# How do Banks Respond to Capital Shocks?[1]

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## Abstract

This paper uses a panel consisting of the largest six banks in Canada, over the period 1997Q1 to 2002Q1, to estimate the dynamic responses of banks to capital shocks. Instead of modelling a bank's assets explicitly in a vector autoregression (Hancock, Laing, and Wilcox (1995)), the distance between the asset portfolio of the bank and the efficient frontier is incorporated into the analysis. The measure is used as a proxy for the risk-return trade-off chosen by an optimizing bank with a capital requirement. The theoretical framework is taken from D'Souza and Lai (2002) which models the capital allocation decision of a bank across its various banking activities. The impact on the level of activity in a number of business-lines with varying degrees of secondary market liquidity is examined.

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# 1. Introduction

In this study, we are interested in how adjustments by Canadian banks to capital shocks affect banking activities and efficiency. The basic premise is that the adjustments are not instantaneous and the adjustment process is costly in terms of efficiency losses. Because a bank has a portfolio of different bank activities, with differing levels of ease of adjustment and a correlation structure among them that an optimizing bank must take into account, capital shocks will have differential effects on various bank activities.

Following shocks to a bank's assets, capital shortfalls will put pressure on a bank to either reduce its assets holdings or increase its capital levels. Evidence suggests that banks raise their capital- asset ratio by reducing their supplies of various types of credit, which changes the composition of the bank's asset portfolio. How a bank changes the composition of its assets will depend not just on regulatory requirements, but also on risk and return considerations, and the liquidity of each asset. The time it takes for a bank to adjust its portfolio following a shock will depend on how easy it is to adjust its assets. Assets that are traded in well-developed secondary markets, such as securities, may adjust more rapidly. Understanding the impact of capital shocks on secondary market activity is important to policy-makers who worry that such shocks among financial institutions may cause liquidity in these markets to fall. Ample liquidity in the government securities and credit markets is an integral part of a well functioning financial system, promoting growth in an economy via an environment in which consumers and firms can make optimal savings and investment decisions.

In this paper, we focus, in general, on three variables: capital shortfalls (or, surpluses), efficiency losses, and volumes in a number of bank activities. We focus on four banking activities: real-estate lending in residential and non-residential markets, and trading in the Government of Canada fixed income market and spot foreign exchange market. We use a VAR methodology to obtain estimates of banks' dynamic responses to shocks to bank capital, since VARs can approximate complicated, interdependent adjustment paths. A panel of quarterly data between 1997Q1 and 2002Q1 for the Big-6 banks in Canada is used to estimate these responses. The direction, size, and duration of the response of a bank's portfolios are important to understanding how portfolio and aggregate shocks affect credit and secondary markets and the economy.

The ability of a bank's trading operations or loans portfolio to generate profits is directly related to the amount of risk capital allocated to that activity. The capital allocation decision takes into account the correlation structure in returns across business lines and the regulatory capital requirements at the firm-level. The allocation will have a direct correspondence to the bank's desired holding of assets in a given business line.

Instead of employing assets values or asset shares to determine asset composition as other authors have done, we construct a measure of efficiency that takes into account how individuals banks have allocated assets in a risk-return efficient frontier framework. The approach is new for this type of study. We argue that when a bank's capital is "shocked", it must make trade-offs in terms of risk and return, which correspond to changes in asset composition that satisfy their capital requirements. This efficiency measure incorporates the risk-return tradeoff faced by banks better than simply having asset values from banks' balance sheets. Impulse response functions are based on VARs with the following ordering: bank capital, efficiency, and activity level. The ordering reflects our assessment of which variables were more 'endogenous.' Impulse response functions are based on shocks to capital.

We measure efficiency by how well banks achieve an optimal risk-return trade-off in their business activities. Banks, as financial intermediaries, generate financing from depositors, equity- holders and debt-holders. They then allocate these funds to a credit portfolio made up of securities, loans, mortgages, etc. As in any portfolio allocation, banks face a risk-return trade-off. Specifically, for a given level of risk, banks attempt to maximum returns. Equivalently, banks minimize risk for a given level of returns. This optimization problem leads to an efficient frontier in risk and return. Any point on this frontier indicates the optimal trade-off between risk and return, for any given level of risk. Hence, we view banks as taking financial inputs, solving a portfolio allocation problem, and producing outcomes measured by risk and return.

The impulse response functions estimated in the paper indicate that capital shocks to banks have an adjustment period of more that 10 quarters. Inefficiency increases with a capital shock as banks attempt to maintain their capital requirement and forsake higher risk-adjusted returns. The response of the four banking activities considered in this paper have interesting differences. Bond trading activity and the number of non-residential mortgages approved increase over the adjustment period. This is not the case for residential mortgages. One possible explanation is that secondary markets for residential mortgages are more developed than non-residential loans. The increase in activity in bond trading and non-residential mortgage loans may be explained through the correlations structure in returns across business lines.

# 2. Related Literature

## 2.1 Bank capital and real estate lending

Our paper is related to Hancock and Wilcox (1994a,b) and Hancock, Laing and Wilcox (1995) who look at the relationship between bank assets and capital shocks. Employing a number of econometric models, these authors find that capital shortfalls significantly affect a bank's loans while capital surpluses stimulated lending. In Hancock and Wilcox (1994b), the authors address the question of whether a capital shortfall affects real-estate lending. Using U.S. data between 1986 to 1992 by state, the authors estimate the effects of a capital crunch and of national and local economic conditions on lending. The authors also find that increased credit from non-bank institutions can offset banks' reduced credit supply, thereby insulating real estate activity. Another finding suggests that capital pressures may also have less impact on real estate activity with the existence of mature secondary markets. Capital pressured banks that originate loans, can sell them to other banks that are not capital constrained.

