12	-0.12	-0.13	1

As evident within the correlation matrix (Table 3), multicollinearity should not be a problem as all except one relationship has a correlation of below 0.5. Real housing price growth is correlated above 0.5 with real GDP growth, but such a correlation is reasonable and is likely to arise due to the cyclical nature of housing price booms. Both leverage variables are relatively strongly negatively correlated with each other at -0.37. This makes sense as a higher capital to asset ratio (LEV1) means that less assets can be financed via debt (LEV2).

4 Results

Table 4: The general to specific approach

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
BB(-1)	0.006 (0.09)	-	-	-	-	-	-
INFL(-1)	0.024 (0.09)	0.025 (0.095)	-	-	-	-	-
RDCG(-1)	-0.149 (-0.28)	-0.138 (-0.27)	-0.123 (-0.25)	-	-	-	-
LEV1(-1)	-0.010 (-0.57)	-0.101 (-0.58)	-0.101 (-0.58)	-0.108 (-0.63)	-	-	-
RIR(-1)	0.163 (1.46)	0.161 (1.47)	0.160 (1.47)	0.148 (1.50)	0.092 (1.14)	-	-
YG(-1)	0.288** (2.01)	0.291** (2.11)	0.292** (2.12)	0.285** (2.12)	0.153 (1.51)	0.125 (1.28)	-
M2RES(-1)	0.009* (1.73)	0.009* (1.75)	0.009* (1.87)	0.009* (1.86)	0.010** (2.25)	0.008* (1.90)	0.008* (1.88)
LIQ(-1)	-0.141 (-0.75)	-0.143 (-0.76)	-0.141 (-0.76)	-0.124 (-0.74)	-0.194 (-1.42)	-0.199 (-1.56)	-0.218* (-1.70)
RHPG(-3)	0.057 (1.31)	0.058 (1.35)	0.059 (1.53)	0.058 (1.50)	0.085*** (2.64)	0.010*** (3.23)	0.105*** (3.42)
Sample	1999- 2017	1999- 2017	1999- 2017	1999- 2017	1990- 2017	1990- 2017	1990- 2017
Number of crises	13	13	13	13	17	19	19
Number of observations	336	336	336	336	516	531	531

Note: z-Statistics in parentheses and variable definitions in appendix. *denotes significance at 10% level, **denotes significance at 5% level and *** denotes significance at 1% level.

Table 4 shows the nested testing of the crisis prediction model. Contrary to Barrell et al. (2010a), the final specification, the baseline model within this research excludes unadjusted capital adequacy (LEV1) which is the least significant variable in specification 4 and therefore eliminated. We note that our source, the Global Financial Development Database only has LEV1 from 1998 and hence the difference with Barrell et al (2010a) may link to the omission of 1990s crises in our estimation. This accounts for the jump in data from equation (4) to equation (5). We note that the result for LEV1 also holds if one restricts the sample to the 14 countries that Barrell et al (2010a) focused on. It suggests that the explanatory power found by Barrell et al (2010a) arose from the crises of the 1990s, while it is not significant for explaining the GFC crises alone.

A further possible explanation for lesser significance of LEV1 is that following the GFC, many lessons have been learned and regulatory gaps filled thus reducing its importance, or it may link to the wider range of countries covered in our work. The former point might suggest

that today both countries and creditors have learned from their mistakes, and the world is unlikely to see a major wave of defaults due to better-informed macroeconomics and more discriminating lending practices. However, such a view is not likely to hold in the long run as the ever-changing landscape and innovation of the banking industry will most likely bring a new batch of systemic issues, leading people again to assert “this time it’s different” as noted for the GFC by Reinhart and Rogoff (2009).

Another possible explanation of LEV1 being insignificant is that after the GFC, regulatory measures, notably Basel III, strengthened defence mechanisms such as unweighted capital adequacy but comparatively, liquidity retains its explanatory power. Intuitively, this makes sense as the risk of illiquidity usually is amongst the first to arise within a crisis and when liquidity fails it often provides a trigger for insolvency where levels of capital are not able to sufficiently absorb asset losses. It therefore seems that our sample of 1987-2017 is heavily influenced by the GFC and thus 2007 onwards with leverage ratios probably being a cause of the GFC. Since regulatory measures have focused on resolving the low levels of leverage ratios seen prior and during the GFC, leverage ratios may have lost their significance.

