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How vulnerable is the Canadian banking system to fire-sales?

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Abstract

Using a model based on the work of Duarte and Eisenbach (2015), I stress test the Canadian banking system using publicly available data from 1996 to 2015. I find that the Canadian banking system is resilient to all but the most extreme event. This is because (i) strong macroprudential regulation in Canada improves the quality of assets, (ii) given a scenario of severe losses, banks retain a sufficient quantity of liquid assets that these could be used to meet short-term liabilities, and (iii) sufficient equity is available to absorb losses. However there remain some areas of concern. Using aggregate vulnerability (AV), I find that the Canadian banking system has become more vulnerable to a fire-sale episode since 2011 and this raises the possibility of future losses. I focus my study on Canadian assets, but these have grown much faster than the overall economy since 2004. The concentration of loans-to-households, including residential mortgages and consumer loans, should be of some concern to regulators. Indeed, recent government announcements and policy changes reflect an overall concern with the ability of households to repay their loans. In the fourth quarter of 2015, if the government decided to remove its explicit guarantee of mortgage insurance, losses due to a fire-sale event would have been 20 percent higher.

1 Introduction

How resilient are the balance sheets of Canadian banks to a crisis? The banking system in Canada is perceived to be one of most resilient in the world. According to the World Economic Forum in 2016, the Canadian banking system slipped from first to third in soundness of banks behind only Finland and South Africa. However much of this study is based on survey results[1]. The Bank for International Settlements (BIS) warned that Canada appears vulnerable to a financial crisis. This is based on credit to GDP levels that in March 2017 were some of the largest among developed nations, and Canadian households were highly vulnerable to an increase in interest rates. BIS estimates that a 250 basis point increase in rates would have increased the average debt-service ratio from 3.6 to 7.9 per cent. To quantify some of these risks, I measure the vulnerability of Canadian bank balance sheets to a fire-sale event. Duarte and Eisenbach (2015) and Greenwood et al. (2015) create a measure of aggregate vulnerability (AV) that capably predicted bank losses in the dotcom bubble and the financial crisis of 2007-09. Applying a similar model of fire-sale price-impacts to publicly available information on the Canadian banks from 1996 to 2015, I find potential losses to the banking system, as measured by the aggregate vulnerability (AV) index, are modest. However I also find that AV increased significantly from 2012 to 2015 – this can be attributed to a concentration of two illiquid assets on bank balance sheets: uninsured residential mortgages, and loans to consumers. The concern should be mitigated by two important considerations: (i) strong macroprudential regulation in Canada, and (ii) a large quantity of liquid assets on bank balance sheets. Overall, the rise in AV parallels a rising concern among government officials and some regulators. In October 2016, the Canadian Federal Government passed new requirements making it more difficult for lenders to issue mortgages. The government also expressed a desire to re-evaluate its explicit guarantee of the mortgage insurance market. Using the stress test model developed in this paper and data from 2015, if the Canadian federal government revokes this guarantee, then under the most conservative of assumptions, the amount of equity vulnerable to a fire-sale will

[1] The report can be found here: http://reports.weforum.org/global-competitiveness-index/competitiveness-rankings/. It is based on 110 variables, a third of which come from U.N. data and the remaining two-thirds come from the Executive Opinion Survey.

increase by a modest 2%.

Broadly, stress tests are used to measure losses in the event of an adverse shock on the financial system. This shock can be modelled in a number of ways, but every model shares common characteristics. Typically, there is an initial shock to asset quality or value such as European sovereign debt or mortgages. Alternatively, the shock is sometimes applied directly to equity. Some stress tests calibrate the initial shock to estimates of exposure to risk while other studies assume a proportional loss. In the next phase of the stress test, there are second-order effects. This can take the form of network effects (Anand et al. (2015), fire-sales (Duarte and Eisenbach (2015)), bank runs (Morris and Shin (2016)), or a combination of the above (Anand et al. (2014)). An alternative to stress tests uses market prices to estimate banking system losses such as the SRISK model of Acharya et al. (2014).

Hanson et al. (2011) argue that if profits are negative and banks are required to maintain a specified leverage ratio, then banks will reduce balance sheet assets. Shleifer and Vishny (2011) observe that financial institutions during a fire-sale sold assets in response to a decline in the asset values themselves. In that environment, selling assets first can avoid losses. Myers (1977) showed that, when banks are perceived to have higher risk of insolvency, the banks will prefer to decrease assets in order to preserve the value of shareholder equity. For an example using U.S. lending data, see Ivashina and Scharfstein (2010). The reduction in bank assets produces two potential social costs: a credit crunch and fire-sales. While my stress tests focuses on the latter, these two costs are interrelated. If fire-sales decrease the price of a security by 10%, then the cost of issuing that same security should decrease its value by 10% – the law of one price holds. Hence, fire-sales can deepen credit crunches and cause real damage to the economy.

The stress test employed is similar to the one developed by Duarte and Eisenbach (2015) and Greenwood et al. (2015). It has certain advantages: (i) it can be done using publicly available data, (ii) it is versatile enough to accommodate multiple scenarios, and (iii) the model can anticipate future crises – Duarte and Eisenbach (2015) showed that it was able to forecast losses among U.S. bank holding companies prior to the U.S. financial crisis – and (iv) it does not require market prices that have historically done a poor job of forecasting. In each period, aggregate vulnerability (AV) provides an estimate of banking system equity lost due to fire-sales. The measure of AV in this paper can be interpreted as a counterfactual estimate of the consequences of a fire-sale episode in Canada. In practice, the regulator or a government body could intervene in markets by purchasing assets to reduce liquidity losses and reward solvent institutions. If the assets themselves are unimpaired, then this policy becomes more beneficial. The estimates of AV provide policy makers and market participants a measure of the costs of non-intervention.

I calibrate a benchmark measure of AV using values similar to Duarte and Eisenbach (2015) but modified to fit the available Canadian data. Further, I limit my data to an estimate of domestic bank assets rather than the total, so that I can identify problems in Canada. An important assumption to calibrate fire-sale price-impacts comes from the empirical studies of Ellul et al. (2011) and Feldhütter (2012) who find that the price of a corporate bond will fall approximately 10 bps per $10 billion sold. In the benchmark calibration, I follow Duarte and Eisenbach (2015) and Greenwood et al. (2015) by assuming that all non-cash assets obey this pricing-rule. Overall, my estimates suggest that the Canadian banking system is quite resilient to a fire-sale episode. The aggregate equity losses necessary to cause insolvency among the big six banks would have to be extreme, well beyond anything seen in Canada since the Great Depression. However there remain some grounds for concern. I find that the AV of the banking system peaked in 2015. The last time it was so high was just prior to the financial crisis though this is not to suggest that such an extreme event is likely to occur, but that there is some cause for concern.

The remainder of this paper is organized as follows. Section 2 provides a summary of the literature relating to stress tests in Canada and internationally. Section 3 provides a detailed explanation of the stress test method derived by Duarte and Eisenbach (2015). Section 4 provides details on the Canadian data including which financial institutions are included in the study and how. Regulation, data availability, and market concentration make the Canadian financial system unique. Accordingly, section 5 explains how the model is calibrated to account for these differences. Section 6 describes the results; I estimate two stress tests from Duarte and Eisenbach (2015): the first with homogeneous fire-sale price-impacts, and the second with heterogeneous price-impacts. I then calibrate the model according to macroprudential regulation in Canada and compare this to the previous results.

Next, I consider the impact on AV if the Federal Government revokes its guarantee on mortgage insurance. In the final two stress tests, I consider how the results change if banks choose to sell liquid assets first rather than sell illiquid assets before their price falls further. Finally I estimate the quantity of initial losses required to cause insolvency in one of the Big Six banks. Section 7 provides a commentary on this study, its implications, and future research.

2 Literature review

Morris and Shin (2016) separate the credit risk of a financial institution (FI) into three components: insolvency risk, total credit risk, and illiquidity risk. If asset values or quality decline to such a degree that the FI cannot meet its short-term liabilities, then the FI becomes insolvent. Alternatively, if short-term investors refuse to supply funds to a distressed FI, because they question the ability of a FI to repay the loans, then the FI could suffer losses or higher interest rates. They call this run risk. Additionally, they consider fire-sale price-impacts. A FI can sell assets to meet short-term liabilities however they may not receive full value for their assets. This can generate further liquidity losses and also lead to insolvency. Morris and Shin (2016) note that in practice, it is difficult to draw a clear distinction between liquidity and insolvency risk, but that our understanding of the link is not readily understood. However even when assuming a clear distinction, these tests create value by measuring a counterfactual scenario. Their model estimates a counterfactual measure of illiquidity risk, and they find that it is decreasing as the liquidity coverage ratio is increasing. If FIs hold more liquid assets, then they are less likely to experience a bank-run. This has important implications for my stress test – institutions should be rewarded for holding liquid assets. In section 6.4, I estimate an alternative scenario where FIs sell their most liquid assets.

At the Bank of England, Burrows et al. (2012) develop a top-down stress-test called the Risk Assessment Model of Systemic Institutions (RAMSI). It is used to assess the solvency and liquidity risk of UK banks. More details on the model calculations can be found in Alessandri et al. (2009). RAMSI relies on a series of reduced-form econometric models to forecast balance sheet and income statement items including an asset pricing model that relates changes in equity prices and interest rates to the market value of assets. Once the forecasts are made, the bank is subjected to feedback effects. If the forecasted equity of a bank declines, then the cost of funding will increase as investors perceive the bank to be less creditworthy. If this decline in fundamentals is severe enough, a bank will not be able to acquire any funding in certain markets. If a bank is perceived to be insolvent, then, and only then, fire-sales and counter-party credit risk will create further losses. Similar to Duarte and Eisenbach (2015) and Greenwood et al. (2015), RAMSI assumes that banks have a targeted, or desired, leverage ratio which they would like to maintain. This implies that if the forecasted equity at a bank changes, the managers will change the amount of risk-weighted assets until the desired leverage ratio is achieved. Although RAMSI uses reduced form models that may lose accuracy during a period of stress, it is a helpful indicator of vulnerability. It is also an earlier top-down stress test upon which much work has been built.

