Simulation: A Powerful Research Tool in Payment and Settlement Systems

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The last several years have seen a growing interest in research and development in interbank payment and settlement systems. Central banks have allocated effort and resources to this special area. Among the factors behind the movement are international cooperation, technological advancement, growing dependency on smooth functioning payment systems and risk perspectives. Co-operation has been a particularly important factor in the euro area, which has seen extensive linking of payment systems in order to give the area a totally integrated interbank payment system. The key official fora have been payment system committees of G10 central banks and of the European System of Central Banks, and working groups of the European Commission.

At the Bank of Finland, simulation methods have been used for several years in the analysis of payment systems. This type of research was initiated around the time Finland was joining the Economic and Monetary Union and it became necessary to examine the impact that the new methods of transferring payments and covering funds would have on Finnish payment systems. Out of this concern evolved the construction of the first payment system simulator. The simulator proved to be an excellent tool for studying liquidity needs and system risks. Although the simulator was not intended for outside use, other central banks made use of it with the help of Bank of Finland.

Experience with the system prompted the Bank of Finland to proceed with the development of a new and more diversified simulator, designed especially for external use and international distribution. The new simulator—BoF-PSS2—was completed in Spring 2004 and is available for research purposes free of charge.

The purpose of this article is to introduce the basic issues and research topics related to payment systems that have been studied with the aid of simulation models as well as the possibilities for using the Bank of Finland simulator. A more detailed description of payment system features and interesting topics for simulation studies can be found in Leinonen-Soramäki (2003).

Simulation – The Possibilities

The development of payment and settlement systems often involves the hands-on work of designing and operating systems. The analytical work must tackle the problem of handling of large amounts of data and transactions. Simulation techniques enable the construction of models that closely mimic the real world. The typical econometric models are too limited to deal in sufficient detail with the many dimensions of payment systems, which entail important dependencies, both within and between systems. Decision-making and other behaviour issues are heuristic and dependent on counterparty and situation. For this reason, payment system models must allow for the embedding of different kinds of behaviour models.

A reality-friendly simulation model provides a veritable laboratory setting, in which one can analyse the probable affects of different structural options and decision parameters on payment flows and system participants. An on-stream payment system is so sensitive that one cannot use it for direct experimentation without endangering daily operations.

Another area of research is the study of different crisis scenarios and how to prepare for them. While realisations of such crisis scenarios are extremely rare, simulation models enable one to study numerous crisis-like situations and thus to prepare in advance for the real event.

Nonetheless, simulation models are subject to their own important limitations. Optimisation analysis requires complete enumeration and iteration, so that one may actually miss the true optimum. There may be problems with the behavioural models and assumptions, which may not hold in certain special situations. It is fairly simple to use payment-flow time series in simulation studies, but this may result in the failure to detect the impact of future changes in payment flows.

Basic Structures of Payment Systems

Traditionally, payment systems have operated on the basis of batch-processing and system-specific timetables. At the end of the day, a net position is calculated from payment flows for each participating bank. In such deferred net settlement systems (DNS), covering funds are usually transferred, with a lag, across accounts at central banks. In order to speed up payment transfers, especially for large payments, online continuous settlement systems (CNS) have been developed. But because a netting system can give rise to large interbank credit risk positions, authorities have generally required that these risks be limited or have provided in their stead real-time gross settlement systems (RTGS).

Payment and settlement systems are often hierarchically structured. The top level comprises central banks' RTGS systems, where large payment transfers are executed, interbank debits and credits are settled, and other systems' final transfers of covering funds are effected. For example, the Bank of Finland's RTGS system (BoF-RTGS) handles interbank transfers of covering funds for certain other Finnish systems: Retail payment system (PMJ), express and cheque transfer system (POPS) and two securities settlement systems (OM for shares and RM for debt instruments). The international dimension of the BoF-RTGS is represented by its continuous linkage with the European System of Central Banks' TARGET system, through which covering funds are transferred for systems handling private large-value payments in Europe (EURO 1) and international currency transactions (CLS). Figure 1 shows the hierarchical structure of payment and settlement system networks in general.

