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Carol Ann Northcott

Monetary and Financial Analysis Department
Bank of Canada
Ottawa, Ontario, Canada K1A 0G9
cnorthcott@bankofcanada.ca

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Abstract

Payments systems operate virtually unnoticed in our daily lives and yet are crucial to a well-functioning economy and financial system. Because they explicitly link financial institutions, payments systems provide a way to transmit risk within, and between, financial systems. Ideally, payments systems should be designed and operated so as not to add risk in the event of a crisis. The author examines the potential for contagion through linkages arising from the interaction of financial institutions in a Canadian payments system, the Automated Clearing Settlement System (ACSS). A method of measuring risk in the system, given its unique design, is developed and used to estimate contagion over a wide range of conditions. The author finds, first and foremost, that the ACSS has only a limited capacity, if any, to facilitate contagion in the current environment.

JEL classification: E44, G21
Bank classification: Financial institutions; Payments, clearing and settlements systems

Résumé

Bien qu’ils passent presque inaperçus dans la vie quotidienne, les systèmes de paiement n’en sont pas moins indispensables au bon fonctionnement de l’économie et du système financier. En raison des liens explicites qu’ils créent entre les institutions financières, ils constituent un vecteur de transmission du risque à l’intérieur des systèmes financiers ainsi qu’entre ceux-ci. Idéalement, les systèmes de paiement devraient être conçus et exploités de façon à ne pas augmenter le risque en cas de crise. L’auteure étudie ici la possibilité que les liens reliant entre elles les institutions financières au sein du Système automatisé de compensation et de règlement (SACR), l’un des systèmes de paiement canadiens, soient une source de contagion. En tenant compte des caractéristiques particulières de ce système, elle élabore une méthode pour y mesurer le risque de contagion dans un large éventail de circonstances. La principale conclusion qui ressort de son travail est que, dans l’environnement actuel, la propension du SACR à faciliter la contagion est limitée sinon nulle.

Classification JEL : E44, G21
Classification de la Banque : Institutions financières; Systèmes de paiement, de compensation et de règlement

1. Introduction

Financial systems around the world are becoming increasingly interconnected. Recent high-profile financial crises have focused attention on the interlinkages between financial systems and the potential they pose for contagion. Payments systems provide one such explicit link and are crucial to a well-functioning economy. Ideally, payments systems should be designed and operated so as not to add risk in the event of a crisis.

Humphrey (1986) was the first to empirically examine the potential for contagion through payments systems. Using data from a net settlement system in the United States, he shows that the default of a large participant in the netting system could create exposures for its counterparties that would be sufficiently large to make them unable to meet their obligations to the system. That is, linkages through a net payment system could facilitate contagion. Subsequent authors have used and expanded Humphrey's approach.

This paper examines the potential for contagion through linkages between financial institutions in a Canadian payments system, the Automated Clearing Settlement System (ACSS). A method of measuring risk in the ACSS, given its unique system characteristics, is developed and used to estimate contagion under different conditions. Building on the work of previous authors, this study attempts to capture the behaviour of various agents in the system and the effect this behaviour has on contagion.

Section 2 summarizes the empirical and theoretical literature relevant to this work. Section 3 describes the model used to measure risk in the ACSS. The first part of section 3 addresses the overall structure of claims in the ACSS and what this implies for risk, and the second part describes a simulator model of the system based on its rules and structure. In section 4, the model is used to conduct a sensitivity analysis and thereby examine the capacity of participants to absorb the risks associated with the default of another participant under varying conditions. Contagion is measured in this context by the number of knock-on defaults caused by the default of the initial participant. The very encouraging results of the analysis, described in section 5, can be summarized as follows:

- First and foremost, the ACSS has only a very limited capacity, if any, to facilitate contagion in the current environment.
- A uniform decrease, of even 25 per cent, in the value of payments sent (across all participants) greatly reduces the already limited risk of contagion through the ACSS.
- A participant's capital and liquidity holdings are essential to its ability to withstand knock-on effects.

- Recovery of losses from the estate of the defaulting institution increases the ability of survivors to withstand a default.
- The effectiveness of an “unwind” of payments as a risk-management tool depends on the participants’ use, and enforcement, of provisional credit provided to clients.
- Certain participants are more likely than others to initiate knock-on defaults, or to experience a knock-on default.

Section 6 offers some conclusions and suggestions for future research.

2. Literature Review

The empirical literature that examines the potential for risk in payments systems has traditionally been hindered by a lack of data and the complexity of individual system design. Nonetheless, a class of empirical models exists that provides a framework for systematically addressing risk in payments systems. These models study risk by examining the effect on participants when a counterparty defaults in a net settlement system.

Humphrey (1986) was the first to approach the problem by examining bilateral exposures in a payments system in the United States. He assumes that, on a given day, a participant defaults on its payment obligation. All transfers to and from that participant are removed from the clearings (“unwound”) and revised multilateral net positions are calculated for the survivors. To the extent that a survivor has allowed its clients to use expected incoming funds due from the defaulter (provided provisional credit) with the expectation of final settlement at the end of the day, it will experience a liquidity problem due to the unwinding of payments. The survivor’s net position change resulting from the unwind is used as a measure of this liquidity problem. To measure the potential for contagion, a standard assumption is used. If a survivor experiences a net position deterioration greater than or equal to its capital, and is in a revised net debit position, the survivor is assumed to be unable to meet its obligation and it too defaults. All payments to and from any participant exceeding this threshold are unwound, and further revised settlement positions are calculated. This process continues until all remaining participants are below the threshold.

The results of the first simulation, portraying the default of a large participant, are indicative of the whole. Humphrey finds that, after the initial default, 37.3 per cent of the institutions subsequently default. This is taken to indicate that significant contagion could be associated with the unexpected settlement failure of a participant in the system.

While providing new insights into the potential seriousness of risk in net settlement systems, these results must be considered in the light of certain caveats:

- The study centres on a survivor's ability to cover the deterioration in its net position; that is, it is concerned about liquidity risk. The potential for credit risk is not discussed.
- The failure threshold is motivated by simplicity. There is no discussion to motivate the use of capital, or which measure of capital is used.
- Although Humphrey describes the importance of the possibility of recovering funds from client accounts by survivors, this aspect is not addressed in the simulation, nor is the possibility addressed of eventual recovery from the estate of the defaulting institution.
- Only three simulations are conducted over two days of data. This is a very small sample from which to make generalizations.

Angelini, Maresca, and Russo (1996) employ a similar method using end-of-day bilateral net balances in the Italian netting system. They add to the literature by attempting to address both credit risk and liquidity risk through the choice of failure threshold. To address credit risk, a subsequent default occurs if the change in the net position following the unwind is greater than the participant's capital.[1] For liquidity risk, a default occurs if the net position change is greater than the participant's liquid assets.[2] The authors simulate the default of each participant in the system, one at a time, for each of the 21 business days in the data set for each failure threshold.

Upon the default of a major participant, only 0.3 per cent of the remaining participants subsequently default, as opposed to 37 per cent in Humphrey's study. There is a high degree of concentration, both in triggering banks and in failing banks. On a given day, on average, only 4 per cent of the participants are capable of initiating knock-on defaults, and over the 21 days only 20 per cent of the sample are capable of initiating at least one. Therefore, although the overall probability of contagion appears to be small, there are some banks whose default is more likely to produce systemic problems than others. The authors also find that a high concentration of banks experience a knock-on default.

Although Angelini, Maresca, and Russo attempt to separate liquidity and credit risk, they continue to use, without much motivation, the net position change of survivors as a measure of both liquidity and credit exposure. Kuussaari (1996), using data on Finnish payments systems, addresses such exposures separately. For credit exposure, an institution is determined to be insolvent (and defaults) following an unwind if its net position deteriorates by more than 50 per cent of the bank's own funds. As for measuring liquidity risk, the participant is assumed to be in default if its revised net position exceeds its overdraft limit with the Bank of Finland. Kuussaari finds that, although one participant's failure to settle can lead to serious problems for the

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1. Angelini, Maresca, and Russo define capital as "eligible capital reported under the 1988 Basle Capital Accord."
2. A proxy for liquid assets is constructed comprising the portfolio of securities eligible as collateral for borrowing at the discount window.

survivors, there is not a large risk of successive failures. The degree of contagion found is of a similar magnitude to that found in the Italian study.

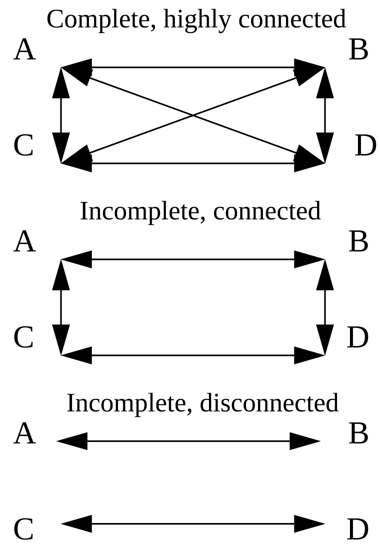
More recent studies have looked beyond exposures in payments systems specifically to those in the interbank market more broadly. Furfine (1999) estimates interbank exposures using payment flow data and expands on the methodology of previous authors by addressing the possibility of recovery from the estate of the defaulting institution. Two different recovery rates are used—40 per cent and 95 per cent—which are chosen based on studies of past bank failures. Given the failure of a participant, a subsequent default is assumed to occur if the credit loss to a bank, adjusted for recovery, is greater than its tier 1 capital. Not surprisingly, the findings show that the potential for contagion is related to the level of loss recovery. With a 100 per cent loss, the failure of the most significant bank causes up to 3 per cent of the remaining participants to default. With a recovery rate of 95 per cent, which Furfine purports to most closely reflect recovery in a systemic crisis, there are no knock-on defaults with the default of the largest participant.[3] Upper and Worms (2002) construct an estimate of interbank bilateral exposures in the German market and perform a similar analysis. They also find that the level of contagion is contingent on the recovery rate. In fact, they find that large-scale contagion occurs only if the level of recovery on interbank loans is less than 60 per cent.

The general premise of these studies is similar. Using bilateral data, the authors estimate the risk exposures experienced by participants and compare them with some measure of their ability to cover such exposures. While focusing primarily on the number of subsequent defaults, these studies also highlight interesting patterns of contagion. For instance, some banks are more likely than others to subsequently default or are more capable of initiating knock-on effects. This aspect of contagion is also explored in the theoretical literature and two important contributions in this area are described below. The risk of contagion and its pattern and extent depend on the structure of interbank linkages.

3. Actual recovery may take some time and recovery rates used are the ex-post recovery of previous incidents. Furfine reconciles this fact by assuming that the recovery in the simulation reflects the amount of immediate support given by the central bank based on previous recovery rates.

Allen and Gale (2000) examine contagion in the context of a banking system with regional banks connected by interbank deposits. Liquidity shocks in one region can spread to other regions through this network of deposits. The extent of contagion depends on the structure of interbank connections. A “complete” market structure is one where each bank has a symmetric link with each of the other banks. An “incomplete” market structure is one where each bank has a link only to those banks in adjacent regions. A second characteristic relates to the connectedness of the economy. This refers to the extent that regions or segments of the economy are joined (Box 1). The authors demonstrate that:

Box 1: Market Structures
Allen and Gale (2000)



- In a complete market, the effect of a shock is spread among all other banks, lowering the cost of the shock to any one region. Although contagion can occur, it is less likely than under an incomplete market. Furthermore, as the number of banks (regions) increases, the impact on any one bank decreases, reducing the potential for contagion.
- In an incomplete market, the impact of the shock is borne by few banks, increasing the likelihood that the shock will spread to connected banks. Incomplete market structures are more susceptible to contagion. As the number of banks (regions) increases, the effect is opposite to that under complete markets. As the shock spreads to adjacent regions, the spill-over effects increase, making it easier for the contagion to gain momentum and continue spreading.
- The combination of an incomplete and highly connected market structure poses the highest possibility for contagion.

