Modelling an RTGS system with SLAPP *

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Abstract

In a typical day of a developed country, the amount of economic transactions processed by the payment system is roughly 20% of the yearly GDP. This huge volume of payments is closely supervised and regulated by central banks in order to minimize their main risks (operational, credit, liquidity). Real Time Gross Settlement systems have been implemented from the early nineties for major payments, and these payment systems are often directly managed by central banks. A model that simulates realistically a RTGS can be a useful tool to analyze the intrinsic characteristics of these complex structures. In this work we present an agent-based simulation using a SLAPP protocol and we check the property of this simulation model with an empirical application on Italian data. The agent-based approach generates complexity from single agents' interplays and it is particularly suitable in a context where analytical solutions are often unfeasible. The SLAPP protocol has enabled to develop a fully functioning model which encompasses a realistic number of agents that deal with true payment requests data. A monetary market is included too, where agents interact to find the necessary liquidity. Further planned developments include the insertion of payment scheduling rules that reproduce those really implemented by the banks' treasurers.

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1 The relevance of payment systems in advanced economies and role of Central Banks

A payment system is the set of organisational procedures through which entities (be they individuals or institutions, either public or private) exchange and regulate their payments. Commercial banks actually operate as intermediaries both for other banks and for non-bank entities in all modern payment systems (tiering). They are necessary so that funds can circulate within the different sectors of the economies. The values at stake are huge: around 20% of the GDP of the most developed countries comes up for settlement in payment systems every day (Bank for International Settlements, 2005). Since payment systems are a transmission channel of monetary policy, central banks have a supervisory role over them and were major sponsors of this new approach. Till the end of the 1980's, they were mainly based on the Deferred Net Settlement (DNS) paradigm whereby payments were sent by banks during the day and settled later (typically at the end of the day). In this setting, the credit risk is the paramount one, since participants implicitly grant credit to each other during the day, and its regulation is postponed. With this approach, the liquidity risk is very low, since funds do not circulate for most of the time. After the financial deregulation of the late 1980s, the number of counterparties, the volume of payments and their size increased hugely and credit risk increased exponentially: the DNSs came under stress. Financial innovation also sped these processes up. To prevent systemic failures caused by major participants defaulting, a new paradigm took hold of immediately regulating payments without waiting for the end of the day in the management of interbank payments (the evolution of computer and telecommunication technologies made this approach feasible). This new approach was known as Real Time Gross Settlement system (RTGS). The new organisation calls for huge amounts of liquidity that has to flow and circulate continuously into