Figure 1. Hierarchical Structure of Payment and Settlement Systems

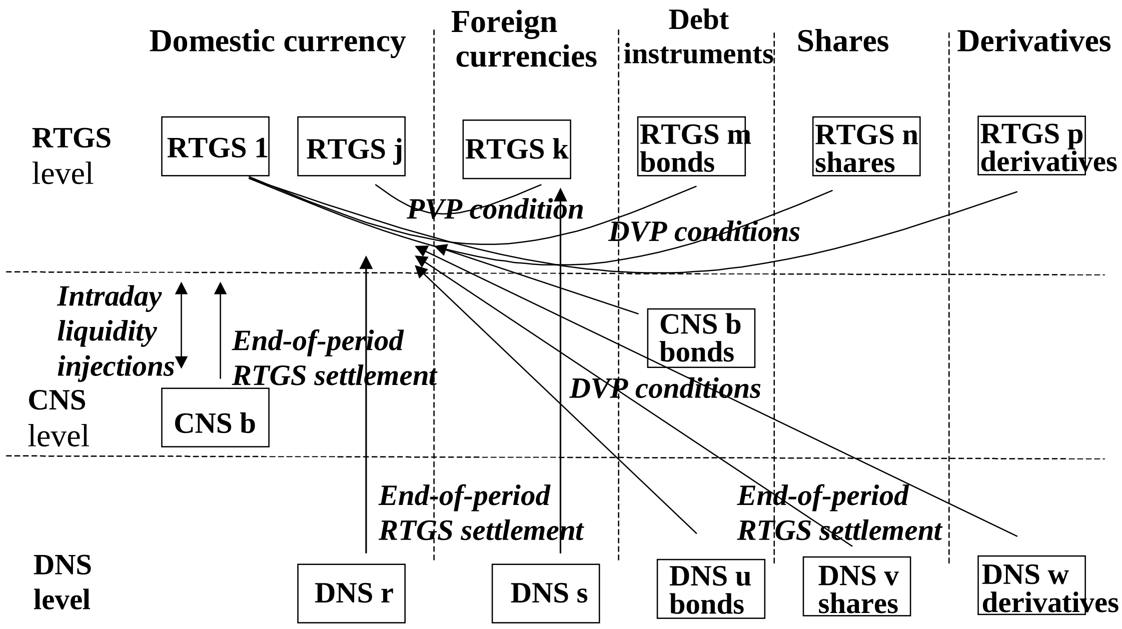


Figure 1 illustrates the linkages for simple and conditional funds transfers. In connection with securities settlement systems, delivery versus payment (DVP) means that delivery of securities is conditional on simultaneous payment. Payment versus payment (PVP) refers to currency trading in which payment in one currency occurs only simultaneously with corresponding payment in the other currency. DVP and PVP were developed as means of reducing settlement risk.

Risk Considerations

Large interbank risk positions can arise in a netting system because banks accept incoming payments on behalf of customers before covering funds are transferred between banks. G10 central banks' Committee on Payment and Settlement Systems, in its Lamfalussy report (BIS 1990), focused attention on this type of risk. Authorities then proceeded to demand that private netting systems employ limits and collateral requirements for risk control purposes. The report also promoted the development of RTGS systems by central banks (BIS 1997). And in order to reduce risks, core principles have been drawn up for systemically important payment systems (BIS 2001).

In some payment systems, counterparty risks can be so large as to give rise to the threat of a domino effect. Financial problems of one participant can be transmitted via payment systems to other participants so as to create a systemic risk to the whole financial sector. Integration of payment systems has increased the likelihood of contagion of systemic risk situations across wide areas of the globe. Authorities have attempted to limit the realisation probability of such risk e.g., by requiring gross transfers of covering funds and collateral coverage of all significant counterparty positions. Systemic risk has also become an important research topic (e.g., Angelini, Maresca, Russo 1995, Kuussaari 1996 and Bech, Madsen, Natorp 2002).

Liquidity risk is related to possible shortfalls of funds for settling payment obligations. Banks attempt to forecast their coming liquidity needs. But payment flows are subject to difficult-to-forecast stochastic fluctuations. These fluctuation may be troublesome, especially in times of market disturbance or when other banks in the system are facing liquidity problems. Realisation of liquidity risks may even cause a temporary disruption of a large part of the flow of payments.