In a related paper by Freixas, Parigi, and Rochet (2000), a network of interbank credit lines (a payment system) is necessary due to depositors’ uncertainty about where to consume. Two of the market structures they describe—credit chain lending and diversified lending—are analogous to the incomplete and complete markets of Allen and Gale. Linkages exist through the extension of credit lines.[4]

Freixas, Parigi, and Rochet examine the contagion implications when one bank is insolvent. As with Allen and Gale, they find that the diversified lending structure has a lower risk of contagion than under the credit chain structure, and that the diversified structure becomes more stable as the number of banks increases. The number of banks, however, has no effect on the contagion risk of credit chain structures. In addition to contagion, the authors describe the effect on market

4. Freixas, Parigi, and Rochet note that the credit lines can be interpreted as a net settlement system or as a real-time gross settlement system with multilateral credit lines.

discipline. While the connections through the diversified lending system may increase the system's ability to withstand the insolvency of any one bank, they can also act as an implicit subsidy, allowing an insolvent bank to continue operating. That is, market discipline is weakened, thereby providing a role for bank supervision.

3. A Model of the ACSS

We construct a model of a deferred net settlement system that builds and expands on the work of previous authors while incorporating the rules and design of Canada's Automated Clearing Settlement System.

In a net settlement system generally, obligations among counterparties over a defined period of time are offset against each other, resulting in a single obligation for each of the counterparties.[5] Some of the participating financial institutions owe funds and others are due funds, so that the sum of the net positions over all participants is zero. Those that are due funds have, in effect, extended credit to those that owe funds. The underlying payment obligations are typically not extinguished until the final net positions are exchanged. Counterparties are exposed to the risk that (at least) one participant may not be able to meets its net payment obligation; that is, it defaults. The impact of this default on the remaining participants (the survivors) is a function of:

- *Risk-control mechanisms*—mechanisms in the system design (such as explicit credit lines) that allow participants to control their counterparty risk, or collateral requirements, which can minimize residual losses. Another tool is the ability to return (unwind) payments with respect to the defaulter, thereby affecting the defaulter's position in the system.
- *Provisional credit*—the extent to which survivors provide provisional credit to clients for payments drawn on the defaulter that will not be received, and the survivors' ability to recover such value from clients.
- *Loss allocation*—how residual losses are allocated among participants.
- *Recovery*—the ability to recover some portion of incurred losses from the estate of the defaulting institution.

Previous authors have focused on the role played by the unwind mechanism, and the exposures thereby created for survivors, in causing contagion, along with the effect of recovery from the estate of the defaulting institution. We build on this research by addressing provisional credit and loss allocation. As well, we more specifically define credit and liquidity exposure within the context of the system we are addressing.

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5. This is called multilateral netting. This description is a simplification because the netting process can take various forms. See the Bank for International Settlements (1989) for more on different netting arrangements. As well, Engert (1992, 1993) provides an overview of netting arrangements and an analysis of risk management in netting systems that conform to international standards.

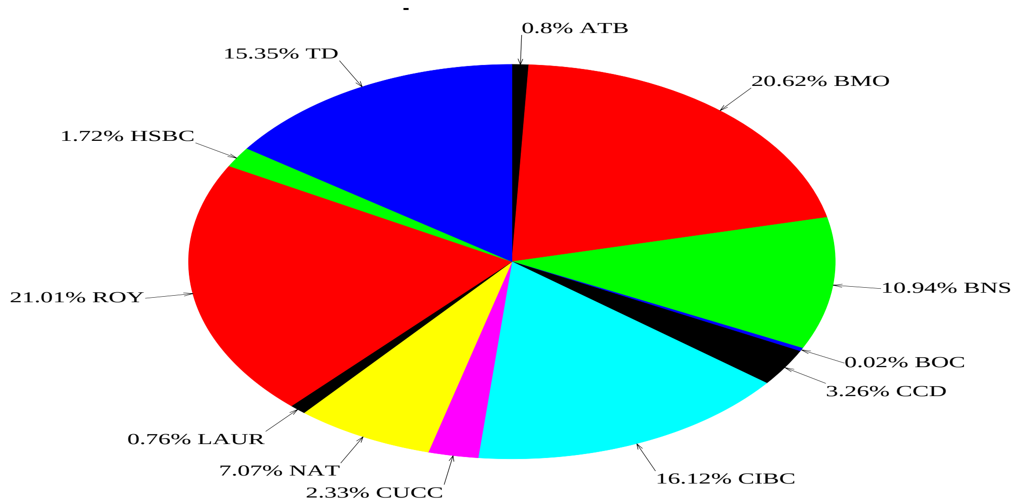
The ACSS is a debit-pull deferred net settlement system. It has many characteristics that are consistent with an ability to allow contagion: counterparties extend credit through the netting arrangement without the benefit of real-time information or risk-control mechanisms to allow them to easily manage such exposures intraday; participants typically extend provisional credit to their clients; and, because there are no collateral requirements, any loss following an unwind of payments with respect to the defaulting institution is borne by the survivors (not the defaulter).

3.1 Overview of the structure of interbank linkages through the ACSS

The ACSS uses a tiered arrangement for settlement. Financial institutions eligible to participate in the system enter as “indirect” or “direct” clearers. Indirect clearers enter the system through a direct clearer, all of which hold settlement accounts at the Bank of Canada. Settlement is completed across these accounts at the end of the ACSS processing cycle. The twelve direct clearers include the largest deposit-taking banks in Canada, most of which are national in scope.[6] Because of the concentration of the banking market in Canada, each of the direct clearers has linkages with every other direct clearer on a daily basis. Direct clearers differ on many characteristics, including asset size and involvement in the payments system, and their interactions with each of the other banks are not symmetrical. That is, each bank does not send one-eleventh of its payments to each of the other eleven banks. Their linkages, however, are broadly proportionate to the participation of the counterparty in the payments system measured by the value of payment items it enters into the system (Box 2). Banks typically send a higher proportion of payments to banks that participate relatively more in the payments system. There are exceptions, where a direct clearer interacts disproportionately more with one or several banks, although the typical pattern holds broadly over the remainder of their counterparties. In this way, interaction among the direct clearers more closely resembles Allen and Gale’s complete market structure with highly interconnected banks than it does an incomplete market structure.[7]

6. See Box 5 on page 22. The Bank of Canada is also a direct clearer.
7. Note that we are dealing only with linkages through the payments system and ignore all other possible linkages.

Box 2: Participation in the ACSS



The picture changes somewhat when indirect clearers are included. As of December 2001, there were 98 active indirect clearers. Information on their bilateral payments flow is not readily available. However, given that these are typically smaller institutions and that they include those with a more regional (as opposed to national) focus, each likely does not have linkages with every other institution. That is, once indirect clearers are considered along with direct clearers, the market structure is less complete (although still connected, because of the concentrated nature of the banking system). Since the eight largest direct clearers account for 81 per cent of all transferable deposits in Canada, and since the direct clearers together account for 98.7 per cent of the volume cleared through the ACSS, we concentrate on the risk of contagion among direct clearers.

3.2 The model

The methodology for measuring risk in the ACSS derives in part from the rules and procedures that govern the clearing and settlement process. The clearing process involves the processing of payment items and the calculation of participants' net positions for settlement. The receipt of a payment item through the ACSS generates an obligation to pay such that the value of payment items received by institution *i* from institution *j* equals the flow of funds flow due from *i* to *j*. *That is, payment items and dollar balances flow in opposite directions*.[8]

8. These types of items are called "debit items": the ACSS is a debit-pull system. The ACSS also facilitates the clearing of "credit items." In this case, the value of the payment items sent from institution *i* to *j* equals the funds flow from *i* to *j*. Credit items and dollar amounts flow in the same direction. Although debit and credit items have different unwind rules, they both adhere to the general rule that items generating balances "due from" the defaulter are reversed. As well, operationally, to process a credit item, it is entered as a "debit" item and is accounted as such in the data. Therefore, in the following equations, all items can be treated as debit items.

Suppose that there are n participants where $n \geq 2$. Let $N = \{i, j, ..., n\}$. A double subscript denotes a bilateral position and a single subscript denotes a multilateral position, so that BNP_{ij} is the bilateral net position of participant i with respect to participant j, and MNP_i is the multilateral net position of participant i. The bilateral net position for participant i with respect to participant j can be written as

$$BNP_{ij} = S_{ij} - S_{ji} ,$$

where S_{ij} is the value of items sent by participant i to participant j. As well, $S_{ij} \geq 0$ and $\forall\ i, S_{ii} = 0$. By entering items drawn on participant j into the system, participant i extends j credit until the obligation is settled at the end of the cycle. The multilateral net position (MNP) is

$$MNP_i = \sum_{j=1}^{n-1} BNP_{ij}. \tag{1}$$

A net position less than zero indicates a net debit position, an obligation to pay. The system settles at the end of the processing cycle, with each direct clearer making or receiving one payment equal to its multilateral net position.

3.2.1 The exogenous default of a participant

A default occurs in the ACSS when a participant with a multilateral net debit position is unable to meet its obligation. The defaulter, $d \in N$, returns items generating balances due to survivors, j, and settles items generating balances due from survivors.[9] Revised net positions are calculated for all participants. The revised positions depend on the proportion of items received by the defaulter that are unwound.

For the defaulter, the revised bilateral net positions (RBNP) and the revised multilateral net position (RMNP) are, respectively,

$$RBNP_{dj} = S_{dj} - S_{jd} + \alpha_j S_{jd}, \text{ and} \tag{2}$$

$$RMNP_d = MNP_d + \sum_{j=1}^{n-1} \alpha_j S_{jd}, \tag{3}$$

where α_j is the share of items that are returned to survivor j.[10]

9. This is done to the extent possible. See section 4.2.1.
10. Some types of payment items cannot be returned in an unwind. They represent a very small share of the total ACSS value. See section 4.2.1.

The survivor's revised bilateral net position with the defaulter and the revised multilateral net position are

$$RBNP_{jd} = S_{jd} - S_{dj} - \alpha_j S_{jd},$$

$$RMNP_j = MNP_j - \alpha_j S_{jd}, \text{ and} \tag{4}$$

$$\Delta MNP_j = -\alpha_j S_{jd}. \tag{5}$$

Therefore, a survivor's net position cannot improve following an unwind. At best, its multilateral position will remain unchanged if no payment items (α_j=0) are returned. That is, a survivor cannot experience a larger net credit position or smaller net debit position following the unwind.

If the defaulter continues to be in a net debit position, the amount needed to bring its position to zero (the shortfall) is called the additional settlement contribution (ASC). The higher the share of items that are returned, the lower the probability of an additional settlement contribution (e.g., if α_j equals one, ASC equals zero):

$$ASC_d = \begin{cases} |RMNP_d| & if \quad RMNP_d < 0 \\ 0 & if \quad RMNP_d \geq 0. \end{cases} \tag{6}$$

The ASC_d is divided among the survivors. Each survivor is assigned a share, β_{jd}, of the defaulter's additional settlement contribution based on its revised bilateral *net credit* position with that defaulter. Survivors in a revised bilateral net debit position with a defaulter do not pay a share of its ASC (i.e., β_{jd}=0 for surviving institutions, j, with $RBNP_{jd} \leq 0$):

$$\beta_{jd} = \frac{RBNP_{jd}}{\sum_{j=1} RBNP_{jd}} \qquad \forall RBNP_{jd} > 0. \tag{7}$$

The value of a survivor's loss allocation for a particular defaulter is $\beta_{jd} ASC_d$. A survivor's final multilateral net settlement position ($FMNP_j$) on the day of default is

$$FMNP_j = RMNP_j - \beta_{jd} ASC_d, \tag{8}$$

where a negative position denotes an overall net settlement obligation to the system.

3.2.2 *Risk exposure in the ACSS*

Institutions participating in the ACSS are exposed to liquidity and credit risk. The lack of real-time payments information and risk-control capabilities makes it extremely difficult, if not impossible, for participants to control their exposures during the cycle. We define liquidity exposure generally as a measure of the immediate liquidity required to complete settlement that day. Credit exposure captures losses, resulting from the exogenous default and unwind, that are unrecoverable in the long run.

Liquidity exposure

In the event of a default, the immediate settlement concern is one of liquidity: whether survivors can meet their final settlement obligation, $RMNP_j - \beta_{jd}ASC_d$, on the day of default, allowing the ACSS to complete settlement. Therefore, *settlement liquidity exposure* is the amount the survivor must cover to allow the ACSS to settle.[11] If the final net position is positive, the survivor is due funds and does not pay into the system; its settlement liquidity exposure (L_j) is zero.[12] If the overall final obligation is negative, the survivor's liquidity exposure is equal to its obligation to the system:

$$L_j = \begin{cases} 0 & if \quad (RMNP_j - \beta_{jd}ACS_d) \geq 0 \\ -(RMNP_j - \beta_{jd}ACS_d) & if \quad (RMNP_j - \beta_{jd}ACS_d) < 0. \end{cases} \tag{9}$$

Liquidity exposure comprises two parts: the survivor's share of any additional settlement contributions and the worsening of its multilateral net position due to the unwind.