Hancock, Laing and Wilcox (1995) use a VAR methodology to examine the direction, size, and duration of responses of bank portfolios to bank capital shocks. They find that bank capital and securities activities adjust in one year to capital shocks. The authors also analyse the dynamics of liabilities in their analysis. They find that liabilities and most loan categories take two to three years to complete adjustment. The panel data available to the authors allowed for a test of whether portfolio responses differed by capital pressure. The authors find that larger banks adjusted their portfolio quicker than smaller one, and that capital shocks caused banks with capital shortfalls to contract more than banks with capital surpluses. FInally, banks adjusted more quickly to capital shocks in the 1990s then they did in the 1980s.

## 2.2 Banking efficiency

We measure banking efficiency of Canada's "Big-6" banks by looking at whether the composition of banks' assets leaves banks on the efficient frontier. Since this efficient frontier is empirically constructed, it is possible for banks to over- and under-perform relative to the efficient frontier. We take the distance of these obsevations from the efficient frontier as measures of banking inefficiency. We consider a number of alternative measures of distance, the vertical and horizontal distances from an observation point to efficient frontier, and the Euclidean distance of an observation point from the efficient frontier (that is, the distance between the observation point and the point on the efficient frontier closest to it). Our notion and measure of efficiency accounts for the risk-return trade-off made by banks subject to a capital requirement.

The study of banking efficiency is relevant for policy issues, such as the consolidation in the financial services industry, and the regulation of the banking sector. In anticipation of the relaxation of the Glass-Steagall Act (1937) in the U.S., recently realized by the passing of the Gramm-Leach-Bliley Act in 1999, several researchers (for example, Kwan, 1997, and Lown, Osler, Strahan and Sufi, 2000) have examined the implications of an integration between commercial banking and securities activities for the profitability and risk of banking firms.

A major problem with existing studies is that they mainly measure efficiency gains in terms of reduced risk only, while holding bank returns constant. While it might be prompted by banking and financial stability concern, this measure ignores efficient risk-return combinations that an optimizing bank selects. A better-diversified banking firm can be riskier but more than makes up for this by increased returns. In fact, a better-diversified firm may take on more risk precisely because its diversified revenue/product base allows it to manage risks better. Kwast (1989) addresses this by constructing a mean-variance efficient frontier for banking firms' business lines. He finds that all the US banks in his sample can simultaneously raise their profitability and decrease their risk by increasing their exposure to securities trading. Hence, the restrictions on securities trading imposed by the Glass-Steagall Act have involved efficiency losses by banks. However, Kwast groups all other banking activities outside of the securities trading into one asset class, which restricts banks to holding their activity levels in many business lines fixed with respect to each other. This amounts to constructing a constrained efficient frontier in which banks chose one portfolio weight for securities trading and one for all other business activities. This produces an inaccurate criterion of efficiency.

It is interesting to compare our view of a bank with the literature on x-efficiency applied to banks. The x-efficiency literature usually takes the number of loans and mortgages as outputs of a bank's production process, which does not reflect return or risk. More importantly, the literature does not deal with the trade-off between risk and return. This shortcoming is serious if we consider that the business of banks is to manage risk. Financial firms are fundamentally different from other businesses. While most business shun risk, attempting to try and pass on their financial risk to others so that they can concentrate on making and selling their products, to succeed, financial firms must seek out risk! In nearly all their business, financial firms earn returns by being able to separate well-priced from underpriced risk, and by managing the risks involved. By avoiding all risk, however, they soon cease to be financial firms.

Eisenbeis, Ferrier and Kwan (1999) found that bank risk (measured by the volatility of bank firms' stocks, financial leverage (asset-to-equity ratio) and the ratio of loan charge-offs to total loans), managerial incompetence (measured by ratio of problem loans to total loans, ratio of book value of equity to assets, and rate of asset growth) are significantly related to x-inefficiency of banks. Furthermore, they found that inefficient banks underperformed (in terms of their stock market valuation) relative to their more efficient counterparts. Berger and Mester (1997) found bank size to have a positive but small relationship to efficiency. Additionally, having been survived a merger, having a bank holding company structure and being a publicly traded firm were associated with more efficient banks. Market power in the deposit-taking market has a negative impact on x-efficiency, as does bank risk (as measured by the volatility of returns to assets). Most other studies also found that well-capitalized banks and those with lower nonperforming loans ratios to be more efficient.

While there exists a multitude of efficiency analyses of US banks, there are few applications of these methods to the Canadian banking system. McIntosh (2002) investigated the existence of scale economies for Canada's five largest banks (Big-6 minus National Bank) using data from 1976 to 1996 and concluded that Canadian banks have large enough returns to scale to offset the consequences of reduced competition that might have arised from a merger between the Bank of Montreal and the Royal Bank of Canada, or CBC and TD Bank, or both. His estimated model predicts that all the mergers proposed in 1998 would have led to slightly lower prices, and consequently, to an increase in consumer welfare.

Since we employ a mean-variance notion of efficiency applied to banks' credit portfolios, our work is also related to the empirical literature on mean-variance efficiency. Empirical tests of mean-variance efficiency have typically focused the efficiency of stock markets. Jagannathan and Wang (1992) find that the NYSE-AMEX market portfolio is mean-variance inefficient even when portfolio weights are constrained to be non-negative. Kandel et al. (1995) propose an alternative Bayesian approach to testing for portfolio efficiency. They use the difference in the expected returns of a given portfolio from that of an efficient portfolio with the same variance as a measure of inefficiency of the portfolio. They do not impose short-selling contraints on their portfolios, however. Kandel (1998), Wang (1997) and Li, Sarkar and Wang (forthcoming) modify Kandel et al.'s efficiency tests to incorporate portfolio constraints. Wang (1997) finds that the NYSE-AMEX value-weighted market portfolio to be inefficient even when portfolio weights are constrained to be non-negative but the degree of inefficiency is smaller than in the case where portfolio weights were unconstrained. Li, Sarkar and Wang test for international diversification benefits to U.S. investors, taking a larger degree of inefficiency to imply greater diversification benefits. They find that the diversification benefits of emerging equity markets remain substantial after imposing short-sale constraints in these markets.