There have been few studies on stress testing the Canadian banks. The most important and recent work has been from the Bank of Canada that has been developing the MFRAF: Macro-Financial Risk Assessment Framework. My work can best be seen as a publicly available complement to the Bank of Canada's MFRAF stress test. The purpose of this stress test is to have a quantitative model to assess the impact of shocks to the Canadian banking system. The three-period model aggregates firm-level data into three categories of system losses: core solvency losses, liquidity, and counter-party, or inter-bank, risk. Liquidity risk takes two forms: the risk that borrowed funds are not 'rolled-over' and spillover price-impacts from asset fire-sales. This approach is ambitious as it aims to model every facet of the systemic risk from the expected initial losses to network effects. In Anand et al. (2014), the model begins with an exogenous initial shock such as a decline in equity prices or the value of real estate, then calculates expected credit losses. It requires data and assumptions on the probability of a specific loan defaulting (PD), the exposure at default (EAD), and loss given default (LGD). Specifically, PD is separately modeled at the Bank of Canada, EAD uses regulatory bank-filings[2], and LGD requires judgment on the part of the researcher. This is

[2]Presumably, the exposure-at-default is calculated using internal bank models that have been vetted by OSFI.

an important area of research, but the multi-layered and complicated procedure magnifies model risk at even the earliest stages of the stress test: a potential oversight calibrating the initial shock might lead to an erroneous conclusion further on. There exists a certain trade-off between complexity and simplicity in stress-testing. Guidara et al. (2013) study how cyclical impacts of leverage vary through the business cycle. They find that capital in excess of regulatory requirements moved in a procyclical relationship with economic downturns, and that this capital buffer and risk appeared to be uncorrelated.

How the MFRAF measures fire-sale price impacts is of most interest, given that is what I attempt to do in this study. MFRAF applies a similar framework to the one in this paper, albeit with differing assumptions. This is explained in the following paragraphs.

(i). What motivates a bank to participate in a fire-sale? The model assumes that banks will only fire-sell assets when they are leverage constrained by regulation. From a regulator's perspective, this assumption is reasonable since Canadian regulatory bodies set these targets in what they view to be in the best interests of the economy and financial stability. Adrian and Shin (2010) show that banks attempt to hit a desired leverage ratio rather than simply comply with regulation. Looking at the Canadian banking system debt to tier-1 net equity leverage ratio, the value peaks in the third quarter of 2007, just prior to the ABCP Crisis[3]. It then falls from 20.7 to 20.1 in the next quarter and continues to fall until the first quarter of 2011 when it is just 16.6.

(ii). Given the bank decision to delever, how does a bank choose which assets to sell and in which order? The MFRAF takes a rational, optimizing approach: a banks sells the most liquid assets first, or to put it another way, banks minimize mark-to-market losses. This is likely conditional on the perceived actions of their competitors. Duarte and Eisenbach (2015) make an argument in favour of a simpler rule: banks sell assets in proportion to total assets. If a bank wants to sell $10 billion worth of assets and equity securities represent 10% of total assets, then the bank will sell $1 billion of equities. Does this pricing rule reflect actual bank behaviour? Perhaps more importantly, how does this assumption affect the results of a stress test? Duarte and Eisenbach (2015) offer two pieces of evidence. First, Basel III's Liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR) place

[3] See Chant (2008) and Halpern (2016) for details

pressure on banks to sell illiquid assets first, so that these institutions can maintain a high ratio. Second, in mid-2008, Lehman Brothers sold illiquid assets rather than more liquid ones. Since the pricing rule can change the result, it is an important assumption. In section 6.4, I employ a pricing rule in which banks sell liquid assets first in order to minimize fire-sale price-impacts.

(iii). Given the fire-sale of assets, how do asset sales affect the price? The MFRAF implements a concave pricing-rule. As more assets are sold, the price falls more rapidly. They also assume that at some level, a bank refuses to sell any more – beyond a certain minimum price, the market fails to clear. An alternative interpretation is that government will intervene. These assumptions represent a fairly new direction beyond from the current literature. Duarte and Eisenbach (2015) report that the great majority of stress tests apply a linear pricing rule. This can be attributed to the fact that it is extremely difficult to quantify how asset sales will affect price. For example, Dick-Nielsen et al. (2012) study the bond market to measure the price impact from trades. Using a highly liquid bond as a benchmark, they separate liquidity effects from the overall price effect for bonds of various ratings and find that the liquidity impact from trades was disproportionately higher when the bond quality was lower. While a concave pricing-rule may be more realistic than a linear pricing-rule, applying it requires detailed information on the type of assets sold, including the credit rating of the bond. Additionally, data on assets that are not frequently traded is likely unavailable.

After the fire-sale, banks face funding risk, and if any bank becomes insolvent, then the others face additional losses due to network effects. Anand et al. (2014) apply the MFRAF to Bank of Canada data collected in the international monetary fund's 2013 financial Stability assessment Program (FSAP). They find that the aggregate capital position of the Canadian banks is 20% lower when liquidity risk and inter-bank exposures (network effects) are added to the direct losses. MFRAF is an impressive stress test. However in this case, it relied on detailed and publicly unavailable balance sheet and interbank exposure data. This information only became available as part of the IMF-led Canada Financial Sector Assessment program. It is uncertain whether the Bank of Canada is able to accurately collect this data on a monthly or quarterly basis. This could limit the ability of the model to identify recent vulnerability build-ups and to predict upcoming crises.

Bai et al. (2016), building off the work from Adrian and Brunnermeier (2016) and Berger et al. (2009), measured the mismatch between the market liquidity of assets and the funding liquidity of liabilities in a recursive, multi-period, framework. Bai et al. (2016) call it the Liquidity Mismatch Index (LMI) and apply it to U.S. Bank Holding Companies. They find that the LMI predicted a build-up of risk prior to the financial crisis. From 2002 to 2008, the mismatch increased from a low of negative $ 1 trillion to a high of $3.3 trillion before returning to pre-crisis level in 2009. Unfortunately, applying the LMI to Canadian data is problematic. OSFI does not publish detailed information on asset or liability maturities, so that quarterly information is not publicly available. Furthermore, the Canadian banks did not rely on repo funding to the extent that U.S. banks had. CIBC, which suffered significant losses during the financial crisis, raised new equity issues worth $2.75 billion in January of 2008[4]: unsecured investors displayed little concern about solvency.

A popular alternative methodology from Acharya et al. (2012) propose the SRISK model that avoids measuring pricing-impacts from fire-sales altogether. It calculates expected capital shortfall conditional on a crisis or shock, and it uses a reduced-form approach along with the market value of equity. Recently, Tavolaro et al. (2014) criticize these approaches on the grounds that they (i) relied on market return data, (ii) were reduced-form models that lacked structure, and (iii) provided limited forecasting potential. Why is a stress test using market prices problematic? Crean and Milne (2017) observe that only under the assumption of a complete market without significant practical market imperfections can risk-neutral pricing models measure risk by the volatility of market prices. However these models do not capture many of the key features of a financial crisis. With prices adjusting instantly to new information, there is no possibility of a flight-to-quality episode or an asset fire-sale. Gorton (1988) find that the majority of U.S. financial crises in the National Banking Era were based on fundamentals rather than panic – they could be predicted by a leading indicator based on the liabilities of insolvent companies. Calomiris and Mason (1994) and Saunders and Wilson (1994) draw similar conclusions. Similarly, Iyer et al. (2016) show that the characteristics of depositors can forecast whether they withdraw their

[4]'CIBC stock sale raises $2.75B to shore up balance sheet', January 14th, 2008 http://www.cbc.ca/news/business/cibc-stock-sale-raises-2-75b-to-shore-up-balance-sheet-1.718601

funds in a bank run. Analysis of bank balance sheets can lead to early detection of financial crises.

I follow the methodology of Duarte and Eisenbach (2015) and Greenwood et al. (2015) who construct a systemic-risk measure that quantifies the equity-at-risk from fire-sale price-impacts. A shortcoming of the measure of AV is that it focuses on liquidity risk rather than insolvency risk. Using time-series data from bank holding companies and repo markets, they find that the aggregate risk measure built-up gradually prior to the financial crisis. This suggests that the measure is a useful predictor of the vulnerability to a liquidity event present in the system. Using straight-forward assumptions, it has the added effect of relying solely on publicly available information, and the model is flexible enough to suit a wide variety of plausible scenarios. Section 3 explains in detail how I derive the model, and section 5 discusses how I calibrate it to Canada's banking system.

3 Stress test methodology

Greenwood et al. (2015) and Duarte and Eisenbach (2015) create a methodology to measure the aggregate vulnerability (AV) of a financial system to fire-sale losses. If such an episode occurs, then asset sales will put downward pressure on prices. That creates system-wide losses to banks that might not even be selling assets. Their measure of losses is called aggregate vulnerability (AV), and it is defined as the sum of system-wide losses resulting from a fire-sale divided by the total amount of net tier-one equity. The AV is then the percentage of system-wide equity that would be lost in the event of a fire-sale. The methodology is extremely flexible and can be adjusted to suit any number of plausible scenarios. For example, the method could be used to analyse losses at a specific bank, such as CIBC in 2007, or to explore system vulnerability to a specific asset, such as real estate loans in 2015. For simplicity and comparability with previous work, I shall follow the specification of Duarte and Eisenbach (2015) and explain the method using the simplest assumptions. These will be relaxed in section 6.

