Policy and Infrastructure Developments

Introduction

The financial system and all of its various components (institutions, markets, and clearing and settlement systems) are supported by a set of arrangements, including government policies, that influence its structure and facilitate its operation. Taken together, these arrangements form the financial system's infrastructure. Experience has demonstrated that a key determinant of a robust financial system is the extent to which it is underpinned by a solid, well-developed infrastructure. This section of the Review *highlights work in this area, including that related to relevant policy developments.*

The stability of the financial system has traditionally been a vital concern of central banks. In fact, some were created for the express purpose of maintaining financial stability. The Bank of Canada has a long history of promoting financial stability and, in recent years, has joined the ranks of central banks that have intensified their efforts in this area. Assessing the evolution of the risks associated with financial instability is no simple matter, since the financial system has become much more complex and integrated, both nationally and internationally, in the wake of the policy liberalization and financial innovations that have marked recent decades. This challenge is magnified by the fact that no well-tested theory or empirical models currently exist to guide central banks when they are making decisions on issues related to financial stability. Given this context, researchers and analysts have advanced the so-called macroprudential approach. In "Analyzing the Evolution of Financial Instability Risk," Céline Gauthier and Pierre St-Amant briefly describe this approach and explain to what extent it provides a useful analytical framework for assessing the evolution of the risks associated with financial instability. The authors conclude that this methodology must be supplemented by theoretical and empirical models that allow systemic risk to be identified and its evolution to be better understood. They also review several studies that may provide paths for future research.

A well-functioning large-value payment system is an integral component of any advanced financial system. It provides the necessary electronic infrastructure to facilitate transfers of funds among participating financial institutions to discharge large-value payment obligations. Safety and efficiency are the primary public policy objectives in the design and implementation of these systems. But, given the different types of inherent risks and costs involved, multiple trade-offs between safety and efficiency can be identified within each system. In "Simulation Analysis: A Tool for Examining the Balance between Safety and Efficiency in Canada's Large Value Transfer System," Neville Arjani focuses on one such fundamental trade-off—that between settlement delay and intraday liquidity—with specific application to Canada's Large Value Transfer System (LVTS). In particular, the article illustrates how simulation techniques developed at the Bank of Finland can be used to evaluate this trade-off. The author concludes that a trade-off does exist in the LVTS between settlement delay and intraday liquidity and that this trade-off could potentially be improved with the introduction of a complex queue-release algorithm in the central queue. The author also highlights the caveats of this analysis and offers some ideas for future research.

Analyzing the Evolution of Financial Instability Risk

Céline Gauthier and Pierre St-Amant

The stability of the financial system[1] has always been important to central banks. Indeed, some central banks were created for the express purpose of preserving financial system stability.[2] Interest in this area was heightened by several episodes of pronounced stress on financial systems between 1990 and 2000 (the Asian crisis, the Long-Term Capital Management affair, the boom and bust in technology stocks, etc.). These events revealed that the inflation-control policies adopted by many central banks were not sufficient to guarantee the stability of the financial system, even though they did contribute to it.

In addition to having an inflation-control policy, the Bank of Canada contributes to financial stability in several ways. It provides liquidity to financial institutions under normal and exceptional circumstances. It advises the federal government on policies related to the financial system. It oversees Canada's major clearing and settlement systems. It offers banking services to those who operate and use these systems. It collaborates with other national and international bodies that promote financial stability. Finally, it analyzes the evolution of risks likely to undermine this stability (systemic risk). This paper examines this final contribution.

The analysis of systemic risk yields valuable information for all activities aimed at promoting financial stability. For example, the Bank must have a thorough understanding of the state of the financial system if it is called upon to inject liquidity into this system in the event of an exceptionally serious problem. The results are shared with other organizations involved in promoting stability in the financial system (prudential authorities) and with the general public, primarily through the *Financial System Review*.[3] The Bank's intent is for this information to contribute to both the better functioning of financial markets and to improved policy design. Finally, the Bank's analysis of systemic risk provides invaluable information for the conduct of monetary policy, given that financial instability tends to depress global demand and make a monetary policy response necessary.[4]

Assessing the evolution of risks that undercut financial instability is no simple matter, since the financial system has become much more complex and integrated, both nationally and internationally, in the wake of the policy liberalization and financial innovations that marked recent decades (Freedman and Goodlet 2002; Freedman and Engert 2003; Houben, Kakes, and Schinasi 2004). The challenge is magnified by the fact that there is currently no acknowledged theory or empirical model to guide central

1. The financial system consists of financial institutions, financial markets, and clearing and settlement systems. This system is unstable if impediments to its good functioning are likely to result in a significant decline in real GDP. Otherwise, it is considered to be stable.
2. The U.S. Federal Reserve System was created in 1913 in response to the panic selling that shook the U.S. financial system in 1907 (Ferguson 2002).
3. The Bank of Canada's principal partners in promoting financial stability in Canada are the federal Department of Finance, the Office of the Superintendent of Financial Institutions, and the Canada Deposit Insurance Corporation. The mandates of central banks in this matter vary from one country to another. Healey (2001) and Oosterloo and de Haan (2004) describe these differences.
4. Some authors (Borio and White 2004) contend that monetary authorities should tighten monetary policy when a speculative bubble develops that could cause financial instability. Laidler (2004) offers a different point of view on the subject. Selody and Wilkins (2004) address this debate in the Canadian context.

banks in the matter. It is in this context that researchers and analysts, especially those at the Bank for International Settlements (BIS) (Crockett 2000; Borio 2003), have proposed the macroprudential approach.

In this article, we briefly describe this approach and evaluate to what extent it can guide the analysis of risk. We conclude that the macroprudential approach provides a useful analytical framework, but that it needs to be supplemented by theoretical and empirical models that allow systemic risk to be identified and better understood. We also review work that we believe may be able to furnish such models. Much remains to be done in this field, and research needs to be ongoing. We conclude by proposing several avenues of future research.

The Macroprudential Approach

The term "macroprudential approach" was initially used to describe analysis that encompasses the entire financial system, rather than focussing on a particular element. In the early 2000s, economists at the BIS proposed this approach as a policy guide for authorities promoting financial stability (Crockett 2000; Borio 2003). The concept was taken up by many central banks, as well as by economists at international financial institutions (Tumpel Gugerell 2002; Selialia 2003; Hoenig 2004; Houben, Kakes, and Schinasi 2004; Gjedrem 2005).