## 2.3 Capital allocation and trading activity

Bank capital is required by regulators and the market as a means of protection against market, credit, liquidity, operational, and legal risk, thereby promoting both financial institution and industry stability. The need to manage risk-return tradeoff subject to a capital constraint entails a capital allocation problem for banks. This process involves estimating how much risk each business line contributes to the total risk of the firm, and thus to it’s overall capital requirements. Capital held by the firm is then “allocated” across business lines. Since investment decisions and risk exposures are determined at the business line level, correlations between the returns of different business lines are externalities among business lines that create a need for centralized risk management. Hence, optimal capital allocation induces the appropriate risk-taking behaviour by business line managers by forcing them to internalize the externalities their business line imposes on the rest of the firm.

D’Souza and Lai (2002) develop a framework in which financial institutions use risk management tools (such as Value-at-Risk) in the allocation of risk capital. Risk capital is determined, and constrained by regulatory capital requirements at the firm-level, and allocated among its separate business lines. We show that the optimal capital allocation is a linear function of risk-taking by the business line, measured by the variance of cash flows from that division. The allocation function will depend crucially on the correlations in cash flows across all business line. This capital charge ensures that risk-taking divisions within the firm internalize the impact of their behaviour on overall firm risk by affecting the risk taking appetite of each business line. The level of activity in a business line is then directly related to the amount of risk capital allocated to it. The allocation of risk capital within financial institutions has policy implications in terms of what types of shocks may be beneficial or detrimental to business line activity. Understanding the impact of impact of capital shocks on business line activities is important to policy-makers who worry that increased such shocks among financial institutions may cause liquidity in these markets to fall. Ample liquidity in the government securities and mortgage lending markets is necessary for governments and central banks to effectively implement fiscal and monetary policies.

# 3. Measuring bank efficiency

We take a portfolio theory approach to Canadian banks' activities by constructing a risk-return efficient frontier over bank activities: liquidity management, non-mortgage lending, mortgage lending, securities trading and securities investment. This differs from Kwast's (1989) approach in that we allow banks to vary their exposure over all of the banks' activities, where exposure to an activity is measured by the proportion of bank assets belonging to that business line over total assets. These exposures sum to one for a bank at any given time and are equivalent to the portfolio weights in the bank's portfolio decision.

Regulatory arbitrage may be a factor in the adjustment of activity levels to capital shocks. The Basle Accord allows banks to hold less capital against mortgages that other business loans. Rather than reducing their mortgage loans in the wake of a loss, banks may reduce capital by selling other loans to agencies and buying mortgage-backed securities. This should then imply little or no impact of a capital shock on activity. Lastly, agency theory suggests that banks may increase rather than lower the proportion of their portfolio devoted to different risky asset. Banks may "bet the bank" with a riskier portfolio.

Consider a bank that is engaged in a number of financial activities that generate income. These activities are indexed by $j = 1,\ldots, N$. Each activity has an expected return $\mu_j$, which depends on the level of risk undertaken in that activity, measure by the variance of returns, $\sigma^2{}_j$. Assuming that the vector of returns is multivariate normal with mean $\mu$ and covariance matrix $V$, let $S$ be the set of all the real vectors $x = (x_1,...,x_N)'$ such that $e'x = 1$, where $e$ is a vector of ones. A set of constraints on portfolio weights is represented by a closed convex subset $C$ of $S$. The case in which portfolio weights are unconstrained is represented by $C = S$ and the case in which short-sale constraints apply to all asset classes by $C = \{x \in S; x_j \geq 0, j = 1,..., N\}$.

An optimizing bank will choose a point on the risk-return efficient frontier given by

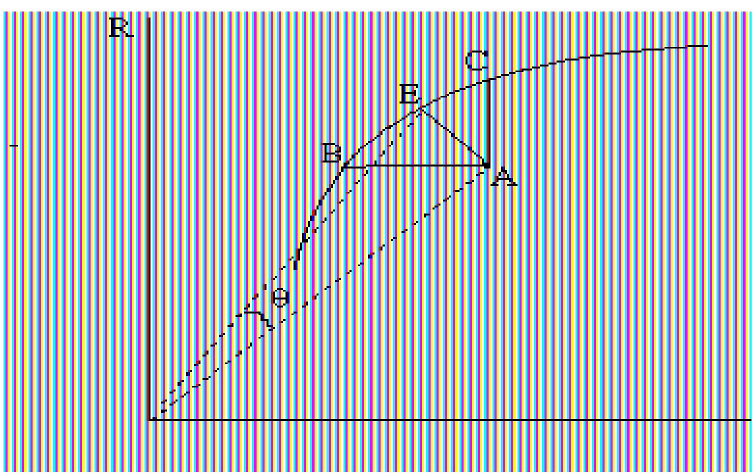
$$\begin{aligned} &\min_x \quad x'Vx \\ &st \qquad x \in C \\ &\qquad\quad \mu' x = z \end{aligned} \tag{1}$$

In the absence of capital adequacy requirements or any other market imperfections, banks should optimally choose their exposures to banking activities so that they are on the efficient frontier. However, we will show later that banks are not on the efficient frontier.

We consider efficient banks to be those that hold efficient portfolios along the risk-return frontier. However, whenever banks hold portfolios that are not optimal, we can obtain three different measures of portfolio inefficiency, two of which are based on Wang (1998) and Li et al. (forthcoming), although we do not implement their Bayesian methodology.