Credit exposure

The potential credit exposure experienced by a survivor in the event of a participant default and unwind also has two components:

- The survivor is exposed for its share of any additional settlement contribution.
- Secondly, survivors are exposed to up to the total value of payment items sent to the defaulter, which are unwound ($\alpha_j S_{jd}$). Potentially, the survivor has credited funds to its clients' accounts for which it had expected to receive payment upon settlement from the defaulting institution. However, because of the unwind, the payment will not be received.

11. Because participants may be net debtors or net creditors on any given day and cannot precisely forecast their exposures, participants face a degree of settlement liquidity exposure even under normal conditions. This exposure can increase greatly in the case of an unwind of payments.
12. Only liquidity exposure within the ACSS is considered. Liquidity pressures that participants may face outside the ACSS because of the default of a participant are not addressed here.

Therefore, the credit exposure (C_j) can be up to

$$C_j = \beta_{jd} ASC_d + \alpha_j S_{jd}. \tag{10}$$

The survivor will be able to recover some portion of the unwound items, ϕ, immediately from its clients' accounts, so it will not be subject to the full loss of $\alpha_j S_{jd}$. The credit exposure from this component is $\phi_j \alpha_j S_{jd}$ so that,

$$C_j = \beta_{jd} ASC_d + \phi_j \alpha_j S_{jd},$$

where $0 \le \phi \le 1$ and $\phi = 1$ indicates that the survivor recovers *no* value from its clients' accounts. The more items that can be recovered immediately from the client, the lower the survivor's credit exposure (i.e., as ϕ_j goes to 0, the $\phi_j \alpha_j S_{jd}$ component of credit exposure goes to 0).

Even if all unwound items can be recovered from clients, the survivor continues to face credit exposure from its share of the additional settlement contribution. In addition to recovery from client accounts, survivors will recover a portion of their losses from the estate of the defaulting institution. This recovery will be spread over several years. In the meantime, the loss must be "financed" by the survivor, either through external financing or from its own resources, the cost of which is the opportunity cost of investing elsewhere.[13] Therefore, the proportion of eventual recovery, R_j, used to mitigate the estimated credit exposure on the day of default is the net present value of the expected recovery at some discount rate, i.[14] A survivor's final credit exposure is[15]

$$C_j = (\beta_{jd} ASC_d + \phi_j \alpha_j S_{jd})(1 - R_j). \tag{11}$$

3.2.3 Liquidity risk, credit risk, and contagion

Both liquidity and credit risk play a role in contagion, defined as the default of a participant in the system owing to exposures incurred by the default of another participant. Survivors with a liquidity exposure, L_j, must have enough liquid assets available to cover their exposure to complete settlement in the ACSS. Therefore, a measure of liquidity risk (LR_j) is calculated as

13. Assume for simplicity that the opportunity cost of the survivor using its own resources and the cost of external financing are the same, i.
14. Administrative costs such as legal fees have been omitted.
15. It is assumed that the survivor can recover losses both on its share of the additional settlement contribution and on any value it could not recover from its clients.

$$LR_j = (L_j)/(la_j(\rho)), \tag{12}$$

where la_j is a measure of the participant's liquid assets and ρ is the proportion of the liquid assets that are unencumbered and available to cover a liquidity exposure on the day of default. A survivor is defined as being illiquid if its liquidity exposure is greater than the value of liquid assets available to cover its exposure; that is, if $LR_j \geq 1$.

Survivors with a credit exposure must be financially sound enough to be able to withstand the credit loss and continue to function. Therefore, participant *j*'s credit risk is calculated as

$$CR_j = (C_j)/(cap_j(\tau)), \tag{13}$$

where cap_j is a measure of financial health—capital—and τ is the proportion of cap_j that can be impaired by a credit loss while maintaining the solvency of the participant. A participant is considered to be insolvent if $CR_j \geq 1$.

To determine whether there is contagion, some threshold must be set that defines when a survivor "fails" due to the initial exogenous default. Let F_j represent the knock-on failure of participant *j*:

$$F_j = \begin{cases} 1 & \text{if} \quad \text{participant } j \text{ fails} \\ 0 & \text{if} \quad \text{participant } j \text{ does not fail.} \end{cases}$$

We define three failure thresholds. Under the credit failure-threshold, a participant subsequently defaults if its credit exposure is greater than its ability to cover the exposure. That is,

$$F_j^C = 1 \quad \text{if} \quad CR_j \geq 1. \tag{14}$$

Similarly, a default under the liquidity failure-threshold occurs for participant *j* when its liquidity exposure is greater than its ability to cover the exposure:

$$F_j^L = 1 \quad \text{if} \quad LR_j \geq 1. \tag{15}$$

Under the joint failure-threshold, a subsequent default occurs only if both a participant's credit exposure and liquidity exposure are greater than its ability to cover them:

$$F_j^{C,L} = 1 \qquad if \qquad \left(F_j^C = 1\right) \cap \left(F_j^L = 1\right). \tag{16}$$

3.2.4 Summary

The model is based on the same basic methodology used by previous authors: using bilateral data, calculate participants' exposures from the unwind of payments owing to the default of another participant, and observe potential knock-on effects. We go further in attempting to capture the behaviour of various agents and the effect this behaviour has on contagion.

Each parameter captures an aspect of the agents' behaviour (Box 3). First, participants' risk-management behaviour is reflected through the S_{ij}, ϕ, ρ, and τ parameters.

Box 3: Behavioural Parameters

1. $0(S_{ij}) \leq x(S_{ij}) \leq 1(S_{ij})$: The value of items sent from institution i to institution j.
2. $0 \leq \phi \leq 1$: The proportion of value that cannot be recovered from survivors' client accounts following an unwind of payments.
3. $0 \leq \rho \leq 1$: The proportion of a participant's liquid assets that are unencumbered and available to cover a liquidity exposure on the day of default.
4. $0 \leq \tau \leq 1$: The proportion of tier 1 capital that can be impaired by a credit loss while maintaining the solvency of the participant.
5. $0 \leq \alpha \leq 1$: The proportion of items received by the defaulter that are subsequently unwound to counterparties in a default situation.
6. $0 \leq R \leq 1$: The proportion of the credit loss (on a net present value basis) that can be recovered from the estate of the defaulting institution.

Participants' exposures are based on the value of payment items sent (S_{ij}) to each other, or, put another way, the amount of credit they extended to a participant that defaults. The higher the value of items sent to the defaulter, the higher a survivor's potential liquidity and credit exposures (equations (4), (9), and (11)). A risk-averse direct clearer can lessen its exposure to a counterparty it considers risky by reducing the value of payments drawn on the counterparty that it enters into the system. This could be done, for example, by having its clients receive funds drawn on the counterparty through a well-risk-proofed system, as opposed to entering the item through the ACSS (or, more generally, any deferred net settlement system of the type described here).[16] Of course, if all participants act in this fashion to minimize their risk with respect to a specific counterparty, it decreases the possibility that the counterparty will be in a multilateral net debit position in the first place.

Given that the ACSS does not provide its direct clearers with real-time information, it can be difficult for them to control to whom, and by how much, they are extending credit during the cycle. A risk-averse participant can decrease its exposures generally by decreasing the value of payments entered into the ACSS vis-à-vis all counterparties. Indeed, if all participants act in this way, a uniform decrease in the value of items sent by participants would lead to a decrease in the

16. In the Canadian environment, such a risk-proofed system is the LVTS. This could be done practically for only very large individual payments.

initial multilateral net positions, decreasing the possibility that any one direct clearer will not be able to meet its obligation to the system.

Nevertheless, some payment items will be sent to those participants that are considered more risky. If there is a default, part of the survivors' credit exposure is the value of payment items sent to the defaulter that are unwound ($\phi_j \alpha_j S_{jd}$). This is a risk to survivors insofar as they granted provisional credit to clients for funds drawn on the defaulter that will now not be received due to the unwind. How much risk the survivor takes on in this regard depends on the survivor's ability to recover such funds following the unwind. A more risk-averse participant may offer less provisional credit to clients, or enforce the provisional nature of the contract more strictly. A participant's choice in this regard may reflect not only its risk profile but the market in which it operates: a highly competitive market where provisional credit is commonly offered may induce an institution to provide a higher level of provisional credit, or enforce such contracts less strictly, than it would otherwise.

The unwind parameter, α, is grounded in the rules established by the governance of the payments system. The parameter can, however, be influenced by the defaulter, reflecting its behaviour in a default situation. To a much lesser extent, all participants have some limited control over this parameter, since not all payment types can be unwound. Participants could, to some extent, influence clients' choice of payment type and thereby influence α. For example, if a participant prefers a higher proportion of items unwound in a default, it could preferentially price payment types that are unwindable.

The rate of recovery from the estate of the defaulting institution, R_j, reflects to some extent the behaviour of regulators and the legal process. Notably, if a supervisor practices forbearance, institutions may be closed with a lower level of net worth, and therefore counterparties have a lower likelihood of loss recovery.

The likelihood of contagion occurring in the ACSS is a function of the behaviour of agents given an exogenous default, the probability of which is very small. To examine the potential for contagion given an exogenous default, a sensitivity analysis is conducted over the behavioural parameters of the model.

4. Sensitivity Analysis

To assess the potential for contagion in the ACSS, a sensitivity analysis is conducted using ACSS bilateral payments data and the structural model of the ACSS. Section 4.1 gives a general overview of the simulation and sections 4.2 and 4.3 describe the design of the sensitivity analysis.

4.1 Overview of the simulation

Each day in the data set, the bilateral and multilateral net payment obligations are determined for each direct clearer. The first direct clearer in a multilateral net debit position is determined to be the initial exogenous defaulter. An unwind of payment items with respect to the defaulter is undertaken and revised multilateral net positions are calculated for each direct clearer.

If the defaulter continues to be in a net debit position, the additional settlement contribution is calculated along with each survivor's share. Each survivor's liquidity and credit risk is then determined and compared to the predetermined failure-threshold. If any survivor exceeds the chosen threshold, they default. A further unwind takes place, followed by the calculation of the additional settlement contributions for all participants that have defaulted (exogenously or subsequent to the initial default), and calculations are made of survivor shares, liquidity, and credit risk. This process continues until all survivors remain under the chosen failure-threshold. This completes the trial for that particular defaulter.

Returning to the original data of the first day, the second direct clearer in a multilateral net debit position is identified. That participant is determined to be the initial exogenous defaulter and the subsequent unwind of payments is completed. The process continues as described above. The exercise is repeated for each direct clearer in a multilateral net debit position in the original data. The process continues using data from day two, until all the days in the data set have been used, at which point the simulation ends for that set of behavioural parameters. Further simulations are run with different parameter assumptions and the results are compared across simulations. Appendix A shows a flow chart of the simulation.

4.2 Critical values and concepts

The results of the analysis depend on the assumptions made for the behavioural parameters: α, ϕ, R, S_{ij}, and the measures of ability to settle (τ and ρ). There is also a choice of failure threshold: credit failure-threshold (equation (14)), liquidity failure-threshold (equation (15)) or joint failure-threshold (equation (16)).

4.2.1 The proportion of items received by the defaulter that are subsequently unwound (i.e., returned), to counterparties, $0 \leq \alpha \leq 1$

In the event of a default, there is an unwinding process such that "the defaulting Direct Clearer . . . shall . . . immediately return to each Direct Clearer from which they received all Items drawn on or payable by the defaulting Direct Clearer . . . that are still in its possession."[17] This rule applies to all but one type of payment instrument cleared and settled through the ACSS.

Payments that are not unwindable account for only a small fraction of the total value in the ACSS: 2 per cent over the period being investigated. Given these payments, a complete unwind would be approximated by $\alpha = 0.98$. Conversely, a defaulter is called on to return only items "still in its possession." It is possible that items to which the unwind rule normally applies will not be returned; this may occur, for example, if the items have already been forwarded to clients or they are in processing. Therefore, although not probable, it is possible to unwind no items ($\alpha = 0$).

Ignoring "non-unwindable" items, α can vary from zero to one and it is difficult to know the most likely value. Increasing α puts conflicting pressures on both liquidity and credit risk. Which pressure dominates is an empirical question. Therefore, the sensitivity analysis includes a range of α values from 0 to 1.