First, we can assume that there are only two types of assets: liquid assets and illiquid assets. This can be relaxed to accommodate multiple assets. For an alternative derivation with multiple assets, see Duarte and Eisenbach (2015). Second, liquid assets are immune to fire-sale price-impacts, so that if a liquid asset is sold, then there will be no change in price. Third, all illiquid assets are subject to an initial direct loss:

$$DL_i = A_{k,i} \left(f_k \right) \tag{1}$$

where DL_i is the direct loss at bank i, $A_{k,i}$ represents the illiquid assets at bank i, and f_k is the initial rate of loss on illiquid assets that are suffered in equal proportion by all banks. After the direct loss to illiquid assets, the debt-equity ratio of each bank is above its initial value. If we assume that each bank wishes to return to its original debt-equity ratio, then they experience an equity shortfall. In order to return to the original ratio, they must sell assets. The equity short-fall (SF_i) at each bank is:

$$SF_i = DL_i \left(b_i \right) \tag{2}$$

where b_i is the original debt-equity ratio. To return to the original b_i, each bank sells assets rather than raise new equity. For simplicity, we can assume that each bank will maintain the same relative proportion of liquid and illiquid assets. Consequently, each bank fire-sells ($F_{k,i}$) of liquid and illiquid assets:

$$F_{k,i} = \left(m'_{k,i} + m'_{l,i} \right) SF_i \tag{3}$$

where k represents the illiquid asset, $m'_{k,i}$ is the fraction of illiquid assets to the total at bank i, and $m'_{l,i}$ is the fraction liquid assets to the total. The prime ($'$) denotes that the asset weight was re-calculated after the direct losses were subtracted from the illiquid assets. Depending on the amount of assets sold, we can assume the price of the entire asset class will fall according to the following linear rule:

$$PI_{il} = \sum_{i=1} F_{k,i} \left(l_k \right) \tag{4}$$

where l_k represents a linear pricing rule that decreases the price of an illiquid asset per unit sold, PI_k is the change in the price of the illiquid assets resulting from fire-sales. The aggregate vulnerability (AV) of the banking system to a fire sale is:

$$AV = \sum_{i=1} \frac{PI_k \left(A'_{k,i} \right)}{(w)(e)} \tag{5}$$

where after the initial direct losses, A'_k is the amount of illiquid assets at bank i, and e is the total amount of equity in the system. w is a measure of the amount of liquidity that can be provided by outside buyers. Duarte and Eisenbach (2015) included this term to reflect the insight of Shleifer and Vishny (1992). Intuitively, if the supply of outside wealth, or funds, is larger, then the demand for fire-sold assets will be higher. This mitigates losses from fire-sales.

The methodology can be extended in a number of ways. For example, it is quite simple to extend the model to multiple illiquid assets. An explicit derivation can be found in Duarte and Eisenbach (2015). When there are multiple assets, $k-1$ illiquid assets and one liquid asset, then the aggregate vulnerability measure becomes:

$$AV = \sum_{k=1}^{K} \sum_{i=1}^{I} \frac{(PI_k) \left(A'_{k,i} \right)}{(w)(e)} \tag{6}$$

where I is the total number of banks and K is the total number of illiquid assets. Equation 6 assumes that sales of one asset class are uncorrelated with the others. For example, selling securitized mortgages has no price impact on corporate bonds. When all illiquid assets are aggregated together, as in equation 5, we find the opposite result: the price impact from selling one illiquid asset class is perfectly correlated the other classes. Either of these assumptions can easily be relaxed. It is relatively straightforward to allow for different price impact correlations between different asset classes. See Greenwood et al. (2015) for an alternative derivation of the model. In section 5, I explain how the model is calibrated.

Lastly, it is possible to decompose accurate vulnerability into three components: illiquidity concentration (IL), leverage (LE), and relative size ($SIZE$). Let A be the sum of all assets in the banking system and define each asset share of the total as $m_k = \frac{A_k}{A}$. Using equation 6 and 4, and the accounting identity $A = e + d$, the components become:

$$
\begin{aligned}
IL &= \sum_{k=1}^{K} PI_k m_k && (7)\\
EQ &= 1/e && (8)\\
SIZE &= A/(w) && (9)
\end{aligned}
$$

and it generates a measure to evaluate changes in the AV index over time.

Another extention from Duarte and Eisenbach (2015) introduces multiple periods of fire-sales. This can include potential negotiated 'haircuts' on different asset classes among market participants. However the insight into systemic risk is mitigated by the possibility that outside investors, such as the government or private equity, will step in and purchase the fire-sold assets. If this occurred, then the price impact from further sales would be zero. The authors conclude that the essential intuition is captured in a static model, and that multiple-period extensions provide limited advantage. The key contribution of the method detailed above is to measure the build-up risk in a financial system using publicly available data.

4 Canadian banking and financial system data

Accounting data on individual financial institutions are taken from the Office of the Superintendent of Financial Services (OSFI). Income statement items and equity-capital reports are available quarterly while balance sheet data is available monthly. All monthly data has been averaged into quarterly values. Balance sheet and income statement items are converted into real 2012 Canadian dollars using the Canadian CPI index from CANSIM. In order to measure the aggregate size of the Canadian financial system, CANSIM provides data on trusts, insurance companies, non-depository credit intermediaries, investment funds, credit unions and caisse populaires. All information on the OSFI website is consolidated to include the assets and liabilities of all subsidiaries. The sample period covers the first fiscal quarter of 1996 to the fourth quarter of 2015. This creates a sample of 80 quarters with a maximum of 22 institutions per period for a total of 1,504 observations. Trust companies and foreign bank branches submit the same filings to OSFI as do chartered banks, so I include the two largest foreign banks: HSBC Canada and Citibank Canada. HSBC Canada operates as a chartered schedule I bank, and it is the seventh largest bank over the sample. Outside of these financial companies, the remaining institutions are all chartered, Schedule I domestic banks. See table 6 for a complete list. The six largest banks, the 'big-six', accounted for more than 85% of all bank assets while the banks included in my sample represented between 45% and 55% of total assets in the Canadian financial system.

Each bank reported consolidated balance sheets and earnings, so failing to exclude subsidiaries could result in double-counting. In 2012, Scotiabank purchased ING Direct Canada, a sizable independent bank, that provided discount financial services. After this event, the bank was removed from the sample. Some of the banks were subsidiaries of larger Canadian financial institutions. For example Zag Bank was founded in 2002 as a subsidiary of Western financial group, an insurance company. In 2010, Western financial group was acquired by DesJardins, a large caisse populaire in Quebec, but since neither of the parent companies were part of the sample, there was no double-counting. Unfortunately, DesJardins does not file similar data to the OSFI hence it is not included directly. They operate in Quebec and had $175 billion in assets in 2010. Similarly, Alberta Treasury Branches (ATB Financial) is a crown corporation that is owned by the province of Alberta; they had $43.1 billion in total assets in 2015.

OSFI reported assets in two categories: total and foreign currency. Following Canadian GAAP accounting rules[5], the value of assets denominated in foreign-currency are converted into Canadian dollars. However in some instances, the data was not reliable or remained unavailable. For example in the calendar year 2009, there was no detailed information on foreign-currency denominated assets except for the total; it was not clear why this was the case. This variability in the quality of the data posed a challenge to research that would need to be addressed. There were also a number of regulatory changes over the sample. A minor regulatory-filing change occurred at the end of 2007, but for the most part this created little discontinuity. A more major change occurred in 2012 when the Canadian banks switched from Canadian GAAP to IFRS accounting standards. This greatly increased

[5] Beginning in 2012, Canadian banks began using IFRS accounting standards. To my knowledge, there was no material difference in their respective treatment of currency conversion.

the value of assets that Canadian banks were required to keep on the balance sheet, and it decreased the amount of equity by changing the rules on how minority equity position was accounted for.

Given data availability and the structure of the Canadian financial system, I focus my stress test on the stability of the chartered banks, and I limit the sample to a selection of independent chartered banks. These are listed in table 6. There is a limited amount of entry and exit among chartered banks during the sample. Equitable Trust acquired a bank charter and became Equitable Bank in 2013, so after this date they are included in the sample. As mentioned earlier, Scotiabank acquired ING direct, a low-cost financial services provider and chartered bank, in the first quarter of 2013, then renamed Tangerine Bank. After the acquisition, I exclude them from the sample to avoid double-counting. Lacking data on asset details and recognizing that they are not chartered banks, Desjardins and ATB Financial are excluded from the sample although their influence on the stress test remains when the measure of outside wealth, w, is defined as the size of the financial system. If these deposit-taking institutions become larger, then fire-sale price-impacts will decrease.

The filing change in 2008 made for only a minor disruption in data continuity, but the regulatory change to IFRS in 2012 was more significant. I do not directly treat this regime change, but I will comment on how it influences the result in section 6. It had a pronounced effect on the behaviour of Canadian banks. For example, the new requirement that unsold NHA MBS[6] and many government-guaranteed insured mortgages must be held on the balance sheet does not change the regulatory requirement that the leverage ratio, capital divided by exposure at default, be no more than 3%.[7] However the simple leverage ratio of assets to equity was affected – the numerator increased and the denominator decreased. In preparation for the transition, banks were required to increase equity on the balance sheet.

[6]This is an acronym for National Housing Act Mortgage Backed Securities.

[7]OSFI can increase this ratio to reward strong risk management practices at a particular bank. If they are concerned with risk at a particular bank, they can also decrease it.

5 Calibration

The following subsections discuss how the model is calibrated to the unique characteristics of the Canadian financial system.

5.1 Initial shock

There are many and varied initial shocks used in the literature. Philippon et al. (2017) observed that the world is fortunate that few of these scenarios ever occur. For example in section 2, I describe how the MFRAF stress test is calibrated to an initial shock in real estate and equity prices using Bank of Canada internal models and data. When the MFRAF stress test is applied to the FSAP scenario, it assumes that real GDP in Canada contracts by 5.9% and that house prices fall by 33%. Greenwood et al. (2015) uses bank exposures, rather than balance sheet assets, and assumes a 50% write-off of all debt from Greece, Ireland, Italy, Portugal and Spain (GIIPS). Taking a different approach, the European Central Bank assumes a 25% fall in equity prices while the Bank of England assumes a 40% fall.