Take a given portfolio, $x_m$. The expected return on this portfolio, $\mu' x_m$ is smaller than the expected return of an efficient portfolio with the same variance, $x_m' V x_m$, unless portfolio $x_m$ is mean-variance efficient. We take the distance of this portfolio's risk-return combination, $(x_m' V x_m, \mu' x_m)$, from the efficient frontier as a measure of inefficiency. There are many possible ways of measuring this distance. Consider Figure 1. Take an arbitrary portfolio represented by the point A. Any point on the frontier between points B and C are better risk-return combinations relative to point A. Thus, the distance from A to any points on the frontier between B and C are conceivable inefficiency measures. We will consider three.

Figure 1: Risk measures




A measure of the inefficiency of portfolio $x_m$, controlling for variance, is

$$\delta(x_m, C, \mu, V) \equiv \max_x \left\{ 1 - \sqrt{\frac{\mu' x}{\mu' x_m}} \mid x \in C, x'Vx \geq x_m' V x_m \right\}$$

Clearly, $\delta$ falls between zero and one, where portfolio $x_m$ is efficient if and only if $\delta = 0$ and inefficiency is increasing in $\delta$. Furthermore, $\delta$ is smaller for a constant absolute vertical difference the further is the portfolio from the origin.

The above measure of efficiency accounts for losses in bank returns due to inefficiency. Another measure of inefficiency, based on horizontal differences, is in terms of the excess risk associated with a portfolio relative to an efficient portfolio yielding the same return, or

$$\phi(x_m, C, \mu, V) \equiv \min_x \left\{ 1 - \sqrt{\frac{x'Vx}{x_m' V x_m}} \mid x \in C, \mu' x \geq \mu' x_m \right\}$$

$\phi$ also falls between zero and one, where portfolio $x_m$ is efficient if and only if $\delta = \phi = 0$ and inefficiency is increasing in $\phi$. $\phi$ is also smaller for the same horizontal vertical difference the further is the portfolio from the origin.

The third measure of inefficiency we consider is based on the Euclidean distance of a given portfolio from the efficient frontier. Specifically, we take the angle, , between the ray from the origin connecting the portfolio and the ray from the origin connecting the point on the frontier, E, that is the shortest distance from the portfolio. This measure has the advantage of accounting for both deviations in risk and return from an optimal portfolio due to inefficiency. In addition, is zero if and only if and are zero. It is also smaller for the same absolute Euclidean distance the further away a portfolio is from the origin, as are and .

# 4. Data

## 4.1 Data sources

Data used to construct asset portfolios of Canadian banks are taken from regulatory reports submitted to the Office of the Superintendent of Financial Institutions (the federal regulator of Canadian banks) and the Bank of Canada. While, in most cases the data is supplied on a quarterly basis, they are important exceptions. For example, disaggregated assets and liability statements are provided monthly. In this situation, monthly asset averages across each three-month period are employed as a measure of average quarterly assets. Our analysis focuses on the assets of the 'big- 6' chartered banks in Canada. They include the Bank of Montreal (BMO), the Bank of Nova Scotia (BNS), the Royal Bank of Canada (ROY), the Canadian Imperial Bank of Commerce (CIBC), National Bank (NAT), and Toronto Dominion Canada Trust (TD). Average assets for each bank during our sample period, January 1997 to March 2002, are plotted on a quarterly basis in Figure?.

The dissaggregation of business-line across banks is determined by the extent to which incomes and expenses from income statements correspond to the relevant assets on a bank's balance sheet. With an accurate correspondence across income statements and balance sheets, we are able to calculate business-line returns (which are used later in the construction of an efficient frontier). The dissaggregation of business lines that banks allocate credit among is constrained by the availability of data on impairment charges. Information about impairment charges is necessary for an accurate calculation of historical returns in each business line. For example, non-mortgage loan income divided by non-mortgage loans is not an accurate measure of returns on this asset class unless the appropriate impairment charges on these loans are considered. Returns are exploited later in our analysis when constructing an efficient frontier.

The data on bank assets are taken from Monthly Average Return of Assets and Liabilities report, except for securities, which are obtained from the Securities Report. These assets are net of allowances for impairment. From each bank, total assets are computed in each of the following business lines.

**Liquidity Management**

A bank undertakes liquidity management to ensure it is able to meet withdrawals by depositors and other short-term liquidity needs. The assets in this business line consist of cash on hand, cheques, deposits with the Bank of Canada, and deposits with other deposit-taking financial institutions.

**Non-Mortgage Lending**

These include loans to governments and public sector entities, financial firms, business firms, and individuals.

**Mortgage Lending**

These include residential and nonresidential mortgage loans.

**Securities Trading**

The assets in a bank's trading activity consist of fixed income securities, commodity securities, equity, and foreign exchange that constitutes the bank's trading account.

**Securities Investment**

The assets in this activity consists of fixed income securities, commodity securities, equity, and foreign exchange that constitutes the bank's investment account.

A few accounting issue must be noted. Securities (in the investment and trading accounts) are quoted in market value while all other assets are in book value. Furthermore, income data on investment account securities do not include unrealized gains and losses while those on trading account securities do. The income for investment and trading account activities are hence not exactly comparable. Further, while income is net of impairment charges it is still gross of interest and operating expenses since we cannot allocate those expenses to the different business lines. Hence, our return measure is gross returns to assets. Kwast (1989) notes that the fact the income is not net of interest expense is an advantage here since this means that the distribution of returns is unaffected by leverage. We exclude services charges and fees as a banking activity since it is not possible to allocate asset to those activities, and hence compute returns to assets for that business line. For the same reason, we have also excluded insurance from a banks' credit portfolio.