4.2.2 The proportion of value that cannot be recovered from survivors' client accounts, $0 \leq \phi \leq 1$

As with α, it is extremely difficult to project what the appropriate level of ϕ would be in a default situation. Anecdotal evidence suggests that banks would be able to recover a substantial portion of such value. Indeed, in a situation where banks were concerned about the viability of a counterparty, it seems likely that the provisional statements in deposit account agreements would be enforced more strictly than usual. This would imply a ϕ closer to zero than one. To explore the importance of this variable, a range of values from 0 to 1 are tested.

4.2.3 Recovery from the estate of the defaulting institution, $0 \leq R \leq 0.95$

Recovery rates are suggested by experience with previous bank failures. For example, studies of banking failures in the United States provide some guidance. Recovery rates are typically calculated as a measure of a bank's assets at the time of failure relative to the value recovered by a Federal Deposit Insurance Corporation (FDIC) receivership, or the value of assets to an acquirer.[18] James (1991) estimates a 60 per cent recovery on assets of a failing bank. Kaufman (1994) estimates a recovery rate of 95 per cent for creditors of Continental Illinois.[19] These recovery rates served as the basis for the recovery rates used by Furfine (1999) and Upper and Worms (2002).

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17. Rule L.12 of the ACSS Rules Manual (http://www.cdnpay.ca). The type of payment instruction that cannot be unwound relates to point-of-sale purchases and ATM cash withdrawals.
18. FDIC acts as insurer for banks and savings associations in the United States.
19. See also Dellas, Diba, and Garber (1996), FDIC (1996, 1998) and Schoenmaker (1996).

Large-scale failures of deposit-taking institutions are rare in Canada. The two most well-known financial institution failures are those of the Canadian Commercial Bank (CCB) and the Northland Bank in 1985. An estimate of the recovery realized by creditors of these institutions can be made based on that realized by the Canada Deposit Insurance Corporation (CDIC). Eleven years after the failure of the CCB, CDIC had received 25 per cent of its claims, 12 per cent on a net present value basis. CDIC's final recovery on Northland Bank claims, 17 years after it failed, was 71 per cent, 34 per cent on a net present value basis.[20] The regulatory regime has changed substantially since (and as a result of) these failures, so these recovery rates are not indicative of recoveries obtainable in the current environment. A general examination of deposit-taking institution failures since 1983 and the subsequent recovery of Canadian Depository Insurance Corporation (CDIC) claims shows that, on average, using various liquidation methods, 84.7 per cent of creditor claims are recovered over a 10-year span. The net present value of the recovery depends on the discount rate: a discount rate of 5 per cent yields a net present value of 74.2 per cent.

The question arises whether this is a realistic figure for the recovery of counterparties in the ACSS. CDIC is typically the largest unsecured creditor. The liquidator shares out proceeds from the resolution on a pro-rata basis to like-ranked creditors. Therefore, CDIC's recovery is indicative of the recovery of like-ranked creditors. As well, to the extent that the banking supervisor intervenes while the net worth of the financial institution is positive, there is a higher probability that creditors will recover their losses.

Therefore, although recovery of approximately 75 per cent may be normal on average, it is useful to test over a range of recovery rates.

4.2.4 Measure of ability to settle

An institution's measure of ability to settle (MAS) is a measure of its ability to cover an exposure. For each institution, two measures are used: one to cover a liquidity exposure and one to cover a credit exposure.

Liquidity MAS: ρ**(liquid assets) where 0.05** $\leq \rho \leq$ **1**

The value of liquid assets held by a participant that are unencumbered and available for use on the day of default is used as a measure of its ability to cover a liquidity exposure. Unfortunately, few data are available to ascertain the portion of reported assets that are encumbered, and the data that do exist are unreliable. We assume that 50 per cent are normally unavailable and ρ is varied from 0.05 to 1 to test a range of possibilities.

20. For more information, see the annual reports of the CDIC (for example, 1995/1996 and 2001/2002), in which actual and projected recoveries are listed.

Credit MAS: τ(capital) where 0.05 $\leq \tau \leq$ 1

The measure that best depicts a survivor's ability to cover a credit exposure is crucial but difficult to determine. Tier 1 capital (or a close substitute) is used, because it is accepted by regulators as a measure of financial institutions' strength. In Canada, it plays an essential role. The Office of the Superintendent of Financial Institutions (OSFI) has established a target of tier 1 capital to risk-adjusted assets of at least 7 per cent for banks.[21] For total capital, the target is at least 10 per cent. The amount of capital that can be impaired in a particular institution (in this case, a survivor) while it continues to remain solvent depends on many issues; for example, the initial risk-weighted capital ratio of the specific institution under discussion and other exposures it may have outside the payment system. It would be interesting to determine a participant-specific threshold that defines a subsequent default according to each participant's particular credit exposure and capital level, but this is very difficult to do. Following previous authors, we assume that participants can normally use 100 per cent of their tier 1 capital to cover a credit exposure under normal conditions. However, we also test over a range of capital levels.

4.2.5 Value of items sent, $0.05(S_{ij}) \leq x(S_{ij}) \leq 1(S_{ij})$

As described in section 3, a proportionate decrease by all participants in the value of items sent puts downward pressure on survivors' liquidity and credit risk in the event of an exogenous default. The sensitivity of these exposures to a proportional decrease in value is tested by decreasing the value of items sent by each participant by a set proportion. Therefore, although the overall value of items sent is decreased, the underlying pattern of linkages is preserved.

4.2.6 Contagion rules

The goal of the sensitivity analysis is to gauge the potential for contagion in the ACSS as measured by the number of knock-on defaults caused by an initial default. Because the simulation is carried out on one day only (the day of default), when in reality the impact on survivors may be spread over several days, it is necessary to outline the conditions (i.e., the thresholds) that define a "knock-on" failure in this closed context. Three different failure thresholds are defined. The first two set out the credit and liquidity pressures while the third is more relevant to contagion in the Canadian context.

21. The minimum requirement suggested by the Bank for International Settlements is 4 per cent.

Credit failure-threshold: *A knock-on default occurs if a participant's credit exposure is greater than its ability to cover it (equation (14)).*

Suppose that the participants are regulated for solvency by a banking supervisor that will not allow an insolvent bank to continue operating, and that the supervisor can accurately assess, on the day of the default, the credit impact of the default on survivors. If a participant experiences a credit exposure greater than its credit MAS, it is "insolvent" and is closed by the supervisor. It is therefore in default and a subsequent unwind takes place and further calculations are made.

Liquidity failure-threshold: *A knock-on default occurs if a participant's liquidity exposure is greater than its ability to cover it (equation (15)).*

Of paramount importance on the day of default is whether participants can meet their obligation to the system. If a participant's liquidity exposure is greater than its liquidity MAS, it is "illiquid" and it subsequently defaults.

Joint failure-threshold: *A knock-on default occurs if a participant's liquidity and credit exposure are greater than the respective MAS (equation (16)).*

Consider a central bank that has standing liquidity facilities open to solvent participants on a fully collateralized basis. The central bank receives an opinion of participant solvency from the banking supervisor, which can in reality have an imperfect view of a bank's solvency on the day of default. Therefore, it is possible that the central bank could lend to what it erroneously believes is a solvent institution. As well, because of the implicit credit granted through the net payments system, an "insolvent" bank may be "liquid" with respect to its payment obligations. That is, it may be in a multilateral net credit position, or it may be in a multilateral net debit position that it is able to cover, even though insolvent.

Consider, then, four cases. If a survivor is liquid and solvent following an unwind, it will fulfill its settlement obligation. If it is illiquid but solvent, it will be advanced the funds necessary to complete settlement from the central bank under the standing liquidity facilities. If an institution is liquid but insolvent, it could complete settlement because it will be able to meet its obligation to the system on the day of default. An assessment of the survivor's solvency (by the supervisor) following any credit loss from the initial default may not yet be determined and its liquidity may be taken as an indication of solvency. In each of these cases, despite the default of the initial participant, the survivor is able to meet its obligation to the system. If the survivor is illiquid and insolvent, however, it will not be able to meet its obligation to the system. As already discussed, the central bank (through the supervisor) may not correctly assess the solvency of the bank and therefore lend, even in the fourth case. For the purposes of this study, we assume that where a bank is illiquid, a correct judgment of solvency can be made. This combination of illiquid and insolvent defines a subsequent failure (contagion) under the joint failure-threshold. Although a simplification, this threshold most closely reflects the Canadian environment in the context of this model.

4.3 Base states and scenarios

A sensitivity analysis is conducted over each of two separate states: a "normal" state and an "extreme" state. Through the assumptions made for each of the parameters, the normal state presents a view of agents' behaviour in the current environment. The 75 per cent rate of recovery is commensurate with the Canadian experience. Participants use 100 per cent of their capital to cover a credit exposure (τ=1), as with previous authors, and 50 per cent of their liquid assets are unencumbered and available to cover a liquidity exposure (ρ=0.5). Because the "normal" level of unwind and amount unrecoverable from client accounts are difficult to ascertain, they set at 50 per cent (α=0.5, ϕ=0.5).

Box 4: Base States and Scenario Examples

Normal state: τ=1, ρ=0.50, α=0.50, ϕ=0.50, R=0.75, $1(S_{ij})$
Extreme state: τ=0.10, ρ=0.10, α=1, ϕ=1, R=0.75, $1(S_{ij})$

Scenarios
Base state
1. R=0
2. R=0.50
3. R=0.95
4. ϕ=0.75
5. ϕ=0.50
6. ϕ=0
7. α=0.75
8. α=0.50
9. α=0
10. ρ=0.75
11. ρ=0.50
12. ρ=0.05
13. τ=0.75
14. τ=0.50
15. τ=0.05

The extreme state presents an extraordinarily improbable view of the world. Extremely conservative measures of both capital and liquidity are used. It is assumed that participants have only 10 per cent of their current levels of capital and liquid assets to cover exposures (τ=0.1, ρ=0.1). As well, assumptions are made for other parameters that maximize exposures: all items sent to the defaulter are unwound but none of this value can be recovered from client accounts (α=1, ϕ=1, respectively).[22] It is unlikely that each of these assumptions would occur on their own, let alone concurrently. Although a reasonable level of recovery from the estate of the defaulting institution is used (R=0.75), no recovery (R=0) is examined through the sensitivity analysis.

For the sensitivity analysis, each parameter is changed one at a time from the base state to generate a separate scenario (Box 4 gives some examples). This allows a range of conditions in both states to be examined. As a result, even under the assumptions for the "normal" state, very unlikely scenarios are considered. For example, in Box 4, scenario 1 is R = 0. Therefore, under the

22. Setting α=1 ensures that there is no shortfall (additional settlement contribution). However, this produces more knock-on defaults than by having no value unwound (α=0) and thereby maximizing the shortfall (see Appendix C and Figure 5).

normal state, scenario 1, the assumptions for the parameters are: τ=1, ρ=0.50, α=0.50, ϕ=0.50, R=0, and $1(S_{ij})$ That is, it is assumed that participants use 100 per cent of their capital to cover a credit exposure and 50 per cent of their liquid assets to cover a liquidity exposure. The defaulter unwinds half the value of payments it had received and survivors recover half of the unwound value from their client accounts. Survivors do not recover any remaining credit loss from the estate of the defaulting institution. The exposures are calculated using all of the value sent between participants in the data set.

5. Results

5.1 Data

For each day in the 231-day data set (August 2000 to June 2001, inclusive), the bilateral value of items sent between each of the twelve direct clearers in the ACSS is used (Box 5). Over this period, the average daily value of items sent through the ACSS was $20.6 billion.

Box 5: Direct Clearers in the ACSS

1. ATB Financial (ATB)
2. Bank of Montreal (BMO)
3. Bank of Nova Scotia (BNS)
4. Bank of Canada (BOC)
5. Central Caisse Desjardin (CCD)
6. Canadian Imperial Bank of Commerce (CIBC)
7. Credit Union Central of Canada (CUCC)
8. HSBC Canada (HSBC)
9. Laurentian Bank (LAUR)
10. Banque Nationale (NAT)
11. Royal Bank of Canada (RBC)
12. TD Canada Trust (TDCT)

For all but the CUCC, a portfolio of liquid assets is constructed from monthly or quarterly balance-sheet data. The portfolio comprises cash deposits and securities issued or backed by the Government of Canada. For the CUCC, liquid assets consist of the monthly value of assets (cash and Government of Canada-backed securities) committed by the provincial credit-union centrals to segregated accounts for the exclusive use of the CUCC in its role as direct clearer.