Crean and Milne (2017) observe how financial crises are often initiated by slow-downs in the real business sector, or Systematically Important Real Sectors (SIRS), rather than by problems in the financial system. Firms over-invest in these sectors and it results in oversupply, price-corrections, and losses that spillover into the economy at-large. For example, the Great Financial Crisis in the U.S. had real estate as the SIRS that generates an initial shock. Too many houses were built relative to demand, so inventories increased and new constructions decreased. Prices fell. Many loans against the underlying asset became impaired, and consequently many financial institutions and their clients were exposed to the losses. When calibrating the initial shock to the Canadian banking system, it would be useful to incorporate a shock along the lines of SIRS. Unfortunately, the data is not quite detailed enough for this sort of calibration. Ideally, I would need more granularity in my data. Information on the level of loans to specific sectors is available in financial statements, but even here it is difficult because many different kinds of companies will fall with a sector.

As a starting point, I follow Duarte and Eisenbach (2015) who assume that in each quarter, the banks are faced with a 1% decrease in the book value of each asset other than cash. In a given fiscal quarter, this is commensurate with a 17 to 23 percent decline in the value of aggregate equity. This simple assumption will allow comparison to one study and permit variation of the shock in further simulations. A linear methodology is flexible enough to allow for alternative specifications. In Duarte and Eisenbach (2015), they find nearly identical results when the initial shock is a function of the volatility of different asset classes. In section 5.3, I test an initial shock that uses the NSFR Basel III guidelines to calibrate the shock to different asset classes. I find that the initial shock causes a 25 to 34 percent decrease in aggregate equity. Overall, the stress test results are similar, and I provide a discussion in section 6.2. After the initial shock, I check whether any banks have a negative equity position.

What would happen if a member of the Big Six became insolvent? The Canada Deposit Insurance Corporation would act in conjunction with OSFI, the Bank of Canada, Financial Consumer Agency of Canada, and the Ministry of Finance to protect the financial system. Looking to Canadian history, it is possible that a foreign bank would be invited to take-over the failed institution. When the Bank of British Columbia failed in 1986, HSBC was permitted to acquire it. Similarly, Lloyds Bank acquired another failed bank, Continental Bank of Canada, at the same time. Other possibilities are that the distressed bank would be merged with another member of the Big Six or the government itself would take control of the institution and guarantee all liabilities. This is sometimes known as the 'Swedish model'. Similarly, the Canadian government may choose to inject equity into the insolvent entity. In 2008, the UK government purchased £37 billion of Royal Bank of Scotland equity[8] which amounted to giving the government control of the bank. In the stress test, I will assume that if a bank becomes insolvent, then the regulator will intervene to halt any further asset sales.

5.2 Foreign and domestic assets

This study aims to stress test the Canadian banks and to do so, it would be ideal to separate domestic and foreign exposures to identify made-in-Canada crises from international

[8] The UK Treasury statement can be found here http://webarchive.nationalarchives.gov.uk/20081231055300/http://www.hm-treasury.gov.uk/press_105_08.htm

ones such as the U.S. Financial Crisis of 2007-09. As previously stated, separation is made difficult because the largest Canadian banks do have significant international operations, and it is no easy matter to differentiate between these and domestic operations[9]. If Canada experiences a major shock such as a home-price correction, it is certain that Canadian asset prices will be detrimentally impacted. However given the small size of Canada, there is little reason to believe that foreign asset prices will be impacted at all. Canadian regulators and Statistics Canada provide a measure of domestic assets in two ways: addresses associated with an asset and currency denomination. Neither of these measures is perfect. For example, an American firm with a Canadian address could receive a loan from a Canadian bank and that would be considered a domestic loan even if the proceeds of the loan were spent in a foreign country. Using currency denominations, a Canadian firm that borrowed in U.S. dollars from a Canadian bank would be considered a foreign loan. Additionally, there is nothing to prevent a Canadian bank from collecting Canadian dollar deposits, exchanging these for U.S. dollars, and purchasing U.S. government T-bills. In neither case is it absolutely certain whether the loan is related to the domestic or international operations of the Canadian bank.

While it is difficult to separate domestic from international operations and it is not entirely necessary for the purposes of a stress test, I would like to separate the two to focus on banking in Canada. I assume that when the shock is a made-in-Canada crisis, then all assets denominated in foreign currency will be unaffected by fire-sales. This assumption is analogous to assuming Canada is a small-open economy. More specifically, my benchmark stress test will only consider assets denominated in domestic currency. To avoid any beneficial diversification effects and to maintain simplicity, I also assume that domestic operations are 'ring-fenced' from international operations. In the event of a fire sale and in order to return to its desired leverage ratio, a Canadian bank cannot sell assets denominated in non-Canadian dollars. The equity at Canadian banks is stated almost entirely in Canadian dollars, so this requires the additional assumption that the proportion of foreign-to-total equity equals that of foreign-to-total assets. For example, if a bank has 40% of its assets denominated in Canadian dollars, then I assume that 40% of its equity is held in Canada

[9] OSFI itself collects data on domestic and foreign assets. Presumably, this can overcome the identification issue I describe however they are not made publicly available.

while 60% is held internationally. This can be relaxed in further simulations. However, there is little change in aggregate vulnerability whether domestic or total assets are used.

In some time periods, the data from OSFI on foreign currency was either unavailable or inconsistent. Although the amount of total assets in foreign currency was available, they did not publish asset-level data on foreign currency from January 2009 until December 2009. To overcome these missing observations, I applied a simple linear interpolation with a begin date of December 2008 and an end date of January 2010. Regarding derivatives on the asset side of the balance sheet, in some periods the amount of derivatives in foreign currency was larger than the sum of foreign and domestic currency. In fact, this occurred frequently. There also appeared to be a great deal of variability in foreign derivatives from one period to the next that could not be justified by the total value of derivatives in all currencies. For example, the Bank of Montreal (BMO) had $3.5 billion in foreign-currency derivatives in the second quarter of 1999, but it had $13 billion in the fourth quarter of 1998. By comparison, BMO had $9 billion in total derivatives in the second quarter of 1999, but it had $12.7 billion in the fourth quarter of 1998, less than the total in foreign currency. The changes in foreign-currency derivatives also appeared to be too large when compared to total changes. Fortunately, the total value of derivatives appeared to fluctuate in a believable manner throughout the entire sample. To avoid this potential measurement problem, I created a ratio of foreign currency assets to total assets that excluded derivative assets. Then I assumed that the division between foreign and domestic currency derivatives followed this ratio, so that 30-40% of derivative assets were held in foreign currencies.

5.3 Assets and firesale price-impacts

Following Duarte and Eisenbach (2015) and Greenwood et al. (2015), I assume that fire-sale price impacts follow a linear function, so that fire-sale price-impacts are increasing with total fire-sold assets. Duarte and Eisenbach (2015) and Greenwood et al. (2015) follow empirical studies by Ellul et al. (2011) and Feldhütter (2012) who find that the price of a corporate bond will fall approximately 10 basis points per $10 billion sold. This is consistent with the liquidity term in equation 4, l_{il} , having a value equal to 10^{-4} when assets are measured in the billions of dollars, and in section 6, it is the measure of price-impacts for the benchmark scenario. However this value may underestimate the price impact from a fire-sale for U.S. corporate bonds, as mentioned in Greenwood et al. (2015), and this is even more true given the smaller market for Canadian corporate bonds. Dick-Nielsen et al. (2012) note that the U.S. corporate bond market is quite illiquid: the average bond was not traded on 60.7% of trading days. Traditionally, Canadian corporations relied less on capital markets and more on bank loans than in the U.S., so this makes the market for Canadian bonds even smaller. In fact, debt securities at the Canadian banks were mostly held in foreign currency. Table 1 shows that on average, more than 80% of debt securities that were not issued by the Canadian government were denominated in foreign currency. These included securities issued by foreign governments, and domestic and foreign corporations.

Table 1: Mean statistics

	Total	CAD $	For. assets in CAD $
Cash	79.0	14.5	64.5
Can. gov't	187.5	181.0	6.5
Other debt	262.5	47.2	215.3
Equity	158.3	100.8	57.5
Loans to inv. dealers	10.0	1.8	8.1
Loans to financial insti.	26.5	3.6	22.9
For. gov't	5.1	0.0	5.0
Business	325.8	154.1	171.7
Consumption	305.0	261.3	43.8
Rev. repo	221.1	96.8	124.3
Mort unins.	271.8	243.3	28.4
Mort ins.	270.0	269.0	0.9
Mort bus.	40.8	25.8	15.0
MBS NHA	36.1	36.1	0.0
Derivatives	346.9	208.9	138.0
Acceptances	55.8	53.7	2.1
Total	2602.1	1697.9	904.1
Tier 1 net capital	119.3	74.2	45.14

Assets denominated in foreign currency are converted to Canadian dollars following Canadian GAAP or IFRS accounting standards, so this presents the value of foreign-currency assets in Canadian dollars. Values are in real 2012 Canadian dollars. Tier 1 net capital in foreign currency is estimated by total tier 1 net capital multiplied by the ratio of total foreign currency assets to total assets. National Housing Act (NHA) is associated with mortgages sold to the Canadian Mortgage Housing Corporation (CMHC). Source: OSFI.

As previously discussed, the Bank of Canada's MFRAF methodology is one of the few major stress tests on the Canadian banking system. The method employed in this paper and described in section 3 is similar to the MFRAF approach: both begin with a shock to bank assets.[10] Under both approaches, banks sell assets to achieve a targeted asset-equity ratio and this inadvertently creates a fire-sale. MFRAF applies a concave pricing function to fire-sales, and it assumes there will be some lower bound beyond which no sales will occur. One explanation for this is that banks will refuse to sell at such a low price-point when these large losses must be recognized immediately. However I have yet to find details on how this pricing process has been calibrated, and it is unclear whether it provides significant advantages over a more simple linear-pricing rule. Greenwood et al. (2015) note that nearly all stress tests use a linear pricing rule.