To construct an efficient frontier for the credit portfolio of Canadian banks historical returns must be calculated in each asset classes or business line. Data for the income generated from the different business lines are taken from the Consolidated Statement of Income report. We calculate income net of charges for impairment, which we obtain from the Allowance for Impairment report. From each bank, the returns to assets are computed for each business line listed above. The computed risk-return characteristics of each of the banks' activity allows us to derive a risk-return efficient frontier defined over business lines across all banks. By pooling returns across all bank in each business line, we are assuming that banks are to a large extent homogenous (e.g., managerial expertise and/or monitoring capabilities). The only heterogeneity we allow for across banks is the actual chosen portfolio allocations of assets across business lines. The data on banks' asset holdings over the same period allows us to plot a banks' actual portfolios allocation each quarter in our sample period on the risk-return space relative to the efficient frontier. Figure 2 in Appendix A indicates that banks systematically under-perform relative to the efficient frontier. Table 1 presents risk-return profiles across business lines over the sample period 1997Q1 to 2002Q1.

## 5. Econometric Specification: The VAR model

We focus on how capital shocks affect three activities: real-estate lending in residential and non-residential markets, and trading in secondary activities like the Government of Canada fixed income market. Since all three activities have access to secondary markets with differing levels of liquidity, and risk and return trade-offs, there is a potential for differences in the response of each activity to a capital shock. If secondary markets are mature and liquid, and risk-adjusted returns are high there should be little effect in the activity level of that business line as a result of capital pressures. Capital pressured banks that originate loans, can sell them to other banks that are not capital constrained.

Our analysis also distinguishes between shocks to capital and other (economic) factors. Bernanke and Blinder (1992) and Wilcox (1993) find that interest rate shocks affect composition of portfolios for more that two years. Included in the VAR are three economic variables that serve as proxies for current and expected economic conditions: 5-year Government of Canada interest rates, GDP, fixed investment, and the output gap between current and potential output in Canada.

This section strives to determine the impact of capital shocks on the efficiency of banks and the level of activity in a number of business lines. In the process, the framework establishes a rich characterization of the dynamics by which the capital shortfall and the our efficiency measure interact. he capital shortfall we employ is equal to

$$K^T - K = (k^T \times A) - K \tag{2}$$

where $K$ is Tier 1 and 2 capital and $k^T$, the target capital-asset ratio, is 8% of risk-weighted assets.

A vector autoregression (VAR) is constructed in this section to determine the duration, direction and size of a capital shock. The response of activity levels will depend on the risk-return preference of the bank, as well as the level of liquidity in the secondary market. Three different activities are considered: Government of Canada fixed-income trading, residential loans approved, and non-residential loans approved. All volumes in these three activities are in logs. In addition, we also employ a number of control variables: 5-year interest rates, GDP, fixed investment, and the difference between current and potential output growth rates. These economic variables serve as proxies for current and expected economic conditions. In each equation of the VAR there are also individual bank dummy variables.

The VAR described in this section captures the dynamic relations among the variables and allows for lagged endogenous effects. The most useful statistic from this approach are impulse response functions, which are used to access the impact of capital shocks on efficiency and activity levels. A VAR is a linear specification in which each variable in the model is regressed against lags of all variables. Letting $z_t$ denote the column vector of model variables, the VAR specification can be written as:

$$z_t = A_1 z_{t-1} + A_2 Z_{t-2} + ... + A_K z_{t-K} + v_t \tag{3}$$

Where the $A_i$'s are coefficient matrices, $K$ is the maximum lag length, and $v_t$ is a column vector of serially uncorrelated disturbances (the VAR innovations) with variance-covariance matrix $\Omega$.. stimates of VAR coefficients and associated variance-covariance matrices can be obtained from least-squares estimation. Textbook discussions of vector autoregressions and related time-series techniques used in this paper are given in Judge et al. (1988) and Hamilton (1994).

To characterize the behaviour of the model, impulse response functions are usually more useful than the estimated VAR coefficients. Impulse response functions represent the expected future values of the system conditional on an initial VAR disturbance, vt, and may be computed recursively

$$\begin{gathered} E[z_t | v_t] = v_t \\ E[z_{t+1} | v_t] = A_1 v_t = \Phi_1 v_t \\ E[z_{t+2} | v_t] = (A_1^2 + A_2) v_t = \Phi_2 v_t \\ etc. \end{gathered} \tag{4}$$

$\Phi_i$ are the impulse coefficient matrices (Hamilton, 318-24).

$$\begin{gathered} E[z_t | v_t |] = v_t \\ E[z_t + z_{t+1} | v_t] = (1 + \Phi_1) v_t = \Psi_1 v_1 \\ E[z_t + z_{t+1} + z_{t+2} | v_t] = (1 + \Phi_1 + \Phi_2) v_t = \Psi_2 v_t \\ etc. \end{gathered} \tag{5}$$

In the present work, hypothetical initial disturbances will be used to study the impact of particular events. The VAR disturbance may be written as $v_t = Bu_t$, where $u_t$ is a (3 × 1) column vector of mutually uncorrelated structural disturbances with the property that $Var(u_{i,t}) = Var(u_{j,t})$ and $B$ is a lower-triangular matrix with ones on the diagonal computed by factoring the VAR disturbance covariance matrix $\Omega$, subject to the desire ordering of the variables. This is equivalent to modifying equation (3 to include a contemporaneous term

$$z_t = A_0 z_t + A_1 z_{t-1} + A_2 z_{t-2} + \ldots + A_K z_{t-K} + v_t \tag{6}$$

where the $A_0$ coefficient is lower triangular.

One hypothesis tested in this paper is whether the capital shocks have similar impacts on different activity levels. Although VARs are commonly used to characterize dynamic models, this approach also has limitations stemming from time aggregation, which leads to co-determined model disturbances and the consequent necessity of identification restrictions. To summarize, the VAR provides a tractable and comprehensive specification that is capable of capturing the dynamic relations among capital shocks, efficiency, and activity levels. Impulse response analysis is one useful way of characterizing a VAR in the present analysis. Hypothetical initial disturbances will be used to study the impact of capital shocks.