For the banks, tier 1 capital as reported to OSFI is used to measure financial health. For the ATB and the CCD, shareholder and member (respectively) equity reported on quarterly balance sheets are used. For the CUCC, members’ equity reported on the quarterly balance sheet of the British Columbia provincial central is used, because it is by far the largest of the provincial centrals associated with the CUCC.

These measures, of liquidity especially, are conservative, and represent the minimum resources direct clearers have at their disposal to cover exposures. Because conservative measures are used, there is the potential to overestimate the number of knock-on defaults; this can be accommodated through the interpretation of the τ and ρ parameters.

5.2 Results

Over the 231 days in the data set, there are 1200 instances of a direct clearer with a multilateral net debit position. Each direct clearer is taken, one at a time, to be the initial exogenous defaulter, and the subsequent unwinds and calculations are made. Each of these defaults is considered one trial, so there are 1200 trials for a given set of parameters and failure-threshold. Contagion is measured as the number of knock-on defaults experienced in a given trial.

Results 1 through 6 described in this section are based on the total value of items sent, $1(S_{ij})$, through the ACSS. Appendixes D and E show results for different proportions of the value of items sent. Unless otherwise stated, the results described are those obtained under the joint failure-threshold. Appendixes B and C show the results under all three failure-thresholds.

Result 1: There is limited potential for contagion in the ACSS.

Under the normal state, there are no knock-on defaults for any of the 1200 initial exogenous defaults (trials). This is true for all scenarios in the sensitivity analysis when contagion is defined by the joint failure-threshold: a participant defaults if both its credit and liquidity exposures are greater than its ability to cover them (Table 1). Under a range of normal conditions, from benign to very risky, no contagion from an initial default occurs under this failure threshold, which is most relevant to the current Canadian environment. Under the credit and liquidity failure-thresholds (respectively), knock-on defaults do occur, but not until participants' capital and liquidity levels fall to very low levels (Appendix B).

Under what conditions could contagion occur? This question is addressed by analyzing an extreme state in which the following assumptions are made: participants have very low levels of capital and liquidity (τ and ρ, respectively), and the defaulter returns all items to survivors (α=1), of which no value can be recovered from client accounts (ϕ=1). Even under these assumptions, on average there is not even one knock-on default for a given exogenous default. The result is similar for the extreme-state worst-case scenario: there is no recovery (R=0) from the estate of the defaulting institution (the shaded cell in Table 1).

Table 1: Contagion under the Joint Failure-Threshold

The numbers below represent the average number of direct clearers that default subsequent to an initial default. For example, under the extreme-state base state, there are 184 knock-on defaults over 1200 trials: on average, 0.153 banks (that is, less than one bank) default following an initial default. The numbers in brackets represent the maximum number of knock-on defaults observed in a single trial.

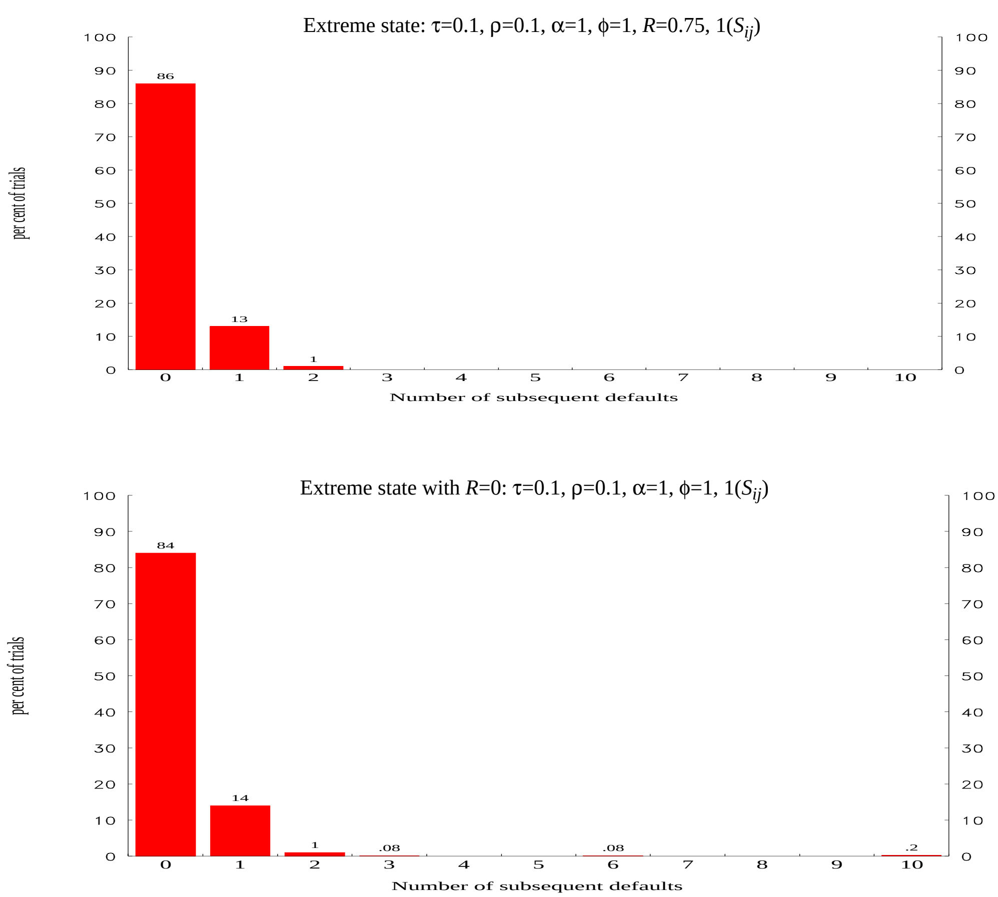
Normal state: τ=1, ρ=0.50, α=0.5, ϕ=0.5, R=0.75, $1(S_{ij})$

Extreme state: τ=0.1, ρ=0.10, α=1, ϕ=1, R=0.75, $1(S_{ij})$

Scenario	Normal state	Extreme state
Base state	0	0.153 (2)
1. R=0	0	0.188 (10)
2. R=0.50	0	0.188 (10)
3. R=0.95	0	0
4. ϕ=0.50	Base state	00.0342 (2)
5. ϕ=0.25	0	0.0008 (1)
6. ϕ=0	0	0
7. α=0.75	0	0.065 (2)
8. α=0.50	Base state	0.0133 (1)
9. α=0	0	0
10. ρ=0.50	Base state	0
11. ρ=0.25	0	0.0008 (1)
12. ρ=0.05	0	0.286 (6)
13. τ=0.50	0	0
14. τ=0.25	0	0.0133 (1)
15. τ=0.05	0	0.188 (10)

The average number of defaults can obscure the potential for contagion. This can be seen in the distribution of the number of knock-on defaults that occur in a given trial. Figure 1 shows the percentage of trials in which there are no knock-on defaults, one knock-on default, and so on, up to the maximum of 10 that can occur. Even in the extreme-state worst-case scenario (R=0), 84 per cent of the time when there is a default no knock-on defaults occur. Nevertheless, there can be contagion for a particular exogenous defaulter: in two of the 1200 trials (0.2 per cent), the initial default causes all other participants, excluding the central bank, to fail.[23] Contagion is possible under conditions such as: all participants have only a small proportion of current capital and liquid-asset levels available to cover an exposure; all payments drawn on the defaulter are unwound and none of this value can be recovered from client accounts; and none of the survivors recover a substantial portion of their loss from the estate of the defaulting institution.

Figure 1: Number of Knock-On Defaults in a Trial



23. Because of rounding, figures may not add to 100 per cent.

This is an extreme confluence of events that calls for, first, the initial exogenous default, and for participating financial institutions to have made a series of extreme choices: banks (unhindered by the supervisor) allow their capital levels to fall to low (relative to current) levels, along with a decrease in liquidity levels, and banks do not enforce provisional credit contracts. Because no contagion is observed under normal conditions (normal state), even with some extreme assumptions such as no recovery from the defaulter (normal state with R=0), and because the assumptions needed to bring on contagion (extreme state) are extraordinary and would seem to have a low probability of occurring simultaneously, there appears to be little potential for contagion in the ACSS in the current environment. Indeed, the number of knock-on defaults that are observed may be overestimated to the extent that our measures of capital and liquidity are conservative.

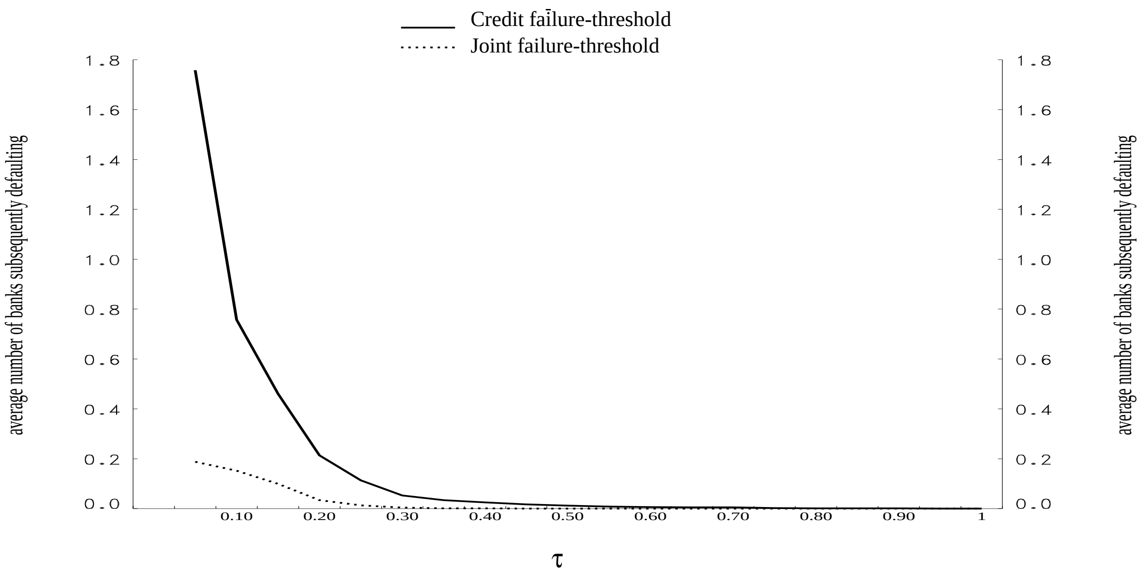
The next three results focus more closely on the effect of varying the behavioural parameters (τ, ρ, α, ϕ, R_j, S_{ij}). The normal state shows no contagion under the joint failure-threshold and minimal effects under credit failure-threshold and liquidity failure-threshold (see Appendix B). Therefore, the extreme state is used to examine the effect of changing parameter assumptions, because the extreme assumptions used produce observable knock-on defaults.

Result 2: A participant's capital and liquidity holdings are essential to its ability to withstand knock-on effects.

A participant's capital and liquidity holdings are essential to its ability to cover its exposures in the event of an exogenous default. Only when capital and liquidity levels fall to low (relative to current) levels is contagion observed.

Figure 2 shows the average number of knock-on defaults for differing levels of capital, τ, under the extreme-state assumptions. The solid line shows contagion under the credit failure-threshold, which defines a knock-on default as occurring when a participant's credit exposure is greater than its ability to cover it. The dashed line shows contagion under the joint failure-threshold. The extreme-state assumptions show how quickly contagion falls with an increase in the value of capital available to cover a credit exposure. Indeed, once this share rises to 42 per cent, no contagion is experienced under the joint failure-threshold, although few defaults continue to be observed under the credit failure-threshold.