Table 4 shows that all ”traditional“ variables are insignificant in the context of OECD countries except for one, M2 to total reserves (also identified as broad money to total reserves), which is found to be significant alongside liquidity and real housing price growth. Such a result could be due to a combination of reasons such as a wider sample of countries, different sample periods of 1990-2017 compared to 1980-2007 and different crisis onset definitions. Barrell et al. (2010a) also include non-systemic crises, however, even when they include only systemic episodes, they find that their results are robust.

M2 to total foreign exchange reserves is a measure of external vulnerability that gauges domestic demand for foreign assets. The positive sign of the coefficient indicates that an increase in the ratio will increase crisis likelihood and supports results in papers such as Demirgüç-Kunt and Detragiache (1998 and Klomp (2010). This makes sense as a high amount of reserves (i.e. lower M2 to reserves ratio) can aid in promoting price and financial stability as they can be used to provide another source of liquidity and mitigate the effects of a credit crunch. Such a relationship clearly applied to the Tequila crisis in Mexico which saw a severe ratio increase prior to the crisis. This ratio is therefore suggesting that OECD countries are increasingly vulnerable to banking crises linked to external vulnerability as argued by Calvo (1996).

Coefficient signs and significance of liquidity and real house price growth are in line with Barrel et al (2010a) and Karim et al (2013). Intuitively, banking systems with greater liquidity prior to a year of a banking crisis are less likely to collapse and be subject to contagious bank runs, collapsing dominoes effects and asset price spirals. Increases in real house price growth 3 years prior to a crisis suggests a higher likelihood of banking system collapse. When property prices are rising, the public and banks alike are all filled with optimism and confidence. In turn, there is likely to be a prolonged period of credit growth within mortgage markets as loan applicants are more likely to apply for riskier mortgages in the hopes of profiting from such housing price growth. Banks are more likely to accept riskier mortgage applications and drop credit standards. As a result, the possibility of defaults and banking crises increases.

Table 5: Baseline model with additional variables

	(1)	(2)	(3)	(4)
M2RES(-1)	0.009**(1.96)	0.010**(2.15)	0.008*(1.86)	0.009**(2.00)
LIQ(-1)	-0.139 (-0.93)	-0.142 (-1.01)	-0.211 (-1.40)	-0.150 (-1.21)
RHPG(-3)	0.076*(1.77)	0.073*(1.95)	0.093***(2.68)	0.010***(3.24)
NPL(-1)	-0.134 (-0.88)			
LEV2(-1)		-0.034 (-0.86)		
CONC(-1)			-0.003 (-0.20)	
SMC(-1)				0.008*(1.65)
Sample	1993-2017	1996-2017	1997-2017	1990-2017
Number of crises	13	14	16	19
Number of observations	380	356	398	510

Note: z-Statistics in parentheses and variable definitions in appendix. *denotes significance at 10% level, **denotes significance at 5% level and *** denotes significance at 1% level.

Table 5 shows results for the addition of variables one by one to the baseline model. Interestingly adding nonperforming loans alters the significance of liquidity making the variable insignificant with a p-value of 0.3499. However, nonperforming loans is the most insignificant variable with a p-value of 0.3811 and therefore, the baseline remains unchanged. In line with this, Čihák and Schaeck (2010) also found the variable to be insignificant.

We note that banking sector concentration is also not significant, contrary to Beck et al (2006). An argument against concentration is that banking systems may be that it does not allow for the impact on risk taking of potential competition from outside the sector (e.g. from cross border lending, securities markets or non-bank lending), and thus the possibility of contestability, which depends in turn on whether there are barriers to entry and exit in the market. A potentially superior measure to concentration as a measure of market power is the Lerner Index as in Davis et al (2020), which we recommend in the conclusion for further investigation.

Meanwhile although the variableLEV2, the banking equity multiplier, shows some promise in showing risks arising from both actual and shadow banking, it does not show as significant over our particular sample.

The most intriguing finding is that adding stock market capitalisation to the baseline model renders liquidity insignificant and therefore it can justifiably be dropped out of the model. Table 6 presents the final specification which suggests that the most important factors in determining a banking crisis episode are vulnerabilities through the stock and real estate markets but also externally through the ratio of broad money to total foreign exchange reserves. All OECD countries within this sample can be considered as industrialised economies with an exception of Mexico and it has been argued by Shezad and De Haan (2013) that banks in industrialised economies have been hit by the financial crisis differently than those in emerging economies. They also found that large bank stock prices were more affected during the crisis than those of small banks. This is an interesting finding as many systemically important banks within our sample of countries had experienced insolvency and many had to be bailed out.