# 6. Estimation Results

When taking into account all possible relations between variables, it seems sensible to construct a model for a vector of time series. In cases where it is not known, a priori, which variable is affecting which, or when it is uncertain which variables are exogenous and which are endogenous, it seems useful to start with the construction of a general time-series model for a vector time series. In this subsection, we test whether capital shocks affect bank efficiency and bank activity levels. We use the VAR methodology to shed light on this question.

VARs can be sensitive to lag length, or K in equation (3). The Schwarz Information Criterion (SIC) and the Akaike Information Criterion (AIC), defined as

$$AIC(K) = \ln(\det \bar{\Omega}) + \frac{2n^2 K}{T}$$

(7)

where $n$ is the number of variables in the system, $T$ is the sample size, and $\bar{\Omega}$ is an estimate of the residual covariance matrix, were employed to determine the lag length of the VAR. The order is chosen to minimize the criterion. Usually two lags (and sometimes one lag) minimized the AIC criterion in each VAR estimated.

One of the key questions that can be addressed with VARs is how useful some variables are for forecasting other variables. A variable, , is said to Granger-cause another variable, , if the information in past and present helps to improve the forecasts of the variable. A block exogeneity test has as its null hypothesis that the lags on one set of variables do not enter the equations for the remaining variables. This is the multivariate generalization of Granger-Sims causality tests. The testing procedure used is the likelihood ratio test:

$$(T-c)(\log(|\Sigma_r|)-\log(|\Sigma_u|)) \tag{8}$$

where $|\Sigma_r|$ and $|\Sigma_u|$ are the restricted and unrestricted covariance matrices and $T$ is the number of observations. This is asymptotically distributed as an $\chi^2$ distribution with degrees of freedom equal to the number of restrictions, c, correction to improve small sample properties. Sims (1980) suggests using a correction equal to the number of variables in each unrestricted equation in the system.

Block exogeneity tests are conducted on activity levels and efficiency, economic control variables. In nearly all cases, the null hypotheses are rejected. Therefore, all VARs performed will include each of these variables. The VAR specification described in the previous section (and slight variations in the specification) is estimated though the coefficient estimates of the VAR are not reported, since little information is to be gained from them. Any one variable in the VAR can affect any other variable in the system either directly or indirectly through another equation. We instead focus on the impulse response functions.

Impulse response functions are plotted in Figure 4. and correspond to the effect of a one-standard deviation capital shock. The response of each variable is normalized by dividing by its innovation variance so that scale are the same across variables. The impulse response functions are based on VARs with variables entered in the following order: bank capital shortfall, inefficiency, spot trading, bond trading, mortgage residential loans, and lastly, non-mortgage residential loans. Inverting the ordering of the last four variables, the volume levels for four activities (spot and bond trading, and residential and non-residential mortgage lending) did not change the impulse response functions.

The impulse response functions indicate that capital shocks to banks have an adjustment period of a little more that 10 quarters. Capital itself adjusts, for the most part, over 8 to 10 quarters, while the inefficiency measure adjusts in just 4 or 5 quarters. The 'inefficiency' response indicates that inefficiency increases with a capital shock as banks attempt to maintain their capital requirement, giving up higher risk-adjusted returns. Interestingly, the response of the four banking activities have some similarities and some important differences, both quantitatively and qualitatively. Both spot FX trading and bond trading operations behave similarly, though while most of the dynamic adjustment in spot trading is nearly symmetric about zero. Bond trading activity increases was always higher during the adjustment. Since Government of Canada fixed-income securities have liquid secondary markets, there should be little effect from a capital shock, except if a bank is attempting to increase its capital. Government of Canada fixed-income securities have a zero risk weight in the calculation of risk capital (Basel accord) while residential mortgage loans have a 50% weight. Lastly, residential and non-residential mortgages also have a similar pattern in their adjustment process to a capital shock, though it is effect is pronounced for non-residential loans. One possible explanation is that secondary markets for residential mortgages are more developed than non-residential loans. Another possible explanation is that increased credit from non-bank institutions may offset banks' reduced credit supply. The increase in activity in non-residential mortgage loans may be explained through the correlations structure in returns across business lines.

## 7. Conclusion

The response of Canadian banks to capital shocks typically takes about eight to ten quarters. This is similar to estimates in the U.S. (see Hancock, Laing and Wilcox, 1995) where banks takes several quarters to a few years to completely adjust their portfolios. Our measure of efficiency or more specifically ‘inefficiency’ was quicker to adjust. This measure is more intuitive than assets values where risk-return considerations are not borne out in the VAR. Our results confirm that the affect of capital shocks on activity varies across markets. The direction of the effect will depend on the correlation structure in returns and the level of secondary in markets.