The sample period covers 1996 to 2015 which witnessed a drastic increase in banking system balance sheets: real assets increased 3.5 times. Without any adjustment, the measure of AV will be much higher toward the end of the sample and it will be non-stationary. The introduction of outside wealth (w) helps mitigate this effect. If real assets are increasing and the number of outside buyers are increasing at a similar rate, then the two effects can offset and the series will be stationary. A measure of outside wealth is the sum of all assets held in the Canadian financial system net of the banking system.[11] Alternatively, GDP could capture the size of the banking system relative to that of the economy. Which measure is most appropriate? Duarte and Eisenbach (2015) use financial system assets net of bank assets in their benchmark model. The size of the Canadian financial system net of the banking system, which can be seen in table 2, grows at a similar rate to the banking system. If this measure of outside wealth is used, then the rapid increase in balance sheet assets is almost completely negated by the growth of outside wealth. However what if these financial institutions are holding a portfolio of assets that is similar to the banks? While the amount of wealth outside the banking system should make for a more liquid market, this assumption requires that these institutions do not hold a similar portfolio of assets. Otherwise, they would be as likely to contribute to the fire-sale as mitigate it. If GDP to banking system assets is the measure, this allows the stress test to capture build-ups in illiquidity that

[10] MFRAF restricts this shock to the trading-book and marketable securities, and it applies more detail and structure on which assets are fire-sold. However in spirit, both approaches take a similar, structural approach, to measuring price-impacts.

[11] Table 6 provides a summary of its calculation.

could also be occurring in non-bank financial institutions and might exaggerate rather than mitigate the illiquidity. I consider both measures in my simulations, but real GDP seems like the more reasonable choice. It also reflects the implicit cost of government intervention who would weigh the costs of that relative to the size of the economy.

Data from OSFI differs from data available from the Federal Reserve in the United States. Consequently, how I define asset classes must differ from U.S. studies. I begin with the assets listed in Table 1 to represent different liquid and illiquid asset classes. Regarding illiquid assets, I make two exceptions; first, I combine business loans, loans to financial institutions, and loans to investment dealers and brokers into one asset class. This follows recent studies in the United States where information at this level is unavailable. Second, I combine insured real estate mortgages, and unsold NHA mortgage-backed securities into one asset class. Both are guaranteed by the Canadian federal government, and data that separately records these two variables only begins with the transition to IFRS accounting standards in 2012, prior to which, the NHA MBS are considered an off-balance sheet item. I also choose to keep these MBS and insured mortgages separate from uninsured mortgages. Given the explicit government guarantee, I assume that separate markets exist for these two types of mortgages. This is equivalent to assuming that the sale of uninsured mortgages will have no price-impact on insured mortgages, or that in the event of a fire-sale, the prices of these assets are uncorrelated. Combining these two together would greatly increase the aggregate vulnerability of the Canadian banking system to a fire-sale.

The Canadian banks have a wide variety of assets on their balance sheets. Some of these are marked-to-market hence they are likely to be more liquid. Other assets, such as loans to business, are extremely illiquid and are unlikely to be priced by a market. The MFRAF seems to focus on securities that are marked-to-market, and they have private information such as the internal models used by large Canadian banks and OSFI. The benchmark simulation follows the assumption from Duarte and Eisenbach (2015) that all illiquid assets follow the same, homogeneous, pricing-rule and that the price-impact from sales on each asset class is uncorrelated with the others. This simplifies the simulation and provides the original stress test with comparability to previous studies.

Table 2: Summary of inputs

DATE	1996Q1	2000Q1	2004Q1	2008Q1	2012Q1	2015Q4
GDP	997	1161	1321	1558	1673	1771
Net fin. system assets	690	1000	1044	1462	1870	2197
Bank assets	718	966	1191	1682	2296	2536
Illiquid assets	718	966	1194	1688	2314	2557
Net tier 1 equity	35.3	47.7	57.4	73.9	109.3	116.6
Debt/Equity	19.6	18.5	18.9	20.3	18.6	19.6

Note: Values are shown in billions of real 2012 Canadian dollars. Financial system assets are net of bank assets.

5.4 Macroprudential regulations in Canada

Canada has unique macroprudential regulations that differentiates its asset quality from those of other development economies. How do these influence the model calibration, particularly the price-impacts from fire-sales? The remainder of this section (i) discusses what these unique features are, and (ii) calibrates the model accordingly. Mortgage rules in Canada, both insured and uninsured, differ considerably from those in the U.S.[12] and in other development economies. In Canada, residential mortgages are mostly five-year fixed-rate, and they are 'full-recourse' loans, so that the lender may make a claim against other assets of the borrower. CMHC notes that in 2014, 0.35% of Canadian mortgages were in 90-day arrears compared to 1.13% for comparable U.S. mortgages. MacGee et al. (2010) finds that Canadian lending standards did not decline as much as in the United States. U.S. mortgage delinquencies rose relative to historical averages prior to the financial crisis which indicates poorer lending standards. In Canada, delinquency rates were less during the financial crisis than they were in the early 1990s. At initiation, the loan-to-value must be no more than 80% otherwise mortgage insurance is required. Since 2008, the maximum LTV is 95%. Allen et al. (2016) consider how this macroprudential regulation constrains Canadian first-time homebuyers from 2005-2010. They find that policies targeting the LTV ratio were effective at preventing home purchases.

Mortgage insurance can be purchased from the Canadian Mortgage and Housing Corporation (CMHC), a crown corporation, and two private insurers: Canada Guaranty Mortgage

[12]For a brief summary comparing U.S. and Canadian mortgages, visit the CMHC website newsroom: https://www.cmhc-schl.gc.ca/en/corp/nero/jufa/jufa_018.cfm

Insurance and Genworth Canada. All premiums are tied directly to the mortgage and paid by the consumer. The Federal Government of Canada guarantees 100% of the mortgage insurance obligations of CMHC. To ensure fair competition with private insurers, 90% of their insured mortgages are also guaranteed. However during the financial crisis, CMHC insured 90% of all new residential mortgages requiring insurance. According to recent statements by representatives of the CMHC, they currently control a 50% market share and aim to keep it at that level.[13] These two facts suggest that in times of stress, CMHC may play a more significant role in the insured mortgages market than in more normal economic conditions.

In recent years, there has been growing concern in Canada about the indebtedness of Canadian households and their ability to meet interest payments if rates rise. Some economists, media, and Federal Government of Canada have expressed concern.[14] Furthermore as writing in February 2017, there is concern over the potential for a real estate price bubble, particularly in the Vancouver and Toronto markets.[15] As of October 17 2016, the Canadian government implemented new mortgage regulations to curb excessive mortgage lending. These regulations include a stress test on new home buyers to determine whether the household budget can withstand an interest rate hike.[16] In the Autumn of 2016, CMHC released information its own stress test. Using hypothetical modelling and historical economic analysis,it forecast losses for a number of different potential shocks to the Canadian economy. In each scenario, CMHC equity was sufficient to absorb losses without generating a loss to tax-payers.

Canadian mortgage quality and insurance are unique but have some similarities with U.S. agency securities. These are U.S. mortgage-backed securities issued by one of Ginnie Mae, Fannie Mae, Freddie Mac, or the Federal Home Loan Banks. Ginnie Mae securities enjoy an explicit guarantee while the others enjoy implicit protection. Accordly, Basel III

[13] See http://business.financialpost.com/personal-finance/mortgages-real-estate/cmhc-goes-from-insuring-90-of-new-mortgages-to-only-50-and-thats-as-low-as-it-plans-to-go.

[14] Carrick, Rob. '*Mortgage overload: the dark side of the boom*' December 12, 2016, http://www.theglobeandmail.com/globe-investor/personal-finance/genymoney/mortgage-overload-canadian-housing-finance/article33279552/.

[15] Siddall, Evan. '*The intended consequences of new housing policies*' October 17, 2016, http://www.theglobeandmail.com/report-on-business/rob-commentary/the-intended-consequences-of-new-housing-policies/article32383166/?ord=1?ord=1.

[16] This article provides an excellent overview of current residential mortgage regulation, recent changes, and new changes under consideration. '*Department of Finance. Technical Backgrounder: Mortgage Insurance Rules and Income Tax Proposals*', October 14, 2016, https://www.fin.gc.ca/n16/data/16-117_2-eng.asp.

desginates these assets to be much more liquid than residential mortgages but not perfectly liquid. CMHC purchases residential mortgages from lenders and securitizes them for sale to other entities: NHA MBS. The quantity and timeliness of NHA MBS payments are guaranteed by the Federal Government of Canada.

A number of studies have raised concerns about the level of consumer debt in Canada. Livshits et al. (2011) and Athreya et al. (2009) show that the increase in consumer debt since the 1970's has been due mostly to better technology that allows lenders to identify high-risk borrowers who are offered a higher rate of interest. However MacGee (2012) notes that consumer credit as a percentage of disposable income was 43% in Canada during 2011 – 13% higher than in the U.S. While a point of concern, he cautions that this does not necessarily suggest that Canadian households are more likely to default. As previously discussed, lending standards are stronger than in the U.S. as evidenced by current delinquency rates. On the other hand, he is cautious about home-equity lines of credit (HELOCs). In January 2014, 45.6% of consumer loans were backed by residential property. If a household has both a mortgage and a HELOC and the bank only observes the loan-to-value ratio, then it is likely to underestimate the risk of default. Additionally, the HELOC is a variable rate, so interest rate risk to households and probability of delinquency is greater. Combined with the high-level of household indebtedness, there is cause for some concern. Although, he further notes that in Canada, HELOCs are limited to 80% LTV – a macroprudential policy that once again demonstrates tight lending standards in Canada.