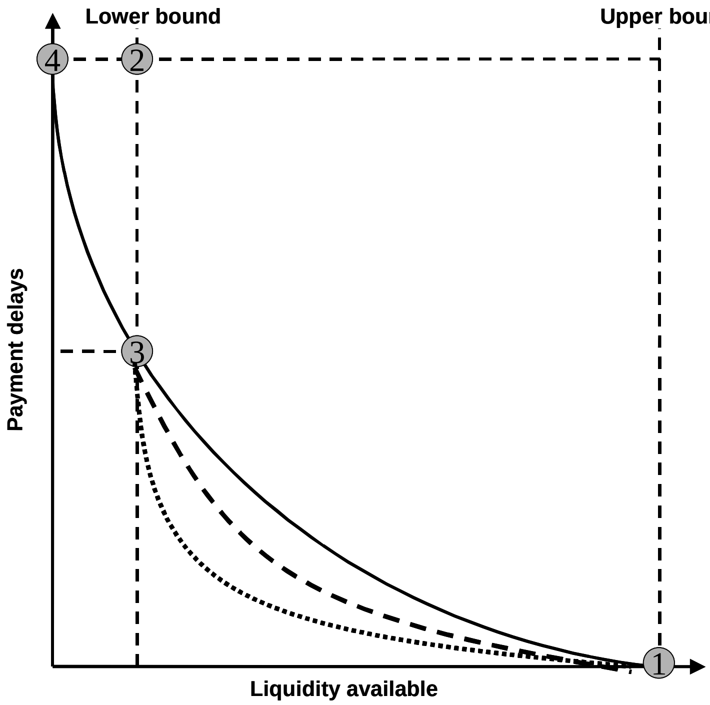
Liquidity Needs

Liquidity needs of payment systems and participants vary according to timetables and system features. Figure 2 gives a general picture of liquidity needs. The lower bound applies at the end of the period, i.e., it is the minimum amount of liquidity needed to settle all payments by the end of the day. If the final interbank settlement and transfer of cover are not carried out until the end of the period, it is sufficient that each counterparty has settlement funds available in the amount of its net liability. Settlement in this case is delayed for the maximum time (point 2). In case payments are settled continuously with this same amount of liquidity and queued whenever not enough liquidity is available, the settlement delays can be reduced (point 3).

The upper bound (point 1) applies to continuous real-time settlement. Payments are settled immediately and liquidity need is maximised. Any liquidity in excess of this amount will not be used. Between these extreme situations is a continuum of options for which settlement is delayed and payments are variously queued. The shape of the curve depends on the extent of the continuous netting effect. If liquidity is reduced below point 3 some payments will necessarily remain unsettled while others are increasingly delayed. If liquidity is reduced to 0 (point 4) no payment can be settled by gross settlement.

Interest in intraday liquidity derives from developments in payment systems and shrinking delivery times. Payment systems are currently in a kind of interim stage. Earlier, before the 1990s, operations were strictly on the daily level and intraday liquidity had no significance. As the processing of payments has been speeded up and central banks have converted to RTGS, intraday liquidity has received increasing emphasis. As speed becomes more important, banks' liquidity needs increase toward the upper bound. (The relation between liquidity needs and settlement speed is studied in Koponen-Soramäki 1998 and Leinonen-Soramäki 1999).

Figure 2. Relation Between Liquidity and Settlement Speed



If payments are queued, various netting and splitting algorithms can be used to reduce liquidity needs and speed up the settlement process. Certain timing methods can also be used for these purposes. In Figure 2 the dotted line shows the possible benefits of a settlement algorithm that solves gridlock situations in the system. In such situations, the parties' transactions are queued and cannot be settled individually one-by-one but could be settled by netting or splitting (Leinonen-Soramäki 1999). A typical example is a circular situation in which participant A is paying participant B, who is paying participant C, who is paying participant A; but no one has sufficient liquidity to pay and thus break the circle.

In seeking a partial netting solution, one encounters the "knapsack" problem. This arises when liquidity is not sufficient to complete all the transactions in a queue and one must compose a smaller group of transactions for settlement. In seeking an optimal combination of transactions to settle, one is faced with so many possibilities that going through the whole list is an inefficient procedure. Algorithms are publicly available that find the optimal solution if the order of payments is fixed (Bech, Soramäki 2001, 2002) and an approximately optimal solution if payments can be settled in any order from the queues (Guentzer, Jungnickel, Leclerc 1998). The problem of gridlock is particularly acute in securities settlement systems that require delivery versus payment (participants must have sufficient money and securities).

Cost Elements

Settlement systems entail three structural cost factors that are partly interdependent: Liquidity costs, delay costs and credit-risk costs. Liquidity, i.e., holdings of funds for completing settlements, involves certain costs. These are, aside from storage costs, mostly opportunity costs, since the interest rate on eligible collateral is usually lower than on other investments, due to the liquidity premium. If settlements and the underlying payments are late, delay costs arise, mostly in the form of sanctions. If the payment system operates on the basis of credit, users also incur credit risk costs. The basic structural interdependencies of cost elements are depicted in Figure 3. Besides structural costs, every system encounters processing costs. These are however generally of the same magnitude regardless of structural option and depend mainly on the efficiency of underlying computer systems.