Furthermore, Shezad and De Haan (2013) showed that banks stock growth is negatively affected by lower managerial efficiency, loan quality, higher leveraged balance sheets and loan volumes. As a result, it seems that stock market downward movements particularly within the banking sector contain valuable information that makes it a significant determinant of systemic crises within this research.

Table 6: Final specification (1990-2017)

Variable	Coefficient	z-Statistic	Prob.
M2RES(-1)	0.0104***	2.5211	0.0117
RHPG(-3)	0.0872***	3.3518	0.0008
SMC (-1)	0.0094***	2.1945	0.0282

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

Previous work has not considered and found such significant relationships for all three variables simultaneously and therefore, past findings potentially may exhibit omitted variable bias. Table 7 presents the marginal effects of the final specification as coefficients in a logit model cannot be simply interpreted as in standard OLS regressions. As in Barrell et al. (2010a), it is customary to compute the marginal effects of the two remaining variables whilst holding the other variables at their respective sample means, since the marginal effects is influenced by the values other variables take.

Table 7: Marginal effect of a one percent rise in a variable on the probability of a crisis – Final model (1990-2017)

	M2RES	RHPG	SMC
AUS	0.028	0.027	0.015
AUT	0.013	0.014	0.012
BEL	0.021	0.023	0.015
CAN	0.033	0.039	0.016
DEN	0.018	0.016	0.012
FIN	0.019	0.023	0.010
FRA	0.020	0.021	0.013
GER	0.013	0.017	0.011
GRC	0.014	0.019	0.014
HUN	0.014	0.012	0.012
ISL	0.023	0.018	0.014
IRE	0.020	0.036	0.030
ITA	0.012	0.015	0.010
JAP	0.016	0.026	0.011
MEX	0.013	0.013	0.010
NET	0.026	0.026	0.014
NZL	0.019	0.015	0.015
NOR	0.018	0.015	0.013
POL	0.016	0.012	0.014
POR	0.012	0.014	0.010
SPA	0.019	0.023	0.014
SWE	0.026	0.022	0.013
CHE	0.047	0.054	0.009
UK	0.032	0.039	0.016
USA	0.029	0.040	0.015
Average	0.021	0.023	0.014

On average, real house price growth has the highest marginal impact on crisis likelihood by an increase of 0.023and. Interestingly, stock market capitalisation to GDP has the smallest average marginal increase out of the indicators suggesting that external vulnerability and shocks to the real estate market are relatively more influential in crisis likelihood.

Many economies suffered during the GFC, but Canada was a prominent exception. Therefore, a rather intriguing finding is the marginal effects of broad money to total reserves and property price growth for Canada as they are reasonably high at 0.033% and 0.039% respectively and similar to that of the United States. Bordo, Redish and Rockoff (2015) argued that the concentrated Canadian banking system that evolved by the end of the twentieth century was able to absorb the systemic risks of the mortgage market and investment banking sector and was tightly regulated. In contrast, the relatively weak and crisis-prone US banking system that had evolved did not contain systemic risks that arose due to the rise of securitisation, investment banks and money market mutual funds alongside multiple competing regulators. Possibly the historical fundamental foundations of

banking systems have made some countries more resilient to systemic issues. However, the concentration variable was found to be insignificant.

A one-point rise in stock market capitalisation to GDP, whilst holding other variables constant, will lead to a rise in crisis likelihood of at least 0.009% (Switzerland) and at most 0.030% (Ireland). Even though Ireland did not have the highest average ratio for stock market capitalisation, it has the highest marginal effect amongst all countries. As previously stated, the marginal effects are dependent upon the other variable values and therefore, in practice, the combinations of the three leading indicators will underline each individual indicator impact as all interact.

Comparing our common country real house price growth marginal effects to those of Barrell et al. (2010a), only Denmark and Spain have seen increases within the up-to-date sample. It appears that the banking system markets are more resilient to increases in property price growth. Overall, the marginal effects obtained seem to be considerably lower but clearly, some caution is needed as our final specification varies. The final specification is robust and remains unchanged when we individually exclude observations for UK and the US. Results are also robust to varying crisis durations.