Basel LCR and NSFR rules provide information on how liquidity varies for different asset classes. Duarte and Eisenbach (2015) consider previous studies showing that if $10 billion in corporate bonds are sold, the price will decline by 10bps. Using this as a starting point, they calibrate a stress test to have differing price-impacts per asset class. They adjust these according to the Basel III LCR and NSFR recommendations, applying 'haircuts' according to illiquidity.[17] However many assets such as loans and derivatives are not considered, so they assign a 100% penalty above the most illiquid asset described. Additionally, asset class data from the Basel Committee do not perfectly match the U.S. or Canadian data. Duarte and

[17] In September of 2014, the United States Federal Reserve Board, the Federal Deposit Insurance Corporation, and the Office of the Comptroller of the Currency released a U.S. variation of the LCR which was based on the report from the Basel Committee on Banking Supervision called 'Basel III: The Liquidity Coverage Ratio and Liquidity Risk Monitoring Tools'.

Eisenbach (2015) applied a degree of subjectivity. I apply their values to the Canadian asset classes and this can be seen in Table 3 along with my price-impact adjustments to Canadian macroprudential regulation.

How best to calibrate fire-sale price-impacts to Canadian macroprudential regulation and the banking system? First, given the explicit government guarantee of insured mortgage and NHA MBS, I will assume that these assets are perfectly liquid. Second, strong regulation on mortgage-lending, including a minimum LTV ratio of 80% on uninsured mortgages, suggests these are of higher quality than predicated in Basel III: LCR. Consequently, I will make a conservative assumption and assume that they have the same liquidity as a corporate bond. Of particular interest to the stress test is whether liquidity effects in one asset class are correlated with those in another class. For example, more than a third of consumer loans are backed by residential property, so it would be reasonable to think that selling one might affect the other. This is simple to account for in the model however it is less clear how to quantify. Duarte and Eisenbach (2015) and Greenwood et al. (2015) leave the asset correlations at zero which is not unreasonable. Table 3 already imposes a stiff liquidity penalty on consumer loans, and HELOCs in Canada have a maximum LTV of 80% which makes them less risky than those in the U.S. Considering these issues together, I keep the price-impacts unchanged from the Duarte and Eisenbach (2015) study.

The following stress test scenarios estimate AV in section 6. (i) I estimate the benchmark stress test that assumes fire-sale price-impacts from any assets is 10bps per $10 billion sold and there is no correlation between assets. This is identical to the Duarte and Eisenbach (2015) study but using Canadian bank data. (ii) The heterogeneous price-impact also from Duarte and Eisenbach (2015) is estimated. (iii) I then consider calibrations unique to Canadian macroprudential regulation and specified in Table 3 and compare this result to those in (i) and (ii). (iv) I measure the impact on AV if the Federal Government of Canada removes its guarantee on mortgage insurance. (v) A reverse stress test estimates the quantity of initial losses required to cause one of the Big Six banks to become insolvent.

Table 3: heterogeneous price-impacts

Asset class	Benchmark	LCR	NSFR	CAD-LCR
Cash	0	0	0	0
Can. Gov.	10	0	1.4	0
Repos	10	1.4	2.9	1.4
Insured res. mort.	10	4.3	4.3	0
NHA MBS	10	4.3	4.3	0
Bonds	10	10	10	10
Equities	10	14.3	15.7	14.3
Uninsured res. mort.	10	28.6	17.1	10
Business loans	10	28.6	21.4	28.6
Consumer loans	10	28.6	21.4	28.6
Non-res. mortgages	10	28.6	21.4	28.6
Derivativies	10	28.6	21.4	28.6
Foreign government loans	10	28.6	21.4	28.6

Source: Duarte and Eisenbach (2015). Price impacts are stated in terms of basis points. Selling $10 billion in assets will result in a price decrease. The Canadian price-impacts (CAD) are my own.

6 Results

6.1 Benchmark stress test

As detailed in section 5, the stress test is measured over the entire sample using bank assets denominated in Canadian dollars. All balance sheet and financial items are converted into real 2012 dollars. In the benchmark scenario, the initial shock is a 1% decrease in the value of assets excluding cash and equivalents. In the next step, banks sell assets until they return to their original debt-to-equity ratio. This creates a fire-sale where price impacts are measured according to equation 4. This is mitigated by the size of the Canadian economy (real GDP) which is normalized to unity in the first quarter of 1996. The price impacts are measured for each illiquid asset, then they are summed and divided by total system equity. Consequently, the measure of aggregate vulnerability (AV) shown in equation 6 represents total system losses from fire-sale price-impacts as a percentage of equity. Figure 1 illustrates AV over time, and table 4 summarizes spillover losses by asset. Table 2 also provides further detail on the other components of aggregate vulnerability such as leverage and outside wealth.

Under the benchmark scenario and prior to 2011, AV remains relatively steady at 4 to

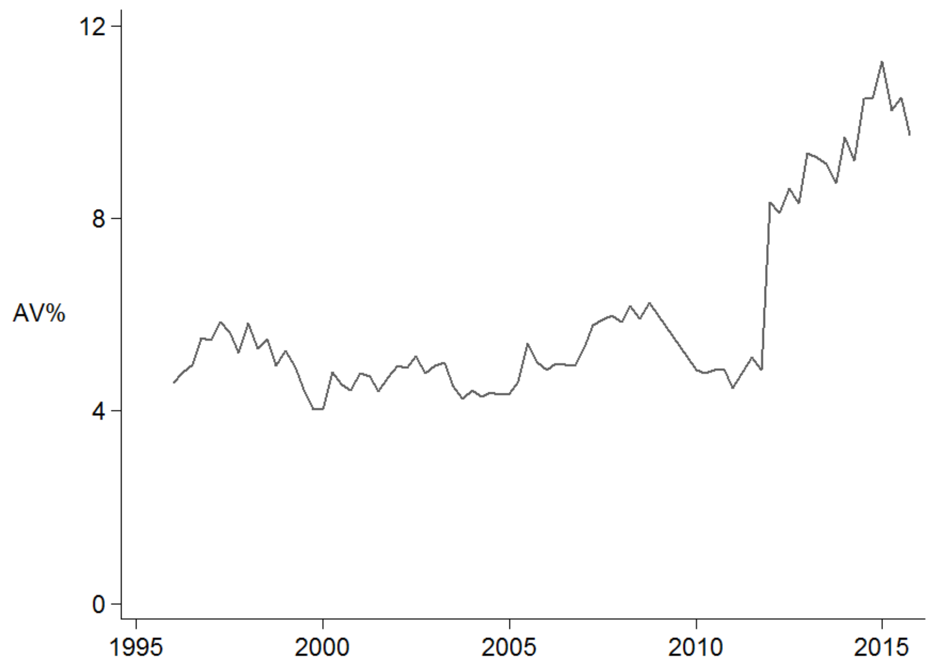

Figure 1: Benchmark aggregate vulnerability index
Note: AV is presented as a percentage of system equity.

6 percent of system equity. Prior to the financial crisis, there is a small run-up from the lower to upper end of the pre-crisis boom and a subsequent drop as banks de-lever. The jump in 2012 corresponds to the IFRS regime change. It requires that banks hold insured mortgages, despite a government guarantee, on the balance sheet. AV continues to increase until it finally peaks at 11.25% of equity in the beginning of 2015. Comparing this to a study on U.S. banks, Duarte and Eisenbach (2015) find that U.S. AV was less than 10% at the end of 2013. Differences in the leverage ratio can explain this variation. At the end of

Table 4: Fire-sale spillover losses

Date	1996Q1	2000Q1	2004Q1	2008Q1	2012Q1	2015Q4
Gov. securities	15.7%	9.3%	10.4%	8.4%	6.2%	4.5%
Consumer loans	13.4%	13.1%	17.9%	20.7%	18.4%	16.9%
Business loans	31.1%	33.0%	15.9%	16.2%	5.5%	7.4%
Insured Res. mort.	6.8%	22.0%	20.0%	16.7%	51.1%	46.0%
Uninsured Res. mort.	30.8%	14.6%	22.0%	19.6%	12.0%	20.2%

Note: The top five contributors to aggregate vulnerability are presented, so the percentages do not sum to 100%.

2013, U.S. aggregate leverage fell from a peak of 16.5 to 11. By comparison, the Canadian banks had an aggregate leverage ratio of 18 to end 2013[18].

Of particular interest is what we do not observe: a significant build-up in vulnerability prior to the financial crisis of 2007-09. There is a fall in AV during the crisis as banks de-lever, but there does not appear to be a rising risk level prior to it. One possibility is that the benchmark stress test only considers assets denominated in Canadian dollars. If the total value is used, or assets denominated in foreign currency, then I find a modest build-up in AV prior to the financial crisis and a similar build-up prior to the dotcom bubble. Indeed, AV itself is modestly increased by roughly 2% prior to 2011. If total assets instead of those in Canadian currency are used, then the build-up in risk prior to the financial crisis is more discernible. Alternatively, the assumption that all illiquidity assets suffer the same initial shock and fire-sale price-impacts could be too strong an assumption. In section 6.2, I calibrate the model to alternative price-impacts based on Basel III LCR and macroprudential regulation in Canada, then compare the results.

6.2 Heterogeneous price-impacts and Macroprudential policy

The benchmark stress test considers all illiquid assets to have the same price-impacts from a fire-sale, namely, for every $10 billion of assets sold, there is a 10 bps reduction in price. This corresponds to previous stress tests on the U.S. and European banking systems in Duarte and Eisenbach (2015) and Greenwood et al. (2015) respectively. However Duarte and Eisenbach (2015) calculates heterogeneous price-impacts using Basel III regulatory requirements. I modify these calculations to account for the unique quality of Canadian mortgages, and the results are listed in table 3 in section 5.3. Otherwise, all calibrations remain the same as in section 6.1.