Figure 3. Structural Costs of Payment and Settlement Systems

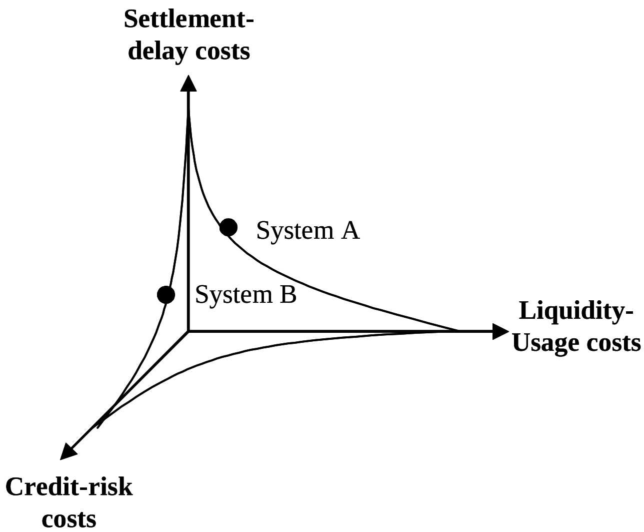


Figure 3 depicts a three dimensional cost minimisation problem in terms of credit risks costs, liquidity costs and payment delay costs. All of the cost dimensions in the chart can be traded off against each other. The relationships with a given technology are usually convex resulting in a unique cost optimum.

Credit risk costs do not arise if the system operates completely on the basis of liquidity. If settlement is wholly or partly based on implicit credit relations between the participants, the cost of liquidity will be smaller. The difference, however, is that liquidity costs fall on sending parties while credit risk costs fall on receiving parties. Similarly, liquidity costs can be reduced by delaying outgoing payments so that they are in synchrony with incoming payments and thus benefit from the netting effect.

Delays in settlement and delivery are usually caused by limits on available liquidity and on permitted credit risks. In practice, delays are the greater, the less the liquidity available and the tighter the control of credit risks. In their role as overseers, central banks have usually attempted to increase liquidity in order to ensure adherence to payment processing timetables. At the same time, they have required reductions and compensation via liquidity transfers, especially to avoid large risk positions. Figure 3 gives an example of a system (A) based on full liquidity and a system (B) based on credit.

Bank of Finland Simulator

The Bank of Finland Payment and Settlement Simulator can be characterised as a deterministic system with decision-making capability, which takes stochastic data as input. For given input data and choice of algorithms and parameters, the simulator will always produce the same results. Usually time series over many days are input in order to get a grasp of the fluctuation ranges of the various results. One can create and use algorithms with decision-making capability that enable payments processing in accord with different settlement modes and behaviour models for settlement parties (banks).

The simulator is built for independent PC usage and is composed of three subsystems—input generation, simulation execution and output analysis. The simulator operates with Microsoft NT, XP and 2000 and requires central memory of at least 256 MB. A users' guide and order and installation directions are available at www.bof.fi/sc/bof-pss. Distribution is handled via Internet. Using Java, the user can build new settlement algorithms and link them to the given structures. The database is based on the cost-free MySQL database.

Using the Simulator

The Bank of Finland Simulator is a modern research tool that has been well received, particularly by other central banks. Currently, about 20 central banks around the world are using it. These include all the Nordic central banks, European Central Bank, several European national central banks, Bank for International Settlements, Federal Reserve Bank of New York, Bank of England, Bank of Canada and several central banks in Asia. The simulator is used *inter alia* for studying liquidity policies and counterparty and systemic risks; making efficiency comparisons; and developing algorithms, pricing policies and settlement modes. The European Central Bank has been particularly helpful in advising on design and in testing the new version of the simulator.

Payment and settlement systems have received relatively little attention from financial market researchers. The solutions have usually been based on conventions applied by those in charge of actual payment system operations. A modern automated payment system is based purely on data transfer logistics except for the fact that even a small number of bits may contain credit transfers worth billions of monetary units. One would hope for an expansion of research in payment systems.

The Bank of Finland Payment and Settlement Simulator affords new types of opportunities in this area. Interesting and sparsely-studied areas of research include DVP-based netting and queuing algorithms in securities settlement systems. Related topics of special interest might be models of participant behaviour in various stress and emergency situations and the consequences for settlement risks. Various risk management systems that may be incorporated in payment systems represents another area that could benefit from further research (e.g., the reactions of participants and the system to terrorist attacks and to participants' liquidity problems).

The intention is to develop and expand the simulator on the basis of experience and user feedback. It is hoped that an active group of users will share experiences and ideas for further developments and will make available user-created settlement algorithms and analytical tools.

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