Table 8: In-sample performance

	Dep=0	**Dep=1**	**Total**
P(Dep=1) <0.038	362	7	369
P(Dep=1)>0.038	145	13	158
Total	507	20	527
Correct	362	13	375
% Correct	71.4	65	71.16
% Incorrect	28.6	35	28.84

The final specification's in-sample predictive performance is shown in table 8 using the in-sample average occurrence of a crisis as the cut-off threshold. Given the final specification has a sample containing 20 crises over 527 observations, the cut-off rate obtained is 0.038 (3.8%). Its in-sample predictive performance is strong as it calls out 13 crises correctly based upon a total of 20 crises. The EWS misses out on the crises of 2008 in Belgium, Germany, Italy and Portugal, 1991 in Norway and Sweden, and lastly, 1997 in Japan. Interestingly enough, the EWS calls the crisis correctly in Sweden for 2008 even though it is considered under Laeven and Valencia (2018) as a borderline case.

The EWS has 145 false crisis calls which seem reasonable when comparing against that of Barrell et al. (2010a) who have obtained a similar incorrect false call rate of 29% with a threshold of 0.032. Overall, the EWS has type II errors of 28.84% and type I errors of 35%. This research stands up well in comparison to others such as DemirgücKunt and Detragiache (2005) that had a 0.05 threshold giving an overall success rate of 69% and type II and I errors of 32% and 39% respectively.

As expressed in Davis and Karim (2020) there is a trade-off between type I and II errors since changing the threshold to reduce one error will necessarily increase the occurrence of the other. Therefore, policymakers can adjust such a threshold to meet their demands and

preferences. Cautious policymakers (i.e. highly risk-averse) that want to prevent a crisis by all means will find type I errors to be of more importance relative to type II errors.

Table 9: Specification with only LEV1 and LEV2

	(1)
LEV1(-1)	-0.138 (-0.85)
LEV2(-1)	-0.015 (-0.54)
Sample	1999-2017
Number of crises	14
Number of observations	381

Note: z-Statistics in parentheses

Table 9 shows the results for a regression including only capital adequacy and the equity multiplier to determine which measure is more informative. Both leverage indicators are insignificant but LEV1 is relatively more significant with a lower p-value of 0.3972 compared to 0.5874. As a result, it seems that capital and reserves to total assets (LEV1) is the measure to use when analysing leverage and its effect on a crisis occurrence.

5 Policy Implications

As a result of the final specification, it seems that the defences of capital and liquidity have lost considerable power in determining systemic banking episodes. Even when using just Barrell et al. (2010a) specification, leverage is not significant, but liquidity is, suggesting that liquidity issues are relatively more important. Therefore, policies targeting risks from excessive leverage and systemic liquidity risk have less predictive power.

Real house price growth retains significance from the previous literature and therefore, it seems that banks need to be extremely cautious in housing booms. Intuitively, this makes sense since banks are profit maximising institutions just like any other business and their main goal of operating within the market is to achieve that. Evidently during the GFC, banks are more willing to lend to riskier borrowers and borrowers are more tempted to apply for riskier mortgages in the hopes of profiting from such pricing growths. Taylor (2009) argued that the low interest rates by central banks encouraged greater ease and availability of mortgages which in turn inflated the housing bubble. Such a combination led to excessive risk-taking on a macroeconomic and banking level. Given periods of inflated bubbles within the stock and real estate markets, liquidity and capital requirements should be adjusted accordingly amongst other defences if present. As a result, a macroprudential tool such as counter-cyclical requirements that adjust to changes and severity of market risk seems to be reasonable. Measures that could be adjusted to have larger countercyclical impacts are caps on the loan-to-value and debt-to-income ratio for mortgage lending.

Stress testing should occur regularly and consider the worst scenarios even if such scenarios seem unlikely to occur. Considering the worst scenarios and ranges of scenarios will ensure that risk management techniques are prudent and that the banking system is robust to whatever scenario it faces.

Imposing lending limits could constrain the macroeconomy, but costs likely to be borne during a GFC are far more severe to the economy therefore lending limits on asset based lending could limit the severity and period of lost output. This situation is more severe when a housing bubble persists and then unexpectedly bursts causing the number of bad loans to

increase and many borrowers to default on their mortgages. Various macroprudential measures could achieve this such as loan-to-value limits, debt service to income limits and direct limits on credit growth.

Central banks could hold greater foreign exchange reserves to provide an alternative source of liquidity when international interbank lending comes to a halt. The Asian central banks did build up reserves in this way after the crises of the late 1990s. However, such an approach can be costly. A possibly more appropriate measure would focus on banks having access to long-term sources of liquidity and therefore, macroprudential policy should encouraged stable sources of liquidity as in the Basel III Net Stable Funding Ratio.