Following table 3, if banks hold more illiquid assets, then they become more vulnerable to fire-sales. Figure 3 presents AV under the benchmark scenario and with heterogeneous price-impacts. Under the latter, AV is now 2-4% higher than the benchmark from 1996 to 2011. The late 1990s remain a period of high vulnerability which is primarily driven by

[18] It should be noted that their might be a difference in how the leverage is calculated. I am using the Basel Capital Adequacy Requirements net tier 1 equity published by OSFI. Regardless, aggregate leverage declined 33% in the U.S. while in Canada it began to rise after 2011.

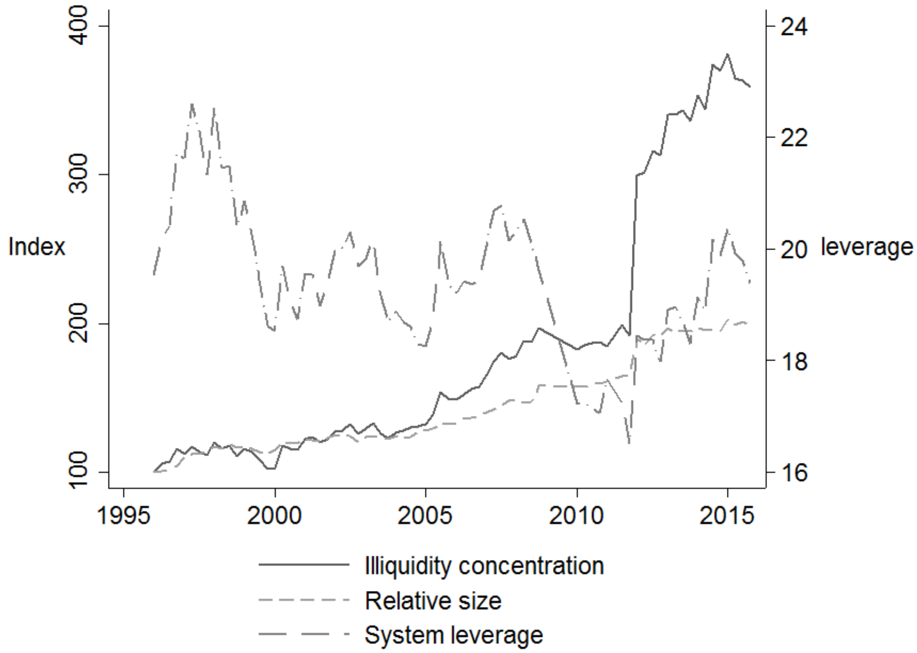

Figure 2: Benchmark AV decomposition

Note: The first observation normalizes the time series, then it is multiplied by 100 to create the index. System leverage is calculated as aggregate bank debt, including deposits, divided by net tier 1 equity.

high leverage ratios. The heterogeneous price-impacts show a build-up of AV leading up to the financial crisis. It reaches a peak in 2008, then declines until it hits something of a nadir in 2011. Between these extremes, Canadian banks decreased their quantity of illiquid assets, increased their liquid assets, and de-levered. Following the crisis, heterogeneous price-impact rules partially smooth the transition to IFRS accounting standards. After 2011, AV under both scenarios nearly converges. This suggests that the amount of equity-at-risk from a fire-sale episode is increasing due to asset illiquidity concentration. In late 2015, the banks response was to decrease leverage led to a modest decline in AV.

As expected, the illiquidity concentration continues to strongly affect changes in AV. The LCR price-impact rules place a high penalty on business loans, residential mortgages, and consumer loans. In the 1990s, loans-to-business accounted for as much as 50% of AV, yet in the last quarter of 2015, they accounted for only 14%. In 2015, the illiquidity concentration on uninsured mortgages and consumer loans alone account for more than 60% of aggregate vulnerability. If insured mortgages are included, then the total becomes 78% in 2015 which

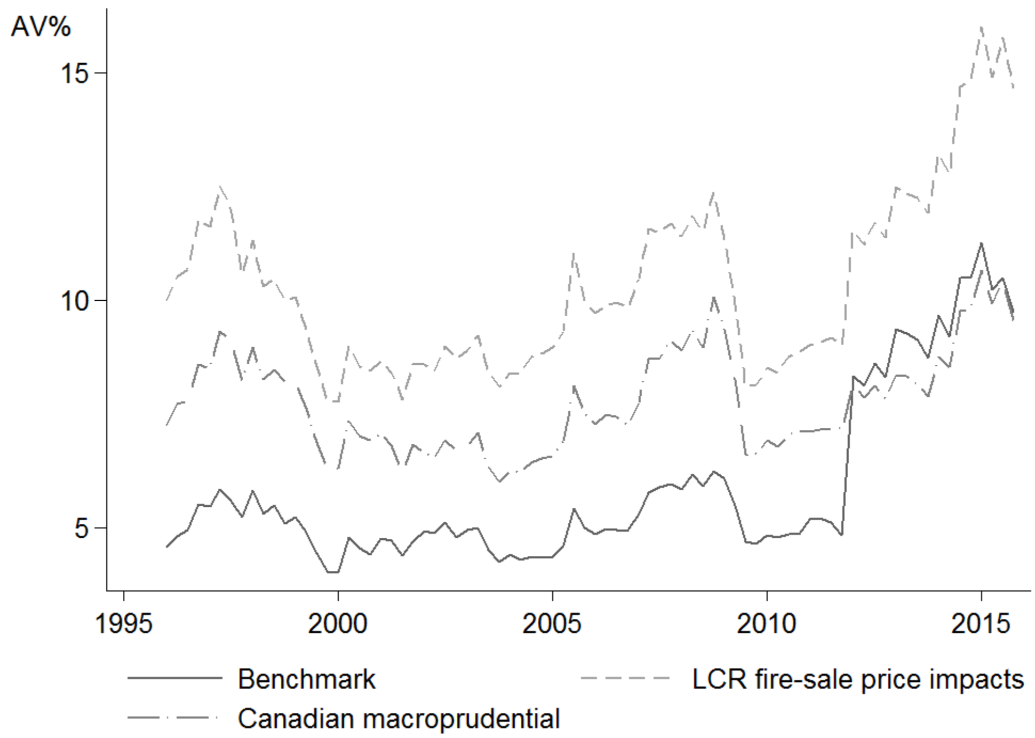

Figure 3: Aggregate vulnerability under three scenarios

is up from a total of 55% in 1996. This reflects two phenomena: first, banks are making fewer loans to businesses as a proportion of total assets, and second, the value of mortgages, and to a lesser degree loans to consumers, are increasing with Canadian real estate prices.

Applying the CAD LCR price-impact calibrations listed in Table 3 generates the final measure of AV in Figure 3. Mortgages insured and guaranteed by the Federal Government contribute nothing to AV and the penalty associated with residential mortgages has been decreased. Prior to the financial crisis, the building-up in risk is clearly discernible and the amount of equity-at-risk to a fire-sale, AV, is less than under the Basel III LCR calibration. Following the transition to IFRS, the benchmark scenario and the prudential regulation calibrations are nearly identical. The AV peak in 2015 is not much worse than the earlier peak in 2008 which was associated with a decline in equity.

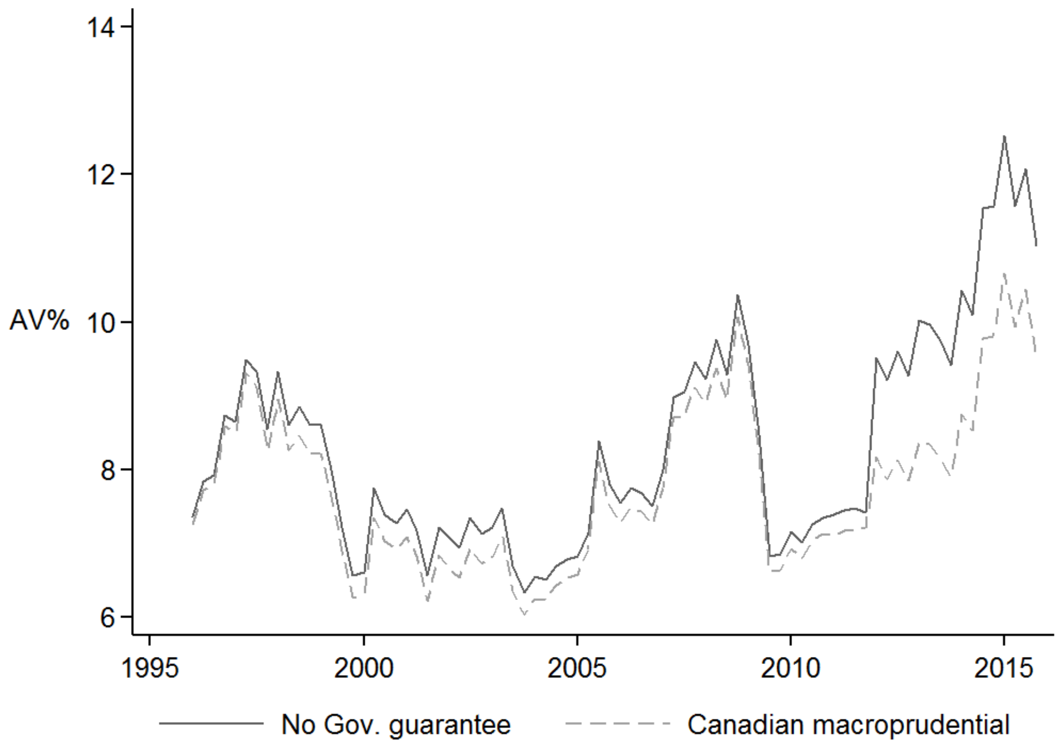

Figure 4: AV without a government-guarantee of insured mortgages

Note: Uninsured mortgages now follow the same price-impact rule as insured mortgages, but it assumes price-impacts between the two are uncorrelated.