Economists who advocate the macroprudential approach contrast it with the microprudential approach, which concentrates on individual contracts and organizations and, ultimately, strives to protect investors and depositors. The microprudential approach attempts to accomplish this by limiting the individual risks to which certain specific agents are exposed. It treats systemic risk as exogenous, in the sense that it does not depend on the reactions of financial agents. In this framework, the correlation in the activities of individual agents is not considered, and systemic risk is simply the sum of individual risks. Consequently, in its most extreme form, the microprudential approach considers the soundness of institutions taken individually to be both necessary and sufficient for the stability of the system.

The macroprudential approach treats the financial system as a whole, and its ultimate goal is to limit systemic risk. It recognizes the endogenous nature of systemic risk, which may be caused by the actions of financial-system stakeholders. For example, strategic decisions made by banks, including the decision to increase the share of an asset in their portfolios, can contribute to systemic risk. The correlation between decisions made by individual agents thus plays a key role in the evolution of risks. Decisions that appear innocuous when taken individually may, in fact, represent a threat to the financial system if they are taken by many agents. Thus, the fact that a single, medium-sized bank decides to increase the proportion of mortgage loans in overall loans may not increase systemic risk. But, if all banks simultaneously do the same, systemic risk may be exacerbated. The entire financial system is now exposed to a less-diversified risk. Moreover, the greater supply of mortgage credit implied by such a shift could trigger a real estate bubble. The eventual bursting of this bubble could cause hardship to economic agents through an erosion in the value of their real-estate holdings, as well as to those who provide the mortgage credit. We have chosen to illustrate this principle with mortgage credit, but systemic risk can also result from decisions taken in other areas of the financial system. Authorities who focus on the decisions of individual financial agents without accounting for the correlations between these decisions may be ignoring a very important source of systemic risk. The macroprudential approach to risk assessment imposes this accounting.

In practice, policy-makers often draw on both the micro- and macroprudential approaches. Consequently, in its role as lender of last resort, the Bank of Canada can provide liquidity to a bank that it deems healthy, but that is experiencing temporary liquidity problems. The goal is to protect economic agents from the consequences of market failure arising from a lack of information. Under the same policy, however, the Bank may inject liquidity into the entire financial system if it considers that such a measure might avert a significant systemic risk. In this case, the stability of the financial system is the primary concern.[5]

5. Daniel, Engert, and Maclean (2004–05) describe the Bank of Canada's lender-of-last-resort policy.

According to Borio (2003), the macroprudential approach implies that supervision and prudential standards are tailored to account for the marginal contribution of an institution to system-wide risk. This may have significant implications for prudential authorities; for example, in relaxing the surveillance of agents that are deemed to pose little, if any, risk to the stability of the financial system and in intensifying the scrutiny of those more likely to have a systemic impact. In practice, the breadth and complexity of the financial system means that it would not be feasible to expect the authorities to be able to analyze each of its elements in detail. Given this constraint, it seems more appropriate that they focus their efforts on those parts of the system considered to represent a heightened threat. Consequently, the macroprudential approach results in a more efficient use of resources for authorities seeking to limit systemic risk.

Nevertheless, it is important to bear in mind that there is currently no theoretical model or proven empirical model that establishes clear cause-and-effect relationships between the actions of participants in the financial system and any impact on its stability.[6] For the time being, the macroprudential approach is, instead, a collection of concepts that can point researchers towards the elements of a sound theory, which should both embrace and inform the intuition of decision makers as to which variables are key to defending financial stability.

Current Avenues of Research for Improving Analysis

In this section, we present several lines of current research at the Bank involving potentially useful models for overseeing and analyzing risk in the financial system.

The first is the contingent-claims approach (CCA), which proposes a method of measuring the evolution of risk in various sectors of the economy, as well as the transmission of risk between sectors. Next, are some approaches to the structural modelling of links between the real economy and the financial system.

The contingent-claims approach

The macroprudential approach recognizes the importance of shared exposure to certain shocks in the determination of systemic risk. The contingent-claims approach is a promising technique for accounting for these common exposures.

The CCA uses options-price valuation techniques to estimate a firm's risk of default based on the value and volatility of its capital stock and on the evolution of the book value of its debt.[7] The greater the volatility of its stock, the greater is the probability that the value of the firm's assets will fall below the value of its debt, and thus the greater is the probability that the firm will fail.[8]

Recently, Gray, Merton, and Bodie (2003) proposed a generalization of the CCA for the assessment of risk in different sectors of the economy (non-financial firms, banks, etc.).[9] They apply the CCA to a sector, rather than to an individual firm, by summing the market capitalization and debt load of each firm in the sector. The correlation between the yields on individual securities, which arises largely from the exposures shared by the issuers, is thus accounted for in the

6. Data problems are often an obstacle to the elaboration of solid empirical models. For example, owing to the absence of adequate data for some countries, Borio and Lowe (2002) were unable to integrate the price of real estate assets into their multi-country empirical models.

7. An option is a derivative whose value depends on the evolution of the price of the underlying asset. Merton (1973) was the first to conceptualize a firm's stock as analogous to a call option on its assets, with the value of the firm's debt being equivalent to the option's strike price. Thus, a stock is worth nothing if the value of the firm's assets is below the value of its debt (the option is "out of the money"). Otherwise, the value of the option is equal to the difference between the value of the assets and the value of the debt (it is, thus, "in the money").

8. Tudela and Young (2003) demonstrate that the CCA possesses the properties of an advanced indicator of the financial health of firms, beyond the information contained in their financial balance sheets.

9. See van den End and Tabbae (2005) and Gapen et al. (2004) for recent applications of this approach.

calculation of the volatility of the sectoral aggregate.[10] All other things being equal, the greater the shared exposure of firms, the greater is the volatility (approximated by the variance) of the sector's market capitalization, and thus the greater the sectoral risk identified by the CCA.

This framework also allows at least a partial evaluation of the transmission of risk from one sector to another via the links between the various sectors' financial balances. Researchers at the Bank of Canada currently apply this method to various subsectors of the non-financial sector and to banking. Our goal is to generate a useful measure of the evolution of risk in particular business sectors over time. Furthermore, sectoral analysis allows us to examine the share of the risk confronting banks that stems from their exposure to these various subsectors. The CCA is open to a wide variety of applications. For example, van den End and Tabbae (2005) apply this methodology to the household and pension fund sectors.

Modelling the links between the real economy and the financial system

Since risk is usually deemed systemic if it has potentially serious consequences for the real economy, and since the financial cycle and the business cycle are intimately linked, the macroprudential approach implies that it is necessary to better understand the links between the financial system and the real economy.