We recommend not to use a singular macroprudential tool but multiple ones as different tools can target the same systemic risk from multiple angles as noted in Lim et al (2011). However, caution is required as regulation should constrain the economy as little as needed. Central banks can also adjust monetary policies to align with macroprudential policy to achieve and complement their goals.

6 Conclusion

This paper highlights estimates of equations for early warning systems for banking crises in a wide sample of OECD countries using variables similar to Barrell et al. (2010a) which notably include measures of bank capital, liquidity and property price growth. Adopting a sample of 25 OECD countries for the period 1987-2017, we obtain a baseline model for 1990-2017. Interestingly, the baseline model we obtain excludes unadjusted capital adequacy as a leading indicator of banking crises. Instead, we find the ratio of M2 to total foreign exchange reserves to be significant alongside liquidity and real housing price growth as leading indicators for banking crises. Property prices and the ratio of M2 to total foreign exchange reserves have a positive impact on banking crisis probabilities as expected, whereas liquidity has a negative impact.

Secondly, this research tests four additional variables, namely nonperforming loans, another form of capital adequacy known as the equity multiplier ratio, banking concentration and stock market capitalisation that were excluded in Barrell et al. (2010a). Such variables have not been extensively tested alongside bank specific variables. Adding each variable one-by-one to the baseline model, we find that only stock market capitalisation is a significant leading indicator. Notably, liquidity drops out of the baseline model to lead us to a final speciation containing M2 to total foreign exchange reserves, real house price growth and stock market capitalisation/GDP. As a result, it seems that systemic banking episodes are heavily influenced by vulnerabilities arising through sudden international capital flows and asset market movements – stock and real estate.

Results have important implications for macroprudential policy and underline the need for having sufficient foreign exchange reserves to provide an alternative liquidity source. A major lesson from the GFC is one of over-reliance on short-term liquidity providers, especially the interbank market which collapsed and froze lending. When such funds dry up, many banks attempted to sell assets simultaneously causing asset price spirals and further losses which erode bank capital increasing the risk of insolvency. Once a systematically important bank such as Lehman Brothers collapsed, the consequences are magnified as seen by the resultant collapse of many banks even if they have healthy balance sheets.

In terms of future research, there's scope for early warning systems that consider macroprudential ratios alongside "traditional" variables and bank specific variables over a wide range of countries, not just OECD. As capital adequacy, liquidity and property prices have only entered the literature within the last 10 years, there is scope to test them alongside other variables especially bank specific and macroprudential ratios depending upon data availability. Future research could look at risk adjusted capital adequacy instead of leverage ratio and assess competition measures such as the Lerner Index instead of concentration. It could also entail deriving data for the unadjusted bank capital/assets ratio (LEV1) for the 1990s using Fitch-Connect banking data to further test its significance on data up to 2017.

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Appendix

Table A.1 – Description of the explanatory variables and sources

Variable name	Definition	Source
YG (and)	Real GDP growth	IMFs International Financial Statistics
RIR (and)	Lending interest rate adjusted for inflation as measured by the GDP deflator. Calculated as (i-P)/ (1 + P), where i is the nominal lending interest rate and P is the inflation rate. If inflation measured by GDP deflator is unavailable, then inflation measured by CPI is used.	World Bank's World Development Indicators
INFL (and)	Inflation as measured by the consumer price index reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly.	World Bank's World Development Indicators
BB (and)	Ratio of fiscal surplus or deficit to GDP.	World Bank's World Economic Outlook database, if years unavailable then the World Bank's World Development Indicators used to fill gaps
M2RES (and)	Ratio of M2 to Central Banks foreign exchange reserves (identical to broad money to total reserves ratio) Money and quasi money comprise the sum of currency outside banks, demand deposits other than those of the central government, and the time, savings, and foreign currency deposits of resident sectors other than the central government.	World Bank's World Development Indicators and archive where necessary