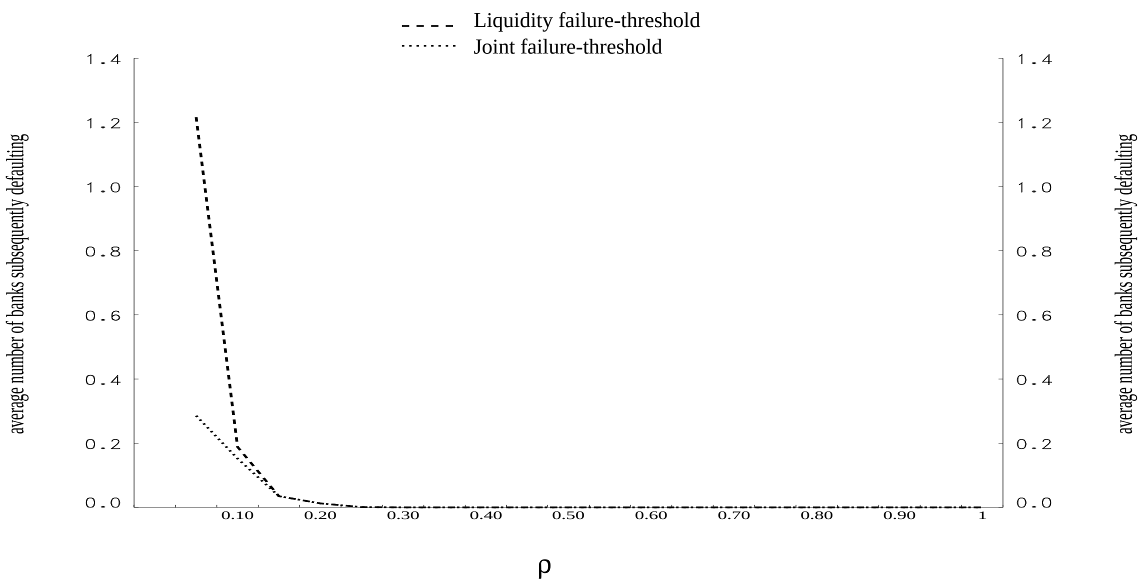
Figure 2: The Effect of Capital on Contagion
The average number of subsequent defaults for a given exogenous defaulter.
Extreme state: ρ=0.1, α=1, ϕ=1, R=0.75, $1(S_{ij})$



For liquidity risk (Figure 3), the results are similar, if more dramatic. Once the share of liquid assets available to cover an exposure (ρ) rises to 30 per cent, there is no contagion under either the joint failure-threshold or the liquidity failure-threshold.

Even under extreme overall conditions, financial institutions can protect themselves from contagion by prudent management of their capital and liquidity.

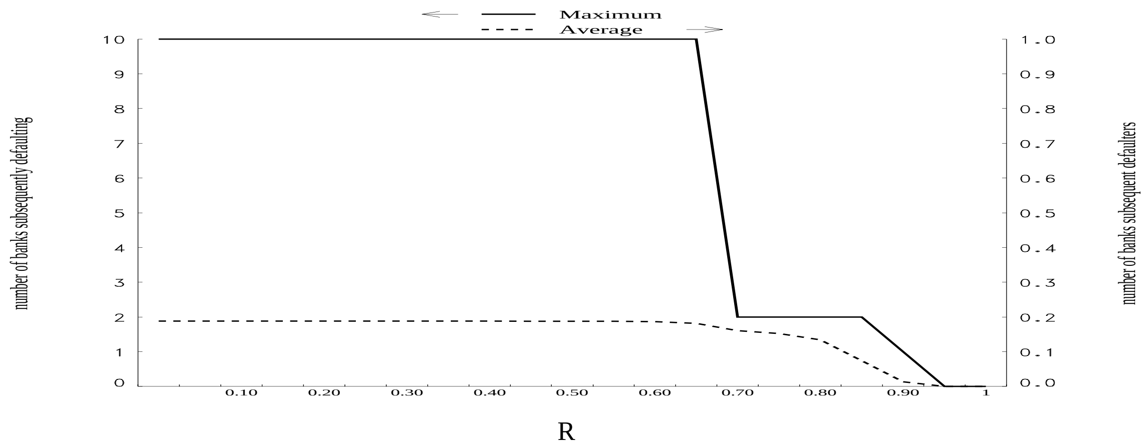
Figure 3: The Effect of Liquidity on Contagion
The average number of subsequent defaults for a given exogenous defaulter.
Extreme state: τ=0.1, α=1, ϕ=1, R=0.75, 1(S_{ij})



Result 3: Higher recovery from the estate of the defaulting institution reduces the potential for contagion.

As previous authors have found, recovery rates are an important factor in determining the level of contagion. Figure 4 shows the average and maximum number of knock-on defaults for the parameters given in the extreme state under the joint failure-threshold. Contagion is low, with an average recovery level of 75 per cent, and it is eliminated with a recovery rate of over 94 per cent. A striking feature is the decrease in the maximum number of defaults that occurs once the recovery rate reaches a net present value of 70 per cent (Figure 4).

Figure 4: The Effect of the Recovery Rate on Contagion
The average and maximum number of subsequent defaults for a given exogenous defaulter under the joint failure-threshold for various levels of recovery.
Extreme state: τ=0.1, ρ=0.1, α=1, ϕ=1, 1(S_{ij})



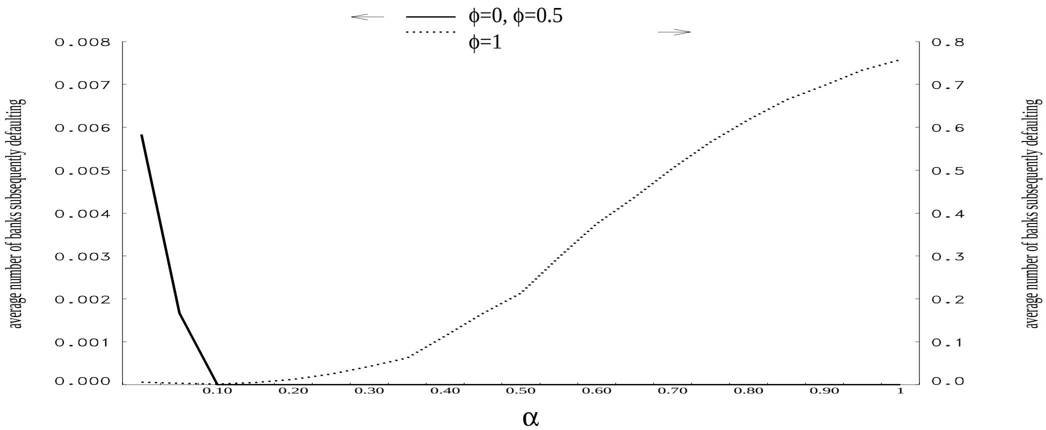
Result 4: The effectiveness of an "unwind" as a risk-management tool depends on participants' use, and enforcement, of provisional credit provided to clients.

Again, the extreme state is used to examine the effects of the proportion of items unwound (α) and the recovery of value from client accounts (ϕ).

An unwind of payments is often used as a risk-management tool in net settlement systems. In the context of the ACSS, returning items drawn on the defaulter improves the multilateral position of the defaulter, decreasing its multilateral net debit position or pushing it to a net credit position (equation (3)). This decreases (or eliminates) the defaulter's obligation to the system. Therefore, the unwind of payments decreases the additional settlement contribution that is allocated to survivors, putting downward pressure on survivors' credit exposure. If survivors have provided provisional credit for those payments that are unwound, however, they are exposed for that amount if it cannot be recovered from client accounts. An increase in the proportion of payments unwound puts upward pressure on credit risk. Therefore, the unwinding of payments puts conflicting pressure on a survivor's credit exposure.

Figure 5 shows defaults stemming from credit failure-threshold for an increasing unwind proportion (α) with complete recovery from client accounts (ϕ=0), partial recovery (ϕ=0.50), and no recovery from client accounts (ϕ=1).

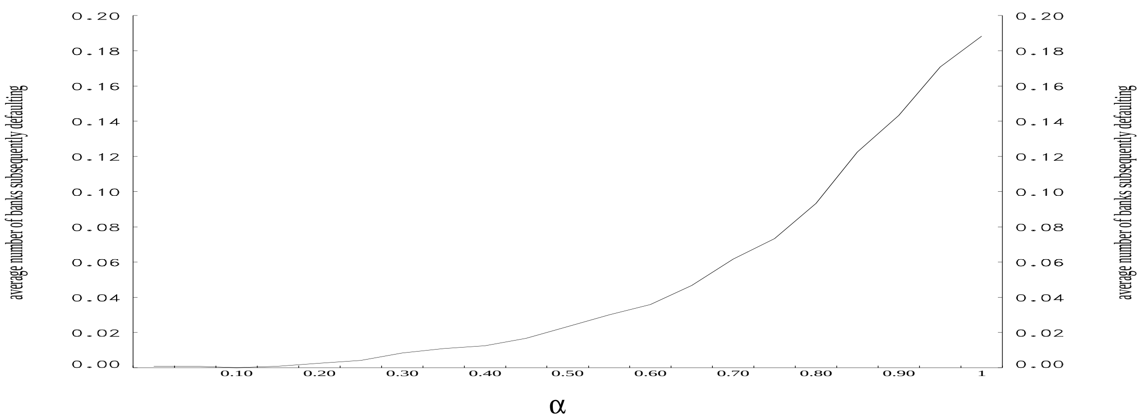
Figure 5: The Effect of an Unwind on Credit Risk
The average number of subsequent defaults for a given exogenous defaulter under the credit failure-threshold for varying levels of unwind (α) and recovery from client accounts (ϕ).
Extreme state: τ=0.1, ρ=0.1, R=0.75, $1(S_{ij})$



Equation (10) explains the interactions observed. As the amount that can be recovered increases (ϕ goes to zero), the $\phi_j\alpha_jS_{jd}$ term of credit exposure goes to zero. With a high level of such recovery, an increase in the level of unwind leads to a decrease in credit exposure through a decrease in the additional settlement contribution. For low levels of recovery (ϕ goes to one), an increase in the amount unwound leads to an increase in the loss from provisional credit provided to clients (an increase in the $\phi_j\alpha_jS_{jd}$ term) and an increase in risk, although at a decreasing rate, since the higher α leads to a lower additional settlement contribution. The usefulness of the unwind mechanism as a risk-management tool for survivor's credit risk depends on the ability of participants to recover value from client accounts. The more value that can be recovered, the more useful the unwind.

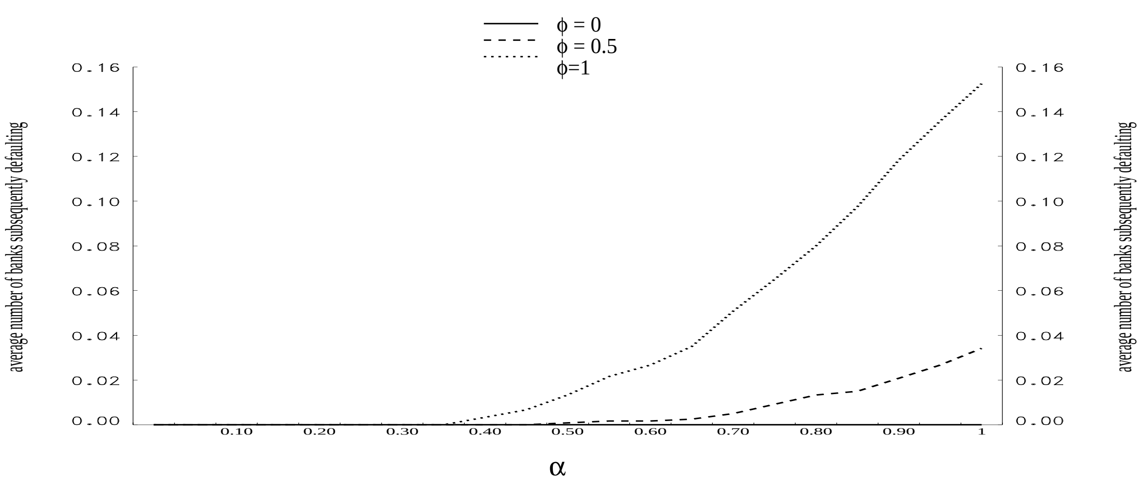
The proportion of value unwound also affects liquidity exposure. As the value unwound increases, a survivor's revised net position worsens (equation (4)), which puts upward pressure on liquidity risk (equation (9)). This is shown in Figure 6, with the level of knock-on defaults under the liquidity failure-threshold increasing as the value of α increases.

Figure 6: The Effect of an Unwind on Liquidity Risk
The average number of subsequent defaults for a given exogenous defaulter under the liquidity failure-threshold for varying levels of unwind (α).
Extreme state: τ=0.1, ρ=0.1, ϕ=1, R=0.75, $1(S_{ij})$



The unwinding process puts conflicting pressure on survivors' credit and liquidity exposures. Figure 7 shows the results of the unwind on contagion under the joint failure-threshold.