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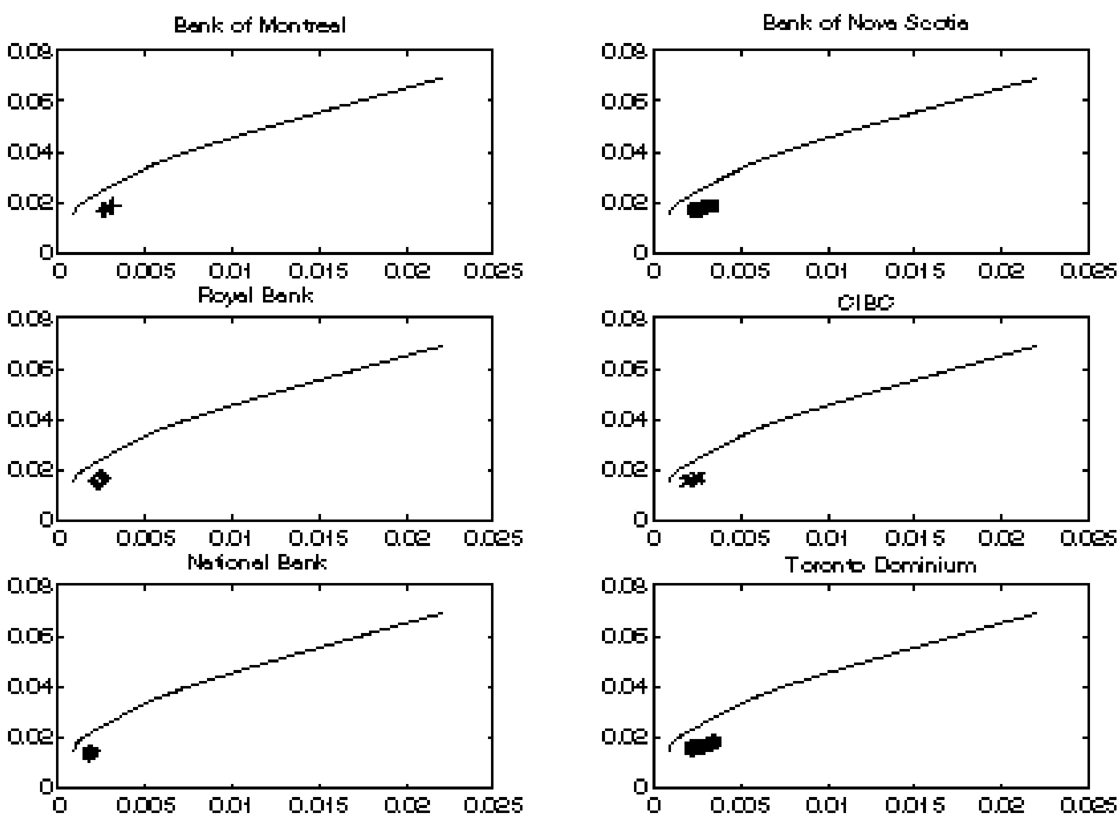
# Appendix A: Bank business lines

**2. Bank business lines and risk-return profile**

| | Liquidity management | Non-mortgage lending | Mortgage lending | Securities trading | Securities investment |
|---|---|---|---|---|---|
| Returns (%) | 1.1583164 | 1.5767200 | 1.6459754 | 0.4525272 | 5.2699987 |
| Covariance | 0.21485188 | 0.02995939 | -0.00338354 | -0.00394417 | 0.06069635 |
| | 0.02995938 | 0.08980176 | 0.00527917 | 0.00579691 | 0.06219008 |
| | -0.00338354 | 0.00527917 | 0.00976945 | -0.00046463 | -0.01092571 |
| | -0.00394417 | 0.00579691 | -0.00046460 | 0.09391139 | 0.01260449 |
| | 0.06069635 | 0.06219008 | -0.01092570 | 0.12604493 | 4.75322510 |
| Correlation | 1 | 0.21568547 | -0.07385269 | -0.02776687 | 0.06006186 |
| | 0.21568547 | 1 | 0.17823310 | 0.063124084 | 0.09518851 |
| | -0.07385269 | 0.17823310 | 1 | -0.01533966 | -0.05070143 |
| | -0.02776686 | 0.06312408 | -0.01533966 | 1 | 0.18865662 |
| | 0.06006186 | 0.09518851 | -0.05070143 | 0.18865662 | 1 |