RDCG (and)	Rate of real domestic credit growth. Calculated by dividing domestic credit to the private sector by the GDP deflator	World Bank's World Development Indicators, if years unavailable then gap in domestic credit to private sector data taken from the Global Financial Development Database.
LIQ (and)	Ratio of bank liquid reserves to bank assets is the ratio of domestic currency holdings and deposits with the monetary authorities to claims on other governments, nonfinancial public enterprises, the private sector, and other banking institutions.	World Bank's World Development Indicators (including archives)
LEV1 (and)	Capital adequacy is measured via the bank capital to total assets where capital also includes reserves. Capital and reserves include funds contributed by owners, retained earnings, general and special reserves, provisions, and valuation adjustments. Capital includes tier 1 capital (paid-up shares and common stock), which is a common feature in all countries' banking systems, and total regulatory capital, which includes several specified types of subordinated debt instruments that need not be repaid if the funds are required to maintain minimum capital levels (these comprise tier 2 and tier 3 capital). Total assets include all nonfinancial and financial assets.	Global Financial Development Database
RHPG (and)	Real house price growth. The real house price is given by the ratio of nominal price to the consumers' expenditure deflator in each	OECD

	country, both seasonally adjusted, from the OECD national accounts database.	
NPL (and)	Bank nonperforming loans to total gross loans are the value of nonperforming loans divided by the total value of the loan portfolio (including nonperforming loans before the deduction of specific loan-loss provisions). The loan amount recorded as nonperforming should be the gross value of the loan as recorded on the balance sheet, not just the amount that is overdue.	Global Financial Development Database, If years unavailable then World Bank's World Development Indicators
LEV2 (and)	Leverage 2 is the ratio between selected financial assets of the banking sector and their total equity; it is also known as the equity multiplier ratio (or financial leverage). The banking sector covers the central bank, and monetary financial institutions, as well as other financial intermediaries (except insurance corporations and pension funds). The financial assets cover currency and deposits; debt securities; and loans. Total equity relates to the market value of equity, excluding investment fund shares.	OECD
SMC (and)	Stock market capitalisation to GDP	Global Financial Development Database
CONC (and)	Bank concentration is a measure of the assets of the three largest commercial banks as a share of total commercial banking assets	Global Financial Development Database

Data issues and potential limitations

Unless specified, gaps in the data have been filled from various sources such as the WDI archive, world economic outlook database, OECD website and the IMF's International Financial Statistics (IFS). In some cases, data on a particular explanatory variables varies in the WDI archive as fifty versions of the WDI exist within archives. As a result, data for a specific variable may be taken from multiple versions of the WDI in an attempt to make data as complete as possible. In turn, accuracy and validity of results could be questionable as multiple versions may adopt different methodology in obtaining data for a specific variable leaving to slight differences in a variable data even though the year they are calculated for is exactly the same.

Austria

Gaps in real interest rate covered by national sources such as Austria's national bank. Lending rates for new business to households used in the above real interest rate formula.

Denmark

Real interest rate data not available via World Bank's WDIs. Data obtained from Denmark's national bank website. Official lending rate used, if not available then discount rate. Real interest rate calculated via formula in table above.

Finland

NPL to total gross loan data for 1992, 1994-1996. Obtained from Bank for International Settlements (BIS), 1996. "Table VI.5: Non-performing loans as a percentage of total loans." Source in: BIS 67th Annual Report, 1996/97, BIS, Basle, Switzerland.

Poland

NPL to total gross loans data for 1991-1996. Obtained from Table 3. Soundness of the Banking Sector: Nonperforming Loans." Source in: "Banking crises in transition economies: fiscal costs and related issues (English)." Policy Research Working Paper No. 2484, World Bank, Washington, DC.

Norway

NPL to total gross loans data for 92-97. Obtained from Norges Bank. International Monetary Fund (IMF), 2005. "Table 3. Norway: Bank Financial Soundness Indicators (FSIs)." Source in: "Norway: Financial System Stability Assessment, including Reports on the Observance of Standards and Codes on the following topics: Banking Supervision, Insurance Regulation, and Payment Systems." IMF Country Report No. 05/200, IMF, Washington, DC

Gaps in real interest data are calculated by replacing the lending rate by the key policy rate (sight deposit rate) which is taken from Norges bank website.

Spain

Legal interest rate from Bank of Spain used to calculate real interest rate for 2017.

Sweden

NPL to total gross loans data for 1992 and 1994-1996. Obtained from Bank for International Settlements (BIS), 1996. "Table VI.5: Non-performing loans as a percentage of total loans." Source in: BIS 67th Annual Report, 1996/97, BIS, Basle, Switzerland.

Real interest date – calculated via obtaining the lending rate via the Riksbank but only goes back to 2012, so data is missing for 2007-2011.

United Kingdom

Gaps in real interest rate for period 2015-2017 calculated by using the annual average of the official bank rate as the lending rate via the Bank of England data.