6.3 No government-guarantee of insured mortgages

On October 14, 2016, the federal government of Canada announced the forthcoming consultation on lender risk sharing. The Canadian government currently backs 100% of mortgages insured by CMHC and 90% of privately insured mortgages. Given the upward secular trend in Canadian home prices since the late 1990's, it is not entirely surprising that the government would like to decrease its exposure. At the same time, it does not want to transfer an excessive amount of risk on to the financial system. If the government removed all guarantees on insured mortgages, what effect will this have on aggregate vulnerability? To answer this question, I calibrate the stress test as if the government-guarantee had been removed from 1996 to 2015. I assume that the new plan will have similar price-impacts as agency securities in the U.S. and that uninsured mortgages are uncorrelated with insured mortgages. From Table 3, I assign a price-impact of 4.3 bps – this is how Duarte and Eisenbach (2015) account for U.S. agency securities. Figure 4 illustrates the effect on AV and compares it to the CAD-LCR price-impacts. If the Canadian government removed its explicit guarantee of mortgage insurance, this would cause little change in AV prior to 2011. IFRS requires insured mortgages are carried on the balance sheet, so subsequent to 2011, AV increases by 1-2% – a fairly modest increase.

6.4 Model extention: alternative selling rule

It is possible that delevering financial institutions prefer to sell liquid assets in order to mitigate fire-sales. Morris and Shin (2016) find that banks with relatively more liquid assets are less vulnerable to bank runs. OSFI requires the Canadian banks to maintain a liquidity ratio of 3%.[19] However the regulator also allows itself the right to vary this requirement under certain conditions, and a fire-sale episode would constitute a legitimate circumstance. In this section, I assume that the regulatory authority removes this regulation and allows banks to sell liquid assets until the desired leverage ratio is achieved. Given the historical profitability of the Canadian banks, it is fair to assume that the banks will be able to replenish their stock of liquid assets in the future. I employ a simple rule where banks are myopic in the sense that they act without considering what other banks are doing. In this stress test, banks sell the most liquid assets in Table 3 first, so that initially price-impacts are muted. In order to meet its short-term liabilities, a bank uses its cash then it sells Canadian government securities for cash and works down the list. If a bank still has a short-fall after it has used all its cash, government bonds, and reverse repos, then I revert to the original pricing rule: banks sell assets in proportion to their current asset weighting. For example, if after selling all corporate bonds the shortfall is $1 billion and the bank has 10% of its remaining assets in an equity securities, then the bank will sell or divest $100 million. I chose this method to reward banks for carrying a higher proportion of liquid assets but also to avoid over-emphasizing any one illiquid asset.

If the initial shock to assets is a decline in value of 1% and liquid assets are sold first in a fire-sale, then the Canadian banking system will avoid any material fire-sale losses. In Figure 5, AV approaches zero and it is only material if the shock is increased to 2% of total

[19] See the *Leverage Requirements Guideline*, October 14, 2014 http://www.osfi-bsif.gc.ca/eng/docs/lr.pdf.

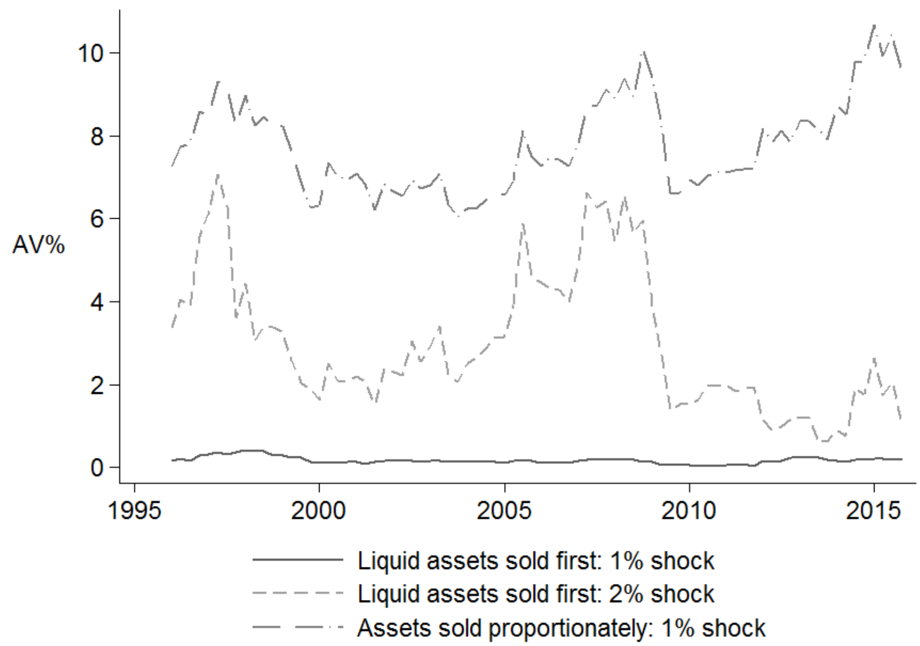

Figure 5: AV when liquid assets are sold first

Note: When liquid assets are sold first, banks first use cash to meet short-term liabilities, they then liquidate Canadian government debt, unwind reverse repo positions, and finally sell insured mortgages. If they still experience a short-fall, then they sell the remaining illiquid assets in proportion to their balance sheets. With this selling-rule, the calibration is for both a 1% initial decline in asset values and a 2% decline. Liquid assets are sufficient that a 1% shock will not produce significant fire-sale losses. If the shock is doubled, fire-sale losses remain below the CAD-LCR losses estimated in section 6.2.

assets. An interesting change in AV occurs – AV is much higher prior to the financial crisis relative to 2015. In fact, the quantity of liquid assets on bank balance sheets, including uninsured mortgages, helps counter the increased concentration in illiquid assets such as uninsured mortgages and business loans.

6.5 Reverse stress and insolvency

I define a bank as insolvent whenever total equity is less than zero. In section 6.1, the model is calibrated to a 1% initial shock to asset values and a homogeneous price decline of 10bps per $10 billion of assets. Over the sample period, the initial shock decreases aggregate equity by 17.8 to 23.6%, and this creates additional fire-sale losses of 4 to 11.3%. Out of all banks and for 1,311 bank observations, the initial shock creates insolvency in 0.15% of observations, and the subsequent fire-sale price-impacts increases this total to

0.38%. However the only bank to become insolvent was Bridgewater Bank: a mortgage specialist based in Alberta. On October 31 2011, the bank had negative retained earnings and a leverage ratio of 77.05, so it was already under significant financial stress. With heterogeneous price-impacts, initial shocks, or a rule that lets banks use liquid assets to pay short-term liabilities, then the rate of insolvency is the same or zero. The Canadian banks can quite easily withstand an equity shock of this calibre.

What magnitude of a shock is necessary to induce insolvency among Canada's major banks? Consider the calibration with heterogeneous price-impacts. If the initial shock is doubled so that 35.6 to 47.3% of equity is lost in an initial shock, then the only insolvency is Bridgewater Bank in the periods between 2010 and 2012. To simulate insolvency among the big six Canadian banks, the D-SIBs, a 3% loss in the value of assets is considered. This is commensurate with a 54 to 70% loss of equity. Given the linear pricing rule, fire-sale sales are scaled up by approximate 3x, so that they become 17.1 to 36% of equity. Fewer than 1% of bank observations experience insolvency from the initial shock, but fire-sale losses increase the number of insolvencies to 11.8%. If the focus is narrowed to the big six banks, then this increases to insolvency in 17.7% of observations. As suggested by the earlier figures of AV, insolvencies cluster around the 2012 to 2015 time period and in the lead-up to the financial crisis of 2007-09'. How would these numbers change if banks sell the most liquid assets first? An initial shock that causes losses of more than 60% of aggregate equity is required to induce insolvency among the big six and insolvencies falls to 12.7% of observations.The reduction demonstrates that there are rewards to holding liquid assets, but these are exhausted fairly quickly in the most severe crisis.

7 Conclusion

Since 2012, consumption growth has outpaced output growth in Canada. The Bank of International Settlements has warned that the risk to households from rising interest rates is higher in Canada than almost anywhere in the world. This increase in loans to households appeared on bank balance sheets and increased the concentration of illiquid assets and led to an increase in equity-at-risk from a fire-sale, or aggregate vulnerability. Despite the increasing AV, I find that the Canadian banking system remains resilient to fire-sale price impacts. This can be attributed to three factors, (i) macroprudential policy in Canada is stronger than in other jurisdictions such that asset quality is higher, (ii) banks have a high amount of liquid assets, and (iii) in the event of a severe shock, system equity is sufficient to maintain bank solvency.

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8 Appendix

Table 5: Canadian financial institutions in the dataset

Name	# of obs.	Mean assets
Bank of Montreal	80	$349.0
Canadian Imperial Bank of Commerce	80	$315.6
Toronto Dominion	80	$461.0
The Bank of Nova Scotia	80	$417.1
Royal Bank of Canada	80	$536.6
National Bank of Canada	80	$115.4
HSBC Canada	80	$53.1
Citibank Canada	80	$11.8
Canadian Western Bank	80	$8.5
Citizens Bank of Canada	76	$0.9
Equitable Bank	80	$4.1
Laurentian Bank of Canada	80	$20.7
Manulife Bank of Canada	80	$9.0
President's Choice Bank	61	$1.0
Tangerine Bank	63	$17.6
Pacific & Western Bank of Canada	54	$1.3
Canadian Tire Bank	50	$2.8
General Bank of Canada	42	$0.4
Hollis Canadian Bank	42	$5.3
Bridgewater Bank	40	$1.4
Zag Bank	52	$0.2
Total	1504	$106.4

Mean assets are not unadjusted for inflation. Tangerine Bank was formerly ING Direct Canada. It was bought out by Scotiabank in November 2012 after which it was removed from the data set. Source: OSFI.

Table 6: Canadian financial institutions in the dataset

Financial sector	**Table**	**Series**
Trust and mortgage loan companies	1760028	v27035
Credit unions and caisse populaires	1760026	v122571
Non-depository credit intermediation	1760068	v1404811
Insurance and segregated funds	1760024	v37000
Investment funds	*Bank of Canada Banking and Financial Statistics: D5*	