Figure 2: Efficient frontier and banks' portfolios



# Responses to a Capital Shock

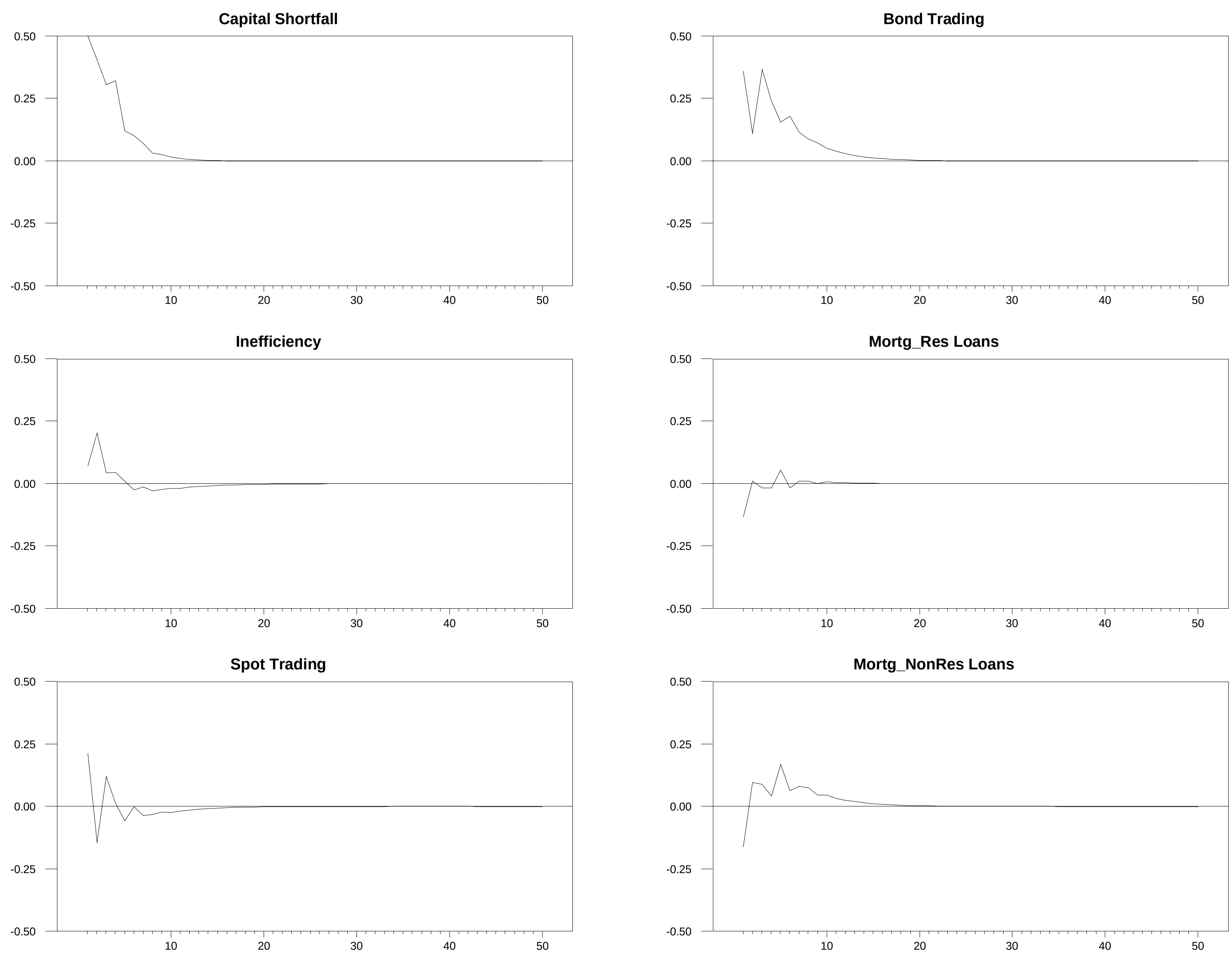


**Table 1: Description of regression variables**

| Variable | Description | Source report |
|---|---|---|
| ROE, return on equity | Ratio of net income to common equity | P3, M4 |
| ROA, return on asset | Ratio of net income to total assets | P3, M4 |
| DOUBT | Ratio of nonperforming assets to total assets | C3, M4 |
| INEFF1 | Inefficiency measure based on vertical distance | |
| INEFF2 | Inefficiency measure based on horizontal distance | |
| INEFF3 | Inefficiency measure based on Euclidean distance | |
| SIZE | Log of total assets | M4 |
| CAP_RATIO | Ratio of total capital to risk-adjusted assets | G3, M4 |
| FIXEDINVT | | |

M4: Balance Sheet; P3: Income Statement; G3: Capital Adequacy Return; C3: Return of Impairment

| **Other capital ratio and doubt variables (* indicates the one for which results are reported)** | |
|---|---|
| CAPRATIO_1 | Ratio of Tier 1 capital to total assets |
| CAPRATIO_2 | Ratio of common equity to total assets |
| * CAPRATIO_3 | Ratio of total capital to risk-adjusted assets |
| CAPRATIO_4 | Ratio of Tier 1 capital to risk-adjusted assets |

## Table 1: Descriptive Statistics

| Bank | Series | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Bank 1 | INEFF, Vert | 0.225917661 | 0.017617599 | 0.194580466 | 0.255363983 |
| | INEFF, Horz | 0.587711919 | 0.015345941 | 0.563600295 | 0.612821056 |
| | INEFF, Eucl | 0.083490839 | 0.003930274 | 0.076314756 | 0.090683609 |
| | CAPRATIO | 0.099934750 | 0.003355246 | 0.092686892 | 0.103768398 |
| Bank 2 | INEFF, Vert | 0.153964337 | 0.017807002 | 0.129108803 | 0.185941663 |
| | INEFF, Horz | 0.546085613 | 0.051829263 | 0.473417741 | 0.626847494 |
| | INEFF, Eucl | 0.078475733 | 0.009236830 | 0.065735566 | 0.094743970 |
| | CAPRATIO | 0.108847373 | 0.011959106 | 0.089583205 | 0.126222518 |
| Bank 3 | INEFF, Vert | 0.2165872337 | 0.0179070080 | 0.1892081765 | 0.2464649763 |
| | INEFF, Horz | 0.5746070199 | 0.0108038436 | 0.5581963710 | 0.5964707538 |
| | INEFF, Eucl | 0.0785803485 | 0.0035440433 | 0.0726552856 | 0.0850620258 |
| | CAPRATIO | 0.1090372619 | 0.0124869465 | 0.0947172274 | 0.1450239115 |
| Bank 4 | INEFF, Vert | 0.2144157925 | 0.0156354657 | 0.1658995167 | 0.2324620273 |
| | INEFF, Horz | 0.5370972451 | 0.0192712130 | 0.5157375805 | 0.5774514075 |
| | INEFF, Eucl | 0.0684279195 | 0.0049165912 | 0.0625663046 | 0.0798814228 |
| | CAPRATIO | 0.1010341441 | 0.0041357647 | 0.0913896119 | 0.1062230497 |
| Bank 5 | INEFF, Vert | 0.1569366089 | 0.0069065869 | 0.1473453823 | 0.1722819203 |
| | INEFF, Horz | 0.5731415152 | 0.0138036689 | 0.5530916778 | 0.5975518986 |
| | INEFF, Eucl | 0.0775356767 | 0.0039954998 | 0.0723762648 | 0.0850140815 |
| | CAPRATIO | 0.1071958142 | 0.0081478883 | 0.0887368881 | 0.1200838325 |
| Bank 6 | INEFF, Vert | 0.2143164290 | 0.0256557476 | 0.1636416275 | 0.2427791239 |
| | INEFF, Horz | 0.6458919180 | 0.0289904624 | 0.5890419418 | 0.6787384795 |
| | INEFF, Eucl | 0.1047392907 | 0.0124072594 | 0.0812647571 | 0.1195165968 |
| | CAPRATIO | 0.0967696405 | 0.0066653191 | 0.0846314154 | 0.1121028545 |