In light of the partial endogeneity of systemic risk, one approach currently being explored at the Bank and elsewhere consists of using various specifications and econometric models to estimate dynamic linkages between certain measures of the health of banks (e.g., yields, or provisions for loan losses) and various indicators of the macroeconomic and financial situation in Canada (GDP growth, interest rate levels, stock prices, etc.).[11] Since Canada is a small, open economy, the incorporation of factors such as commodity prices, U.S. interest rates, and U.S. growth rates as exogenous variables in models of the Canadian economy improves their specification. Such an approach allows the responses of the economy and of Canadian banks to exogenous shocks to be simulated. For example, the impact on Canadian banks of a significant slowdown in the U.S. economy and/or a sharp drop in commodity prices can be estimated. This approach is severely limited by the high degree of imprecision of econometric estimates as soon as the number of endogenous variables exceeds four or five.

Another econometric approach consists of estimating long-term relationships between real variables and certain key financial variables. Estimates of these relationships, provided they are stable, allow the identification of adjustments that could bring the economy into equilibrium.[12]

Considerable effort is also devoted to building dynamic general-equilibrium models that incorporate financial frictions. Specific attention has been paid to linkages between real-estate prices and the business cycle (Iacoviello 2005; Aoki, Proudman, and Vlieghe 2002), the role of bank capital in the propagation of economic shocks (Van den Heuvel 2004; Meh and Moran 2004), and the implications of the rationing of business financing for investment and economic activity in general (Bernanke, Gertler, and Gilchrist 1999; Christensen and Dib 2004).

For example, a model of the Canadian economy based on the work of Iacoviello (2005) incorporates financial frictions by assuming that some households are constrained by a liquidity shortfall. The amount that these households can borrow is limited to a fraction of their real-estate wealth, which introduces a financial-accelerator mechanism to the household sector. Assume that a shock drives up housing prices, all other things being equal. This shock allows constrained households to borrow more. They use

10. Lehar (2005) takes a somewhat different approach. He approximates the risk to a country's entire banking sector using the median of the covariance between the market values of the banks' assets generated by applying the CCA to individual banks. He then employs the idea that, under certain conditions, the total risk of a portfolio converges to the mean covariance (or the mean shared exposures) between the yields of the securities in the portfolio.

11. See Pain (2003); Mawdsley, McGuire, and O'Donnell (2004); Hoggarth and Whitley (2003); and Virolainen (2004).

12. See Pichette and Tremblay (2003), as well as Gauthier and Li (2006) for applications to the Canadian economy. Jacobson et al. (2001) and Cassola and Morana (2002) provide applications to other economies.

their additional funds to consume and invest more, which amplifies the effect of the initial shock on overall demand (this is called a financial accelerator) and may create additional upward pressure on the prices of goods and services, including the price of housing. This type of approach could prove very useful for the analysis of financial stability, at least to the extent that researchers are able to endogenize the other features of the financial system, especially the growth of speculative bubbles. Thus, the ideal model could distinguish between a speculative bubble and a rise in asset prices that is grounded in economic fundamentals.[13]

Moreover, markets appear to be afflicted with what Borio (2003) calls a "risk perception gap." Indeed, risk-perception indicators suggest that risk is usually perceived as low during the growth phase of the business cycle and high during recessions. In fact, there is ample evidence that risk increases during periods of expansion and is low when weaker agents have already declared bankruptcy. Markets appear to have difficulty integrating the externalities inherent in business cycles.

This phenomenon, which gives rise to a gap between the prices of assets and their fundamental value, could contribute to the development of speculative bubbles in financial markets. Several researchers have attempted to better understand this perception gap in the assessment of effective risk (Froot and O'Connell 2003; Gai and Vause 2004; Kumar and Persaud 2002; Tarashev, Tsatsaronis, and Karampatos 2003; and Misina 2003).

Conclusion

The macroprudential approach provides a useful conceptual framework that central banks and other prudential authorities should not hesitate to employ to guide their efforts in analyzing risk to the financial system. This conceptual framework is not a theoretical or empirical model, however. Construction of such models should be a research priority.

Significant progress has been made in the field. In this article, we have emphasized the promising nature of work that draws on the contingent-claims approach and on modern econometric methods with little or no theoretical content, and have also pointed to the potential of stochastic dynamic general-equilibrium models with financial frictions.

We believe that additional research into the following areas will be particularly beneficial:

- Application of the CCA to other sectors, such as households and pension funds, and the integration of sectoral risk into a measure of risk in the entire economy.
- Econometric analysis of panel data to examine the linkages between relevant macroeconomic variables and various sectors of the economy.
- Integration of several financial frictions into a single model. To date, most studies have tended to focus on one type of friction at a time. It would be interesting to look at the interaction of several types of friction within a single model.
- Endogenization of speculative bubbles into dynamic general-equilibrium models.

13. Scheinkman and Xiong (2003) provide an interesting example of this endeavour.

References

Aoki, K., J. Proudman, and G. Vlieghe. 2002. "House Prices, Consumption, and Monetary Policy: A Financial Accelerator Approach." Bank of England Working Paper No. 169.

Bernanke, B., M. Gertler, and S. Gilchrist. 1999. "The Financial Accelerator in a Quantitative Business Cycle Framework." In *Handbook of Macroeconomics*, J. Taylor and M. Woodford (eds.). Amsterdam: North Holland.

Borio, C. 2003. "Towards a Macroprudential Framework for Financial Supervision and Regulation?" BIS Working Paper No. 128.

Borio, C. and P. Lowe. 2002. "Asset Prices, Financial and Monetary Stability: Exploring the Nexus." BIS Working Paper No. 114.

Borio, C. and W. White. 2004. "Whither Monetary and Financial Stability? The Implications of Evolving Policy Regimes." BIS Working Paper No. 147.

Cassola, N. and C. Morana. 2002. "Monetary Policy and the Stock Market in the Euro Area." European Central Bank Working Paper No. 119.

Christensen, I. and A. Dib. 2004. "Monetary Policy in an Estimated DSGE Model with a Financial Accelerator." Available at <http://www.clevelandfed.org/centralbankinstitute/conf2004/september2/index.htm>.

Crockett, A. 2000. "Marrying the Micro- and Macroprudential Dimensions of Financial Stability." BIS Speeches, 21 September. Available at <http://www.bis.org/speeches/sp000921.htm>.

Daniel, F., W. Engert, and D. Maclean. 2004–05. "The Bank of Canada as Lender of Last Resort." *Bank of Canada Review* (Winter): 3–16.

Ferguson, R.W. 2002. "Should Financial Stability Be an Explicit Central Bank Objective?" Federal Reserve Bank Speeches. Available at: <http://www.federalreserve.gov/BoardDocs/Speeches/2002/20021016>.

Freedman, C. and W. Engert. 2003. "Financial Developments in Canada: Past Trends and Future Challenges." *Bank of Canada Review* (Summer): 3–16.

Freedman, C. and C. Goodlet. 2002. *The Financial Services Sector: An Update on Recent Developments*. Bank of Canada Technical Report No. 91.

Froot, K.A. and P.G.J. O'Connell. 2003. "The Risk Tolerance of International Investors." National Bureau of Economic Research Working Paper No. 10157.

Gai, P. and N. Vause. 2004. "Risk Appetite: Concept and Measurement." *Bank of England Financial Stability Review* (December): 127–36.

Gapen, M.T., D.F. Gray, C.H. Lim, and Y. Xiao. 2004. "The Contingent Claims Approach to Corporate Vulnerability Analysis: Estimating Default Risk and Economy-Wide Risk Transfer." IMF Working Paper No. 04/121.

Gauthier, C. and F. Li. 2006. "Linking Real Activity and Financial Markets: BEAM Model." Forthcoming Bank of Canada Working Paper.

Gjedrem, S. 2005. "The Macroprudential Approach to Financial Stability." *Economic Bulletin* (June). Norges Bank.

Gray, D.F., R.C. Merton, and Z. Bodie. 2003. "A New Framework for Analyzing and Managing Macrofinancial Risks of an Economy." MF Risk Working Paper No. 1-03.

Healey, J. 2001. "Financial Stability and the Central Bank: International Evidence." In *Financial Stability and Central Banks—A Global Perspective*, 19–78. Central Bank Governors Symposium series. New York: Routledge.

Hoenig, T. 2004. "Exploring the Macro-Prudential Aspects of Financial Sector Supervision." *Economic Review* 89: 5–17. Second quarter. Federal Reserve Bank of Kansas City.

Hoggarth, G. and J. Whitley. 2003. "Assessing the Strength of UK Banks through Macroeconomic Stress Tests." *Bank of England Financial Stability Review*: 91–103.

Houben, A., J. Kakes, and G. Schinasi. 2004. "Toward a Framework for Safeguarding Financial Stability." IMF Working Paper No. 04/101.

Iacoviello, M. 2005. "House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle." *American Economic Review* 95: 739–64.

Jacobson, T., P. Jansson, A. Vredin, and A. Warne. 2001. "Monetary Policy Analysis and Inflation Targeting in a Small Open Economy: A VAR Approach." *Journal of Applied Econometrics* 16: 487–520.

Kumar, M.S. and A. Persaud. 2002. "Pure Contagion and Investors' Shifting Risk Appetite: Analytical Issues and Empirical Evidence." *International Finance* 5: 401–36.

Laidler, D. 2004. "Sticking to Its Knitting: Why the Bank of Canada Should Focus on Inflation Control, Not Financial Stability." CD Howe Institute Commentary No. 196.

Lehar, A. 2005. "Measuring Systemic Risk: A Risk Management Approach." *Journal of Banking and Finance* 29: 2577–603.

Mawdsley, A., M. McGuire, and N. O'Donnell. 2004. "The Stress Testing of Irish Credit Institutions." *Central Bank and Financial Services Authority of Ireland Financial Stability Report*.

Meh, C. and K. Moran. 2004. "Bank Capital, Agency Costs, and Monetary Policy." Bank of Canada Working Paper No. 2004-6.

Merton, R.C. 1973. "Theory of Rational Option Pricing." *The Bell Journal of Economics and Management Science* 4: 141–83.

Misina, M. 2003. "What Does the Risk-Appetite Index Measure?" Bank of Canada Working Paper No. 2003-23.

Oosterloo, S. and J. de Haan. 2004. "Central Banks and Financial Stability: A Survey." *Journal of Financial Stability* 1: 257–73.

Pain, D. 2003. "The Provisioning Experience of the Major UK Banks: A Small Panel Investigation." Bank of England Working Paper No. 177.

Pichette, L. and D. Tremblay. 2003. "Are Wealth Effects Important for Canada?" Bank of Canada Working Paper No. 2003-30.

Scheinkman, J. and W. Xiong. 2003. "Overconfidence and Speculative Bubbles." *Journal of Political Economy* 111: 1183–1219.

Selialia, F. 2003. "Macroprudential Analysis Approach in Assessing Financial System Stability."A background paper presented at the South African Institute of Bankers, 2 June. Available at <http://www.iob.co.za/downloads/p200306.doc>.

Selody, J. and C. Wilkins. 2004. "Asset Prices and Monetary Policy: A Canadian Perspective on the Issues." *Bank of Canada Review* (Autumn): 3–14.

Tarashev, N., K. Tsatsaronis, and D. Karampatos. 2003. "Investors' Attitude Towards Risk: What Can We Learn From Options?" *BIS Quarterly Review* (June): 57–65.

Tudela, M. and G. Young. 2003. "A Merton-Model Approach to Assessing the Default Risk of UK Public Companies." Bank of England Working Paper No. 194.

Tumpel Gugerell, G. 2002. "Financial Regulation and Systemic Stability." Speech by the Vice Governor of the Austrian National Bank at the CEPR/ESI Annual Conference: "Regulatory Challenges for European Financial Markets," hosted by the Austrian National Bank, Vienna, September. Available at <http://www.bis.org/review/r020923f.pdf>.

van den End, J.W. and M. Tabbae. 2005. "Measuring Financial Stability: Applying the MfRisk Model to the Netherlands." De Nederlandsche Bank Working Paper No. 30.

Van den Heuvel, S. 2004. "Does Bank Capital Matter for the Transmission of Monetary Policy?" In *The Evolving Financial System and Public Policy*, 161–72. Proceedings of a conference held by the Bank of Canada, December 2003. Ottawa: Bank of Canada.

Virolainen, K. 2004. "Macro Stress Testing with a Macroeconomic Credit Risk Model for Finland." Bank of Finland Discussion Paper No. 18.

Simulation Analysis: A Tool for Examining the Balance between Safety and Efficiency in Canada's Large Value Transfer System

Neville Arjani

A well-functioning large-value payment system (LVPS) is an integral component of any advanced financial system. In a market economy such as Canada's, virtually all economic transactions ultimately involve the transfer of funds between a buyer and a seller. An LVPS provides the electronic infrastructure necessary to facilitate exchanges of funds between participating financial institutions to discharge large-value payment obligations on behalf of their own business and that of their customers. The Bank of Canada maintains an active research program in this area, with specific emphasis on Canada's Large Value Transfer System (LVTS).[1] This research contributes to the Bank's broader objective of fostering a safe and efficient financial system in Canada.

Simulation analysis is a recent development in payment systems research. Simulation models are a useful tool since they can often be calibrated to replicate a specific LVPS environment. These models can then be used to assess the impact of changes in the structural arrangements and decision parameters of an LVPS without causing any costly disruption to the operation of the actual system. There is growing interest among central banks in using simulation analysis to conduct research on payment systems. As a contribution to this initiative, the Bank of Finland has developed a general simulation application, called BoF-PSS2, and is offering this software to other central banks free of charge.[2] The BoF-PSS2 is currently being used by over 30 central banks. The Bank of Canada has recently adopted the BoF-PSS2 and is calibrating this application to simulate the LVTS environment.

The Bank can use simulation analysis to understand the trade-off between safety and efficiency in the LVTS.[3] Improving safety and enhancing efficiency are the primary public policy objectives with respect to the design and implementation of an LVPS. A payment system should be safe in the sense that any disruptions within it do not spread to the broader financial system. At the same time, for its users, the payment system should provide a cost-effective means of sending payments. A system that is too safe (and therefore more costly) may discourage financial institutions from using it, and may instead lead them to resort to less-costly and more risky arrangements for sending payments.

There are different types of risks and costs inherent in an LVPS, and multiple trade-offs between safety and efficiency typically exist within each system.[4] This article focuses on a fundamental safety-efficiency trade-off—between settlement delay and intraday liquidity—with specific application to Canada's LVTS. Potential

1. The LVTS is owned and operated by the Canadian Payments Association (CPA). On average, approximately Can$140 billion is transferred through the LVTS each day. The Bank of Canada and 14 deposit-taking institutions participate in the system. The Bank of Canada also supplies the means of settlement and maintains oversight responsibility for the LVTS with a view to controlling systemic risk. For more information on the LVTS, see Dingle (1998) and visit the CPA website at www.cdnpay.ca.

2. The Bank of Canada is grateful to the Bank of Finland for developing the BoF-PSS2 and for allowing other central banks to use it.

3. Simulation techniques have been used by central banks for other types of payment systems research, such as stress-testing. Leinonen (2005) discusses simulation research conducted by central banks worldwide.

4. The risks most often cited in large-value payment systems include credit and liquidity risk, legal risk, operational risk, and systemic risk. See BIS (1997).

improvements to this trade-off will also be discussed. This article shows how simulation analysis can be used to evaluate such a trade-off using actual data on LVTS transactions and credit limits. It also shows how simulation analysis can be used to test hypotheses regarding improvements in the trade-off. In accomplishing this, the usefulness of the BoF-PSS2 as a research tool will be highlighted. The article concludes with some caveats related to the simulation analysis and suggestions for future research.

Settlement Delay and Intraday Liquidity in an LVPS: The Trade-Off

The nature of settlement delay in an LVPS

Participants in a large-value payment system typically maintain a daily schedule of payments that they must send through the system on their own behalf and on behalf of their clients. Payments must be completed by a certain time each day, where the time that a specific payment is due is determined as part of the underlying economic transaction. Most payments must simply be transferred by the end of the day. However, some payments sent through an LVPS are time sensitive. These may include payments related to the settlement of final funds positions in other important clearing and settlement systems, as well as payments associated with the daily implementation of monetary policy. Time-sensitive payments must be sent by a specific time each day.

Payment finality is achieved when an LVPS payment sent from one participant to another cannot be revoked or unwound under any circumstances, as in the case of participant insolvency. A key feature of a modern LVPS is that these systems offer immediate intraday finality—in other words, payments are considered final immediately upon being processed by the system.[5] As a result, recipients of payments can make prompt use of these funds without any chance of a payment being subsequently revoked or unwound.

This article defines settlement delay as a potential time lag occurring between a participant's intended submission of a payment to the LVPS (i.e., when the payment is due) and when the payment becomes final (i.e., when it is processed by the LVPS). Settlement delays in an LVPS are often related to the liquidity constraints faced by participants that are associated with the provision of intraday credit. This will be discussed in greater detail below.

The consequences of settlement delay in an LVPS

Given the high speed and high value of daily payments processed through an LVPS, coupled with the fact that many of these payments are time sensitive, the costs associated with settlement delay can be potentially significant.

A participant that is unable to meet its payment obligations when they are due may face certain costs because of the delay, such as reputation damage with its peers and, possibly, a loss of its clients' business. For the intended receiving bank awaiting payment, not obtaining incoming funds when they are expected will result in a shortfall in its intraday funds position. If this participant is planning on using these funds to send its own payments, then those payments may also be delayed. A comparable disruption to the funds position of the receiving bank's client is also likely, resulting in potentially broader consequences for economic activity.

The existence of settlement delay may also intensify the potential losses associated with other risks in the LVPS, such as operational risk. An operational event (such as a computer outage that prevents one or more participants from sending payments) will likely have a larger impact in a case where a number of payments remain unprocessed at the time the incident occurs (Bedford, Millard, and Yang 2005). Also, if faster, more efficient processing of payments helps to encourage greater use of an LVPS versus systems that are not as well risk proofed, it follows that reductions in settlement delay may translate to lower systemic risk in the broader financial system.

5. The discussion here focuses on the "modern LVPS," which refers to real-time gross settlement (RTGS) and RTGS-equivalent LVPS, such as Canada's LVTS. For a complete description of these systems, see BIS (1997, 2005).

Intraday liquidity in an LVPS

Intraday liquidity refers to a participant's ability to meet its outgoing payment obligations in a timely manner. In today's LVPS, participants require intraday funds in order to send payments through the system. Maintaining intraday liquidity, therefore, means having the funds available to complete payments as they become due. This is typically costly for participants. For example, an important source of intraday funding for participants is the provision of intraday credit. If intraday credit was free and unlimited, participants could borrow funds any time they needed to send a payment, and no settlement delay would occur. However, although settlement delay would cease to exist in this case, lenders of intraday credit (typically central banks) would face large risk exposures vis-à-vis borrowers, which is not desirable from a public policy perspective.

Consequently, intraday credit in an LVPS is not free and unlimited, but rather, is typically subject to eligible collateral requirements (which may entail an implicit opportunity cost), explicit interest charges, or caps on credit provision. These intraday credit constraints may limit participants' intraday liquidity in an LVPS, thus increasing the potential for settlement delay in the system.

The trade-off

Consider a hypothetical reduction in the amount of intraday funding maintained by participants in the LVPS. What would be the impact of this reduction? It is anticipated that such a reduction would entail both a "cost" and a "benefit" to system participants. The benefit to participants is clear: a reduction in available intraday funds will directly result in lower funding costs (e.g., reduced collateral requirements). However, participants rely on intraday funds to send payments to each other. Reducing the amount of funds available to a participant increases the likelihood that it may not have sufficient liquidity when its payments become due. Thus, the cost associated with this hypothetical reduction in intraday funding is a potential increase in the level of settlement delay in the system.

Payments that cannot be processed when due because of a participant's lack of intraday liquidity may be held in that participant's internal queue. Alternatively, these payments could be submitted to the LVPS and held in the system's central queue if one is available. Under standard queuing arrangements, internally and centrally queued payments are released and processed on an individual basis when the sending participant's intraday liquidity improves to the extent that these payments can be processed. This increase in intraday liquidity may be a result of the participant receiving a payment from another participant or acquiring more intraday credit.

It is also expected that the greater the amount of intraday funds removed from the system, the greater will be the magnitude of the accompanying settlement delay. The number of payments becoming queued when due, and also their duration in the queue, will increase as intraday liquidity is further reduced.

A graphical representation of the trade-off

Following a general analytical framework proposed by Berger, Hancock, and Marquardt (1996), the trade-off between settlement delay and intraday liquidity can be characterized as a decreasing convex curve in delay-liquidity space (Chart 1).

Each point in the space represents a possible delay-liquidity combination necessary to produce a given amount of payments. All points along, and above, or to the right of the curve represent feasible delay-liquidity combinations, given the current LVPS technology. Movements along the curve from right to left capture the idea that, as intraday funding is removed from the system, settlement delay is expected to rise at an increasing rate. Points below or to the left of the curve, although preferred, are currently unattainable and can be achieved only through some form of innovation in the LVPS technology.

Improving the trade-off between settlement delay and intraday liquidity

Given the potential consequences of settlement delay, an improvement in the trade-off is desirable. An improvement is characterized by a reduced level of settlement delay for each amount of intraday liquidity. This can be achieved either through quicker processing of queued payments or fewer payments having to be queued upon submission. Such an improvement is represented by a downward shift of the trade-off curve closer towards the origin (dotted line in Chart 1).

As mentioned above, an innovation in LVPS technology is needed to improve the trade-off. The addition of a complex queue-release algorithm to the central queue represents one such innovation.[6] These algorithms are designed to simultaneously search for and offset batches of centrally queued payments.

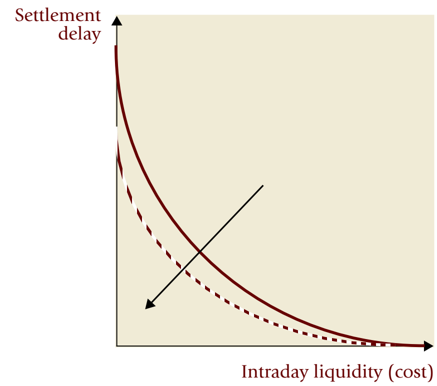
Under standard queuing arrangements, payments are released from the queue *individually* when a participant's intraday liquidity is sufficient for them to be processed. In contrast, under central queuing with a complex queue-release algorithm, the simultaneous processing and release of a batch of queued payments is attempted at regular intraday intervals. In this case, for the entire batch of payments to be released from the queue, participants need access only to sufficient intraday funds to cover any possible net debit (negative) position resulting from the payment offset.

With a complex queue-release algorithm, participants have lower funding requirements for the release of queued payments. Thus, even where intraday liquidity has been hypothetically reduced in the system, the processing time for queued payments can be faster, and average intraday queue length could decrease, compared with a standard queuing arrangement.

Simulation Methodology

It could be interesting to apply this concept to the LVTS environment, and simulation analysis facilitates such an exercise. Specifically, the BoF-PSS2 can be used to assess whether there is a trade-off between settlement delay and intraday liquidity in the LVTS, and whether the introduction of a complex queue-release algorithm could improve this trade-off. This section outlines the simulation methodology involved in this analysis, including a description of the data used, details of the operation of the BoF-PSS2, and how the analysis can be specifically applied

Chart 1 Trade-Off between Settlement Delay and Intraday Liquidity



6. For discussion related to the benefit of these algorithms, see for example BIS (2005) and Leinonen (2005).

in the LVTS environment. Box 1 provides some relevant background on the LVTS. Dingle (1998) contains a more thorough description of the system.

It should be noted that the current version of the BoF-PSS2 does not contain bilateral credit limit (BCL) functionality (Box 1), which is an important component of the LVTS.[7] The simulation model used in the analysis recognizes only multilateral credit limits, and this is considered further in the concluding section. In addition, the analysis focuses on Tranche 2 (T2), since it is the dominant payment stream in the LVTS.[8]

Description of the data

Three months of data on LVTS T2 transactions and credit limits were collected between July and September 2004. Transaction data include the date and time that each transaction was submitted to the LVTS, as well as the value of the payment and the counterparties involved in the transaction. It is assumed that the time stamp attached to each payment represents the intended submission time of the payment. Data on credit limits include the value of the Tranche 2 net debit cap (T2NDC) available to each participant, as well as the date and time that the value of the T2NDC is effective. The value of a T2NDC may change from day to day and also within each day.

Description of the BoF-PSS2

Although it does not have bilateral credit limit functionality, the BoF-PSS2 operates in a similar fashion to the LVTS. Payments are submitted for processing in order based on a time stamp. A submitted payment is processed by the simulator if the payment does not result in the sending participant incurring a net debit position that exceeds its T2NDC. Payments that cannot be processed upon submission because of a sender's lack of intraday liquidity are stored in the simulator's queue. The BoF-PSS2 offers various

7. A new version of the BoF-PSS2 containing BCL functionality is expected to be available in early 2006. Bank of Canada staff are participating in the development of this new version.
8. On an average day, approximately 86 per cent of daily LVTS payment value and 98 per cent of payment volume is sent through the T2 payment stream.

Box 1

Background on the LVTS

In the LVTS, final settlement is guaranteed under all circumstances, thus virtually eliminating systemic risk. This is facilitated by the system's real-time risk controls (net debit caps), collateral requirements, and a residual guarantee provided by the Bank of Canada.[1] Guaranteed settlement enables immediate intraday finality on all payments processed through the system.

The LVTS consists of two payment streams—Tranche 1 (T1) and Tranche 2 (T2). Each stream has its own risk controls and collateral requirements. Participants may use either stream to send payments. T1 is a defaulter-pays stream, since any T1 net debit position incurred by a participant must be fully secured with eligible collateral pledged by that participant. In T2, a survivors-pay collateral pool is used. At any time, there is sufficient T2 collateral pledged by participants to cover the largest possible T2 net debit position of any participant. The T2 payment stream greatly economizes on participants' collateral requirements relative to T1. As a result, the majority of daily payment activity in the LVTS is conducted in T2.

In T2, participants have the ability to draw on a T2 line of credit. Specifically, LVTS participants grant bilateral credit limits (BCLs) to each other. The value of a BCL represents the maximum bilateral T2 net debit position that the grantee may incur vis-à-vis the grantor at any time during the daily payment cycle. A participant's T2 multilateral intraday credit limit, known as its T2 net debit cap (T2NDC), is calculated as the sum of all BCLs granted to it multiplied by a system-wide parameter (SWP), which is equal to 0.24.[2] A participant's T2NDC represents the maximum multilateral T2 net debit position that it can incur during the daily payment cycle. A payment submitted to T2 is processed if it does not result in the sending participant incurring a net debit position exceeding either its BCL vis-à-vis the receiver or its T2NDC.[3] Participants are required to pledge eligible T2 collateral equal to the value of the largest BCL that they grant to any other participant, multiplied by the SWP.

1. In the unlikely event of multiple participant defaults in the LVTS, the Bank will exercise its residual guarantee to facilitate settlement by realizing on available collateral and absorbing any residual loss.
2. When the LVTS began operations in February 1999, the SWP was equal to 0.30. Since then, it has been gradually reduced and has been equal to 0.24 since March 2000. See LVTS Rule No. 2, available at www.cdnpay.ca.
3. For more on LVTS risk controls, see Engert (1993) and McVanel (2005).

queue-release algorithms for users to choose from, representing alternative queuing arrangements typically available in an LVPS.

The BoF-PSS2 generates a variety of time-series output reports when a simulation is completed. These reports include statistics on the number and value of processed and unprocessed payments. Data on the use of credit limits, as well as the number and value of queued transactions, can also be observed. BoF-PSS2 users can choose the frequency at which these output data are generated. For instance, output statistics can be reported daily, as well as on an intraday basis, in intervals ranging from one to sixty minutes. Moreover, these output data are available at the aggregate system level and also at the individual participant level.

Application to the LVTS

Imposing a hypothetical reduction in participants' intraday liquidity is a key aspect of the analysis. In applying the analysis to the LVTS, this reduction is generated by lowering the intraday credit available to participants. Holding BCL values constant, participants' T2NDC value can be reduced by lowering the value of the system-wide parameter (SWP). Similar to the earlier discussion, reducing the SWP is expected to entail both a cost and a benefit to participants. The former arises because participants will find it more difficult to meet their payment obligations when they are due, since they become constrained by their T2NDC more quickly and frequently during the day. Consequently, the level of settlement delay in the LVTS is expected to rise. However, a reduced SWP will also benefit participants since it lowers the value of T2 collateral required and the related costs.

The simulation analysis involves running two batches of eight simulations. Each of the simulations in a batch is characterized by a reduction of intraday credit available to each participant. To achieve this, additional datasets on credit limits are created over the sample period using lower hypothetical SWP values. Transactions data remain the same in each of the simulations, based on the assumption that participants' payment-sending behaviour remains unchanged during the analysis.

LVTS participants generally utilize internal queues to manage the release of their payments to the system. Internally queued payments are released whenever a participant's intraday liquidity is sufficient for them to be processed. The first batch of simulations is meant to replicate, as closely as is possible, this internal queuing arrangement. To accomplish this, a standard queue-release algorithm has been specified in the BoF-PSS2.

Three daily measures of settlement delay are calculated and averaged over the sample period for each of the simulations in the batch (i.e., for each level of intraday liquidity). These measures are as follows:

1. Daily Proportion of Unsettled Transactions Value: This ratio is found by dividing the total value of unprocessed payments remaining in the queue at the end of the day by the total value of payments submitted by participants over the entire day.

2. Daily System-Wide Delay Indicator: Adopted from Leinonen and Soramäki (1999), this indicator can take on any value between 0 and 1. A value of 0 is attained when all daily payments are immediately processed with finality upon intended submission. A value of 1 is calculated when all payments become queued upon intended submission and remain there until the end of the day.

3. Average Intraday Queue Value: This measure represents the average intraday value of queued T2 payments.

The objective in running the second batch of simulations is to assess whether the introduction of a complex queue-release algorithm can improve the trade-off; i.e., reduce settlement delay associated with each amount of intraday liquidity. The LVTS currently employs a central queue complete with a complex queue-release algorithm. With this algorithm, queued payments are offset at regular intervals (every 20 minutes) throughout the day. Under current LVTS rules, participants are not encouraged to use the central queue.[9]

The second batch of simulations is therefore an experiment to assess whether increased use of

9. LVTS Rule No. 7 states that participants can manage their T1 and T2 positions in real time, and should therefore attempt to submit only those payments that will pass the respective risk-control test. Visit www.cdnpay.ca for more information.

Chart 2 Average Daily Proportion of Unsettled Transactions Value

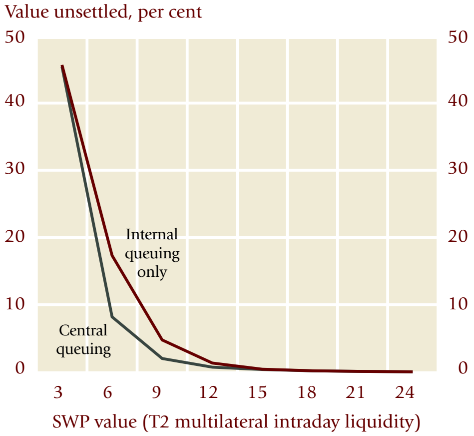


Chart 3 Average Daily System-Wide Payments Delay

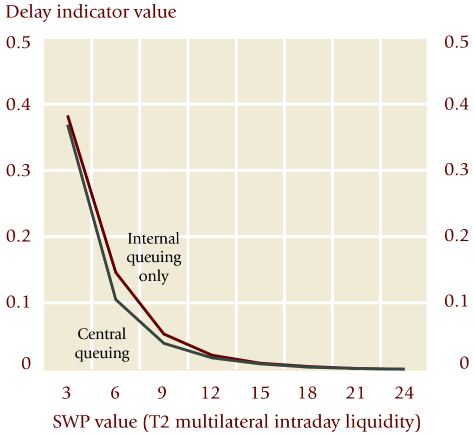
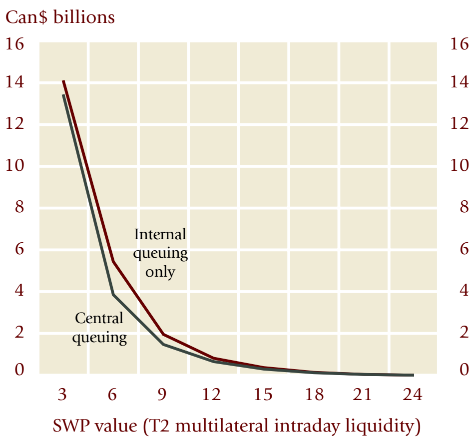


Chart 4 Average Intraday Queue Value



the LVTS central queue could potentially improve the trade-off. It is assumed that, under this alternative central queuing arrangement, participants no longer hold payments internally until they can be processed. Rather, all payments are submitted to the LVTS when they are due. Any payments not processed immediately enter the central queue.

For purposes of comparison, the same transaction and credit limits data are used in the second batch, and the same measures of settlement delay are calculated. The fundamental difference between the first and second batches is that a complex queue-release algorithm similar to that in the LVTS is specified to run in the latter batch every 20 minutes.

Simulation Results

Simulation results are provided in Charts 2 to 4. Each chart shows two curves corresponding to the two batches of simulations. The curve denoted "Internal queuing only" illustrates the results of the first batch of simulations. The curve denoted "Central queuing" depicts results estimated under the alternative central queuing environment.

The simulation findings confirm that a trade-off exists between settlement delay and intraday liquidity in the LVTS, and this relationship is consistent with the assumptions of the earlier graphical framework. Moreover, the introduction of a complex queue-release algorithm is shown to improve this trade-off. Settlement delay in the second batch of simulations is reduced for each amount of intraday liquidity according to all three measures.

The results indicate that the relative benefit of a complex queue-release algorithm (in terms of reduced settlement delay) increases as intraday credit availability is constrained further, reaching a peak when the SWP is equal to 0.06. In this case, the average proportion of unsettled T2 transactions value is reduced by 9 percentage points or about \$10 billion (Chart 2), the average system-wide delay indicator is reduced by 28 per cent (Chart 3), and average intraday queue value is reduced by 29 per cent or about \$1.6 billion (Chart 4) relative to the first batch of simulations.

The relative gains from the alternative central queuing arrangement begin to decline when the

SWP is reduced beyond 0.06. Close to half of the total value of daily submitted transactions remains unprocessed under both batches when the SWP is equal to 0.03 (Chart 2). At this SWP value, it is believed that participants' intraday liquidity is so constrained that only very small groups of queued payments can be processed each time the offsetting algorithm runs.

A further result of this analysis is that the level of settlement delay increases only marginally as the SWP is initially reduced from its current value of 0.24. This is an interesting finding, since maintaining participants' intraday liquidity (and the avoidance of settlement delay) is perhaps the primary objective in determining the value of the SWP. A reduction in the SWP from 0.24 to 0.18 is estimated to increase the average proportion of daily unsettled transactions value by only 0.15 percentage points under current internal queuing arrangements and 0.14 percentage points under the alternative central queuing arrangement (see Chart 2). Similar results are observed with the other two delay measures. As has been mentioned, reducing the SWP also produces a benefit for LVTS participants in the form of lower collateral requirements. Specifically, a reduction in the SWP to 0.18 reduces the total value of participants' T2 collateral required by about $750 million per day, on average, over the sample period, holding current BCL values constant.

Summary and Future Research

This research uses simulation analysis to examine the trade-off between safety and efficiency in an LVPS. This article describes a fundamental safety-efficiency trade-off—between settlement delay and intraday liquidity—and illustrates how simulation techniques can be used to evaluate this trade-off in Canada's LVTS. Simulation results indicate that a trade-off does exist between settlement delay and intraday liquidity in this system, and that this trade-off could be improved with greater use of the central queue and its complex queue-release algorithm. Moreover, the article shows that the SWP value could be reduced to as low as 0.18 at little cost in terms of delayed settlement, regardless of whether use of the central queue is increased.

It must be emphasized that these conclusions are preliminary, and the existence of certain caveats indicates that further work is necessary. Perhaps most importantly, the current analysis assumes that participants' payment-sending and bilateral credit-granting behaviour remains unchanged despite reductions in the SWP and changes in queuing arrangements. This assumption must be challenged. Further research on the factors underlying participants' behaviour, and anticipated developments in the BoF-PSS2, are necessary to conduct more robust simulation analyses in future.

Secondly, the article highlights the benefit of using a central queue equipped with a complex queue-release algorithm. However, it is also necessary to identify and assess the potential implications of such a development, which may not be captured by the current simulation results. For example, BIS (1997) argues that the availability of a central queue may motivate LVPS participants to take on increased credit risk. This could occur where participants have the ability to view information on expected incoming payments in the central queue. A participant, observing that incoming funds intended for one of its clients are waiting in the queue, may choose to credit the client's account with the value of these funds before they are received in the system. Thus, the participant would be exposing itself to credit risk until the payment is processed by the LVPS with finality.

Finally, further research is required to assess whether the benefit of a reduced SWP (in terms of lower collateral requirements) is greater than the associated cost in terms of a marginal increase in settlement delay. This entails attempting to quantify the (social) cost of settlement delay, and will likely depend on a number of factors including how time sensitive the delayed payments are.

References

Bank for International Settlements. 1997. *Real-Time Gross Settlement Systems*. Report prepared by the Committee on Payment and Settlement Systems of the central banks of the G-10 countries. Basel (March).

———. 2005. *New Developments in Large-Value Payment Systems*. Report prepared by the Committee on Payment and Settlement Systems (May).

Bedford, P., S. Millard, and J. Yang. 2005. "Analysing the Impact of Operational Incidents in Large-Value Payment Systems: A Simulation Approach." In *Liquidity, Risks and Speed in Payment and Settlement Systems—A Simulation Approach*, 247–74, H. Leinonen (ed.). Helsinki: Bank of Finland Studies.

Berger, A.N., D. Hancock, and J. Marquardt. 1996. "A Framework for Analyzing Efficiency, Risks, Costs, and Innovations in the Payment System." *Journal of Money, Credit, and Banking* 28: 696–732.

Dingle, J. 1998. "The LVTS—Canada's Large-Value Transfer System." *Bank of Canada Review* (Autumn): 39–55.

Engert, W. 1993. "Certainty of Settlement and Loss Allocation with a Minimum of Collateral." Bank of Canada Working Paper No. 1993-14.

Leinonen, H. (ed.). 2005. *Liquidity, Risks and Speed in Payment and Settlement Systems—A Simulation Approach*. Helsinki: Bank of Finland Studies.

Leinonen, H. and K. Soramäki. 1999. "Optimizing Liquidity Usage and Settlement Speed in Payment Systems." Bank of Finland Discussion Paper No. 16/99.

McVanel, D. 2005. "The Impact of Unanticipated Defaults in Canada's Large Value Transfer System." Bank of Canada Working Paper No. 2005-25.