Figure 7: The Effect of an Unwind on Contagion
The average number of subsequent defaults for a given exogenous defaulter under the joint failure-threshold for varying levels of unwind (α) and recovery from client accounts (ϕ).
Extreme state: τ=0.1, ρ=0.1, R=0.75, $1(S_{ij})$



Overall, if financial institutions can recover a substantial portion of value from client accounts, the use of an unwind is a useful risk-management tool, decreasing participants' credit risk and causing no contagion under the joint failure-threshold. If participants cannot receive value from client accounts, then the upward pressure on credit risk along with upward pressure on liquidity risk from the unwinding process leads to knock-on defaults under the joint failure-threshold; the unwinding process is not as effective a risk-management tool.

The ability to recover from client accounts (ϕ) is, to a large extent, under the control of participants. In accordance with the rules of the system, however, α is controlled by the defaulter. Therefore, to minimize the overall risk of contagion, the system operator would want to set rules in the system that promoted a level of unwind that minimized the potential for contagion, given its belief in participants' ability to recover value from clients. Regardless, participants can minimize their own exposures by pursuing policies that allow it, in the event of a default, to substantially recover any provisional credit it may have granted clients.

Result 5: Certain direct clearers are more likely than others to cause knock-on defaults if they are the initial defaulter.

For example, in the extreme state under the joint failure-threshold, only six of eleven direct clearers are able to instigate a knock-on failure in the model.[24] Indeed, three banks account for 68 per cent of the failures. Under less-strenuous assumptions, the concentration is even more pronounced.

It is typically assumed that the participant with the largest initial net debit position poses the largest risk of contagion if it defaults. This may be true in a world such as Humphrey (1986) describes, where all payments to and from the defaulter are returned to survivors and exposure is measured as the net position change of a survivor following the unwind. It is not necessarily the case in the ACSS. Obviously, those direct clearers that cause larger credit and liquidity exposures will have a higher probability of causing knock-on defaults. As with a Humphrey-style model, the size of the defaulter's initial net debit position is important. The higher the value of the net debit position, the higher the potential value of a shortfall. This higher value must be allocated to survivors. A second important aspect is how the shortfall is distributed. If it is spread out evenly over survivors, each survivor must bear a share, thereby lowering the cost to any one participant. In the ACSS, the shortfall is allocated to survivors according to the credit they extended to the defaulter. Therefore, not only the size of the defaulter's initial net debit position is important, but the underlying pattern of payments that determine how losses are allocated (β). Those direct clearers that create large shares (β) for one or few participants should have a higher probability of causing knock-on defaults.

The results broadly support this hypothesis, although more work needs to be done. The direct clearer that produced the most knock-on effects under the extreme-state joint failure-threshold was not necessarily the largest net debtor, nor was it one of the largest participants in the ACSS.

24. The twelfth is the central bank, which cannot default.

That is, it did not necessarily send or receive the largest share of ACSS payments. What stands out is the pattern of its linkages with counterparties. Although linkages in the ACSS are highly complete (as described in section 3.1), some participants do interact disproportionately with other participants. The direct clearer that caused the most knock-ons (in the context of this model) was one such exceptional bank.

Result 6: Certain banks are more likely than others to experience a knock-on default.

As with the ability to cause knock-on effects, there is concentration in the direct clearers that are involved in knock-on defaults. Only four banks experienced knock-on defaults under the extreme state and two of them accounted for 99 per cent of the defaults. Again, the underlying pattern of payments interaction appears to be a factor, although more work needs to be done.

Result 7: A uniform decrease in the value of payments sent by all participants leads to a significantly decreased risk of contagion.

As described in section 3, a decrease in the value of items sent through the ACSS leads to a lower risk of contagion. A trivial case, of course, is where S_{ij} goes to zero: a system cannot pose a risk if it is not used. However, it is interesting how quickly the maximum number of knock-on defaults decreases as the value sent through the system falls. Figure 8 shows the average and maximum number of defaults for a given exogenous default with increasing levels of value sent under the extreme-state worst-case scenario (no recovery from the estate of the defaulting institution, R=0). A 25 per cent decrease, 0.75(S_{ij}), in the value of items sent leads to a dramatic decrease in the maximum number of knock-on defaults that occur, given an exogenous default; the number decreases from 10, the largest number possible, to 2 (Figure 9).

Figure 8: The Effect of the Value of Items Sent on Contagion

The average and maximum number of subsequent defaults for a given exogenous defaulter under the joint failure-threshold for varying levels of the value of items sent, S_{ij}, through the ACSS.

Extreme case with R=0: τ=0.1, ρ=0.1, α=1, ϕ=1

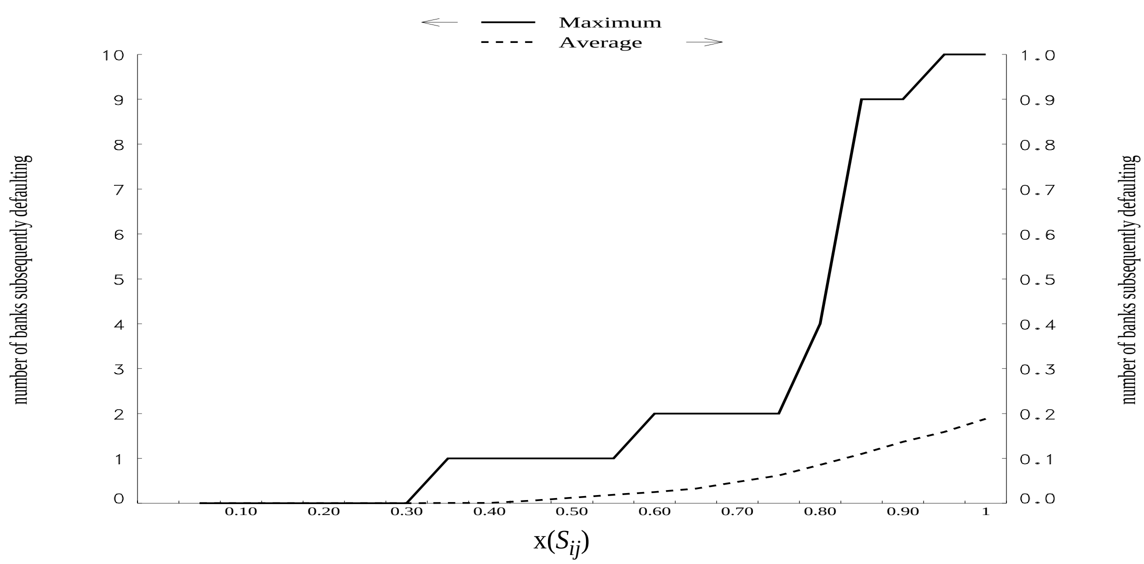
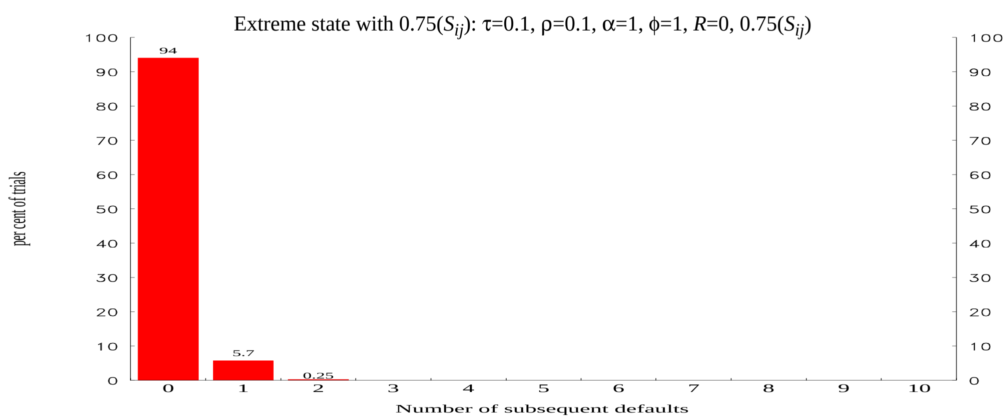


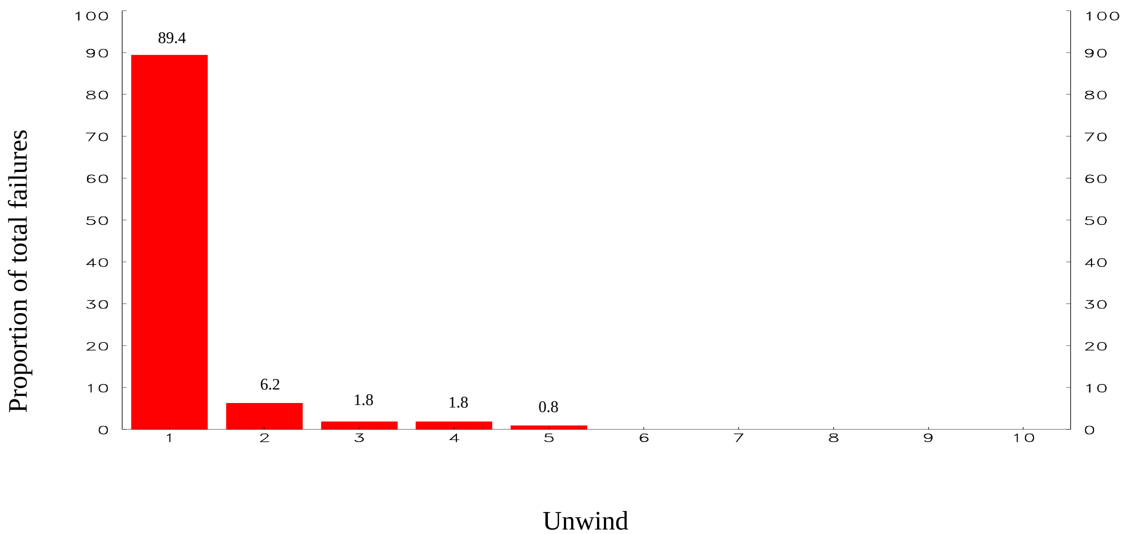
Figure 9: Number of Knock-On Defaults in a Trial



Result 8: The pattern of contagion in the ACSS caused by an exogenous default is consistent with a "complete structure" of interbank linkages.

In the model of the ACSS, all knock-on defaults occur on the day of default, although in reality the effects may be spread over time. Therefore, in the context of the model, time is represented by the number of unwinds that are performed in each trial. Figure 10 shows the proportion of the total knock-on defaults in a trial that occur after each unwind for the extreme-state worst-case scenario under the joint failure-threshold. The initial exogenous default causes the highest proportion of subsequent defaults and the effects then dampen out.[25] This is consistent with the contention that the network of direct clearers in the ACSS is representative of a complete market. Defaults occur due to direct exposure with the exogenous defaulting institution.

Figure 10: The Proportion of Failures that Occur after Each Unwind



6. Conclusions

The methodology described herein for measuring the risk of contagion through the ACSS provides a very encouraging view of the system. Only through a confluence of extreme conditions are knock-on defaults experienced, and even then not even one subsequent default is found, on average, for a given exogenous default.[26] Under more normal conditions, shown by the scenarios under the normal state, no knock-on effects are observed. Indeed, this is the case even under some extreme assumptions, such as no recovery from the estate of the defaulting institution. Based on these results, it appears to be clear that, in the current environment, the risk of contagion in the ACSS is very limited.

Investigations into the effects of participants' behaviour on contagion through the model's behavioural parameters also produce interesting results. As in previous studies, higher levels of recovery from the estate of the defaulting institution are found to increase survivors' ability to withstand a default. As well, the use of the unwind mechanism as a risk-management tool depends crucially on the participants' ability to recover some proportion of the value of unwound

25. Other scenarios tested show broadly the same pattern.
26. Using the joint failure-threshold, failure occurs if a participants' credit and liquidity exposures are greater than its ability to cover them.

payments from client accounts. Also crucial to the participants' ability to withstand a shock are the capital and liquidity levels they have available to cover an exposure. Again, the results are positive: it appears that a large deterioration from current levels of capital and of liquid assets, across all participants, is needed to produce knock-on defaults. As well, because these are variables under the control of participants, levels can be managed according to participants' views of risk in the system, making them effective risk-management tools.

As encouraging as these results are, certain caveats must be considered. The same values of α, ϕ, ρ, τ, and R are applied to all survivors following an exogenous default to facilitate comparisons across institutions and across simulations. In reality, these would all differ among survivors.

Another caveat is that the results of this study are based on the current environment. Therefore, to be forward looking, they must be considered in the context of changes to this environment.

- Since the Large Value Transfer System (LVTS) commenced in 1999, the Canadian Payments Association (CPA) has encouraged their members to move payments, especially large ones, to this well-risk-proofed system.[27] The migration of payments to the LVTS has led to a large decrease in the value processed through the ACSS and, consequently, a decrease in the exposures taken on by participants. This trend is expected to continue as the CPA implements a cap on the value of individual items that can be processed through the ACSS. To the extent that the decrease in value sent through the ACSS does not greatly change the pattern of underlying linkages, the results of this study indicate that such a decrease has the potential to greatly reduce risk in the ACSS.

- How a defaulter's shortfall is allocated is important to survivors' resulting exposures. The CPA is working towards changing the way each survivor's share (β) is calculated. Instead of only those contributing that have a net credit position with the defaulter after the unwind, all survivors that had extended credit to the defaulter would contribute.[28] To the extent that the new formula spreads the shortfall over more survivors, it may reduce the risk of any one survivor taking a disproportionately large share and thereby experiencing exposures that cause it to default. This, as well as the potential behavioural effects of the new rule, would be interesting to investigate further.

- The results support the view that the interactions among participants are currently fairly complete, with a high degree of connectedness. A change to this pattern could affect the potential for contagion. New legislation has recently opened access to the payments system to three new classes of institutions: life insurance companies, money market mutual funds, and securities brokers. The first two classes are constrained to be indirect clearers. Although these new entrants have yet to enter the payments system in a large way, they pose some interesting

27. The CPA is a not-for-profit organization, which owns and operates the two national payments systems in Canada: the ACSS and the LVTS. See their Web site for more information (http://www.cdnpay.ca).
28. This would require a change to the bylaw governing the ACSS. Under the Canadian Payments Act, any change to CPA bylaws requires the approval of the Governor in Council.

questions about how their entrance would affect the composition and structure of the system. A re-examination of the market as a whole, and not just of the direct clearers, may be required.

Overall, the results are very encouraging: there is little potential for contagion in the ACSS in the current environment. It would be interesting to expand more fully on the characteristics that make a participant more likely to initiate or withstand a default, and the characteristics of the environment itself that affect risk. It would also be useful to explore the implications of other measures of the risk of contagion in the Canadian financial system.

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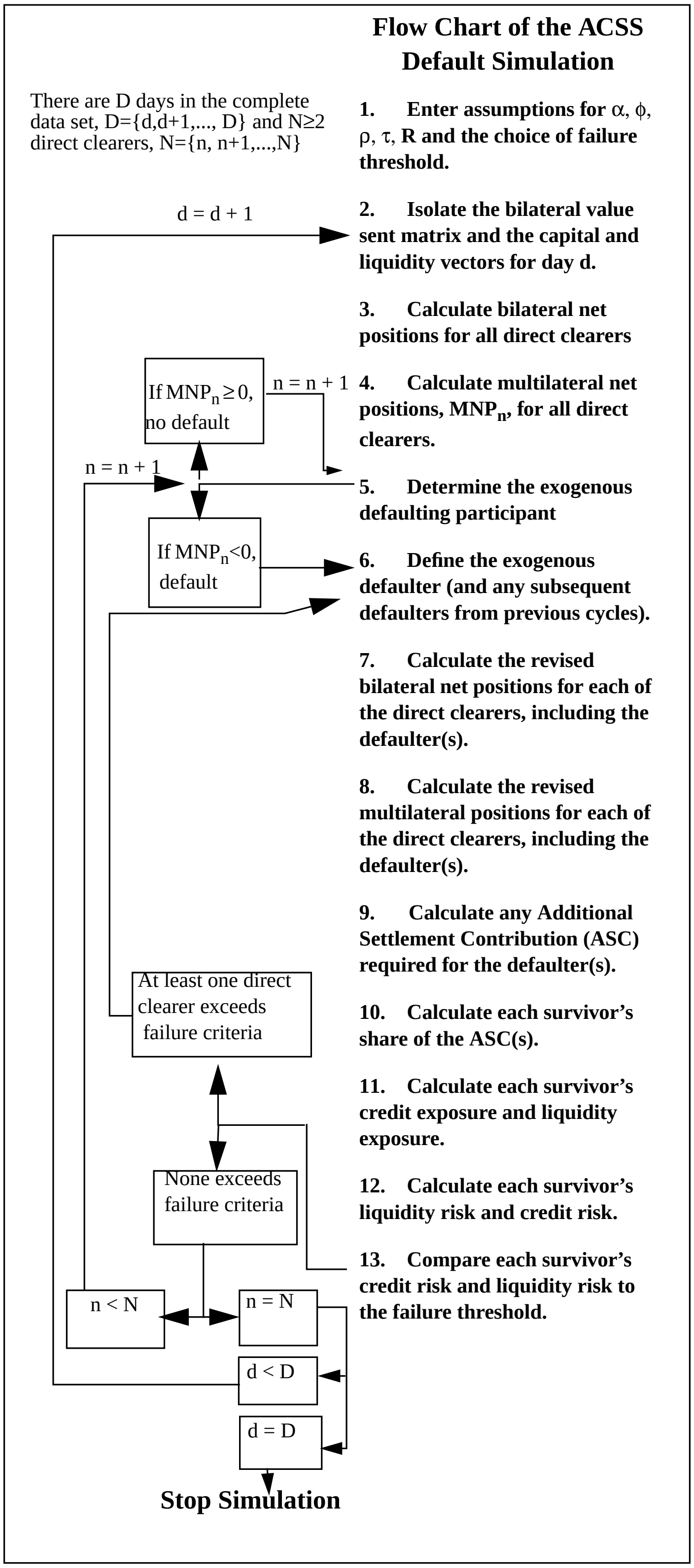
Appendix A: The ACSS Default Simulation



Flow Chart of the ACSS Default Simulation

Appendix B: Normal State

Results show the average and maximum number of knock-ons for each scenario under the normal state for a given exogenous default. The asterisk (*) denotes scenario results that are mathematically the same as the base state.

Scenario	Credit failure-threshold		Liquidity failure-threshold		Joint failure-threshold	
	Average	Maximum	Average	Maximum	Average	Maximum
Base state: τ=1, ρ=0.5, α=0.5, ϕ=0.5, R=0.75, S_{ij}	0		0		0	
1. R=0	0		0*		0	
2. R=0.50	0		0*		0	
3. R=0.95	0		0*		0	
4. ϕ=1	0		0*		0	
5. ϕ=0.75	0		0*		0	
6. ϕ=0.25	0		0*		0	
7. ϕ=0	0		0*		0	
8. α =1	0		0		0	
9. α=0.75	0		0		0	
10. α=0	0		0		0	
11. ρ=0.75	0*		0		0	
12. ρ=0.25	0*		0		0	
13. ρ=0.20	0*		0		0	
14. ρ=0.15	0*		0.00167	1	0	
15. ρ=0.10	0*		0.023	1	0	
16. ρ=0.05	0*		0.267	10	0	
17. τ=0.75	0		0*		0	
18. τ=0.50	0		0*		0	
19. τ=0.25	0		0*		0	
20. τ=0.20	0.0017	1	0*		0	
21. τ=0.15	0.0067	1	0*		0	
22. τ=0.10	0.025	2	0*		0	
23. τ=0.05	0.213	2	0*		0	

Appendix C: Extreme State

Results show the average and maximum number of knock-ons for each scenario under the extreme state for a given exogenous default. The asterisk (*) denotes scenario results that are mathematically the same as the base state.

Scenario	Credit failure-threshold		Liquidity failure-threshold		Joint failure-threshold	
	Average	Maximum	Average	Maximum	Average	Maximum
Extreme state τ=0.1, ρ=0.1, α=1, ϕ=1, R=0.75, S_{ij}	0.758	6	0.188	10	0.153	2
1. R=0	5.128	10	0.188 *	10	0.188	10
2. R=0.50	1.758	10	0.188*	10	0.188	10
3. R=0.95	0.0125	2	0.188*	10	0	0
4. ϕ=0.75	0.566	3	0.188*	10	0.128	2
5. ϕ=0.50	0.213	2	0.188*	10	0.0342	2
6. ϕ=0.25	0.025	2	0.188*	10	0.0008	1
7. ϕ=0	0	0	0.188*	10	0	0
8. α=0.75	0.566	3	0.0733	2	0.065	2
9. α=0.50	0.213	2	0.0233	1	0.0133	1
10. α=0	0.0058	1	0.0008	1	0	0
11. ρ=0.75	0.758*	6	0	0	0	0
12. ρ=0.50	0.758*	6	0	0	0	0
13. ρ=0.25	0.758*	6	0.0008	1	0.0008	1
14. ρ=0.20	0.758*	6	0.0125	1	0.0125	1
15. ρ=0.15	0.758*	6	0.035	2	0.035	2
16. ρ=0.05	0.758*	6	1.216	10	0.286	6
17. τ=0.75	0.0025	3	0.188*	10	0	0
18. τ=0.50	0.0125	2	0.188*	10	0	0
19. τ=0.25	0.025	2	0.188*	10	0.0133	1
20. τ=0.20	0.213	2	0.188*	10	0.034	1
21. τ=0.15	0.461	3	0.188*	10	0.10	2
22. τ=0.05	1.758	10	0.188*	10	0.188	10

Appendix D: Effect of a 25 Per Cent Decrease of S_{ij} on Contagion

Results show the average and maximum number of knock-ons for each scenario under the extreme state for a given exogenous default and 75 per cent of the original value of items sent. The asterisk (*) denotes scenario results that are mathematically the same as the base state.

	Credit failure-threshold		Liquidity failure-threshold		Joint failure-threshold	
Scenario	Average	Maximum	Average	Maximum	Average	Maximum
Extreme state: τ=0.1, ρ=0.1, α=1, ϕ=1, R=0.75, 0.75(S_{ij})	0.5658	3	0.0617	2	0.0592	2
1. *R*=0	3.688	10	0.0617*	2	0.0617	2
2. *R*=0.50	1.1758	10	0.0617*	2	0.0617	2
3. *R*=0.95	0.005	1	0.0617*	2	0	0
4. ϕ=0.75	0.3167	3	0.0617*	2	0.0367	2
5. ϕ=0.50	0.0917	2	0.0617*	2	0.01	1
6. ϕ=0	0	0	0.0617*	2	0	0
7. α=0.75	0.3167	3	0.025	2	0.0208	2
8. α=0.50	0.0917	2	0.0058	1	0	0
9. α=0	0.0017	1	0	0	0	0
10. ρ=0.50	0.5658*	3	0	0	0	0
11. ρ=0.25	0.5658*	3	0	0	0	0
12. ρ=0.05	0.5658*	3	0.50583	10	0.1742	2
13. τ=0.50	0.005	1	0.0617*	2	0	0
14. τ=0.25	0.0425	2	0.0617*	2	0.0017	1
15. τ=0.05	1.1758	10	0.0617*	2	0.0617	2

Appendix E: Effect of Decreasing S_{ij} on Contagion

Results show the average and maximum number of knock-ons for each scenario under the extreme state, joint failure-threshold, for a given exogenous default over various proportions of the original value of items sent.

Scenario	0.30 (S_{ij})		0.50 (S_{ij})		0.85 (S_{ij})	
	Average	Maximum	Average	Maximum	Average	Maximum
Extreme state: τ=0.1, ρ=0.1, α=1, ϕ=1, R=0.75	0	0	0.01	1	0.093	2
1. R=0	0	0	0.0125	1	0.11	9
2. R=0.50	0	0	0.0125	1	0.11	9
3. R=0.95	0	0	0	0	0	0
4. ϕ=0.75	0.0367	2	0.005	1	0.07	2
5. ϕ=0.50	0.01	1	0.0008	1	0.015	1
6. ϕ=0	0	0	0	0	0	0
7. α=0.75	0	0	0	0	0.03	2
8. α=0.50	0	0	0	0	0.0042	1
9. α=0	0	0	0	0	0	0
10. ρ=0.50	0	0	0	0	0	0
11. ρ=0.25	0	0	0	0	0	0
12. ρ=0.05	0.0017	1	0.0342	1	0.2208	2
13. τ=0.50	0	0	0	0	0	0
14. τ=0.25	0	0	0	0	0.0042	1
15. τ=0.05	0	0	0.0125	1	0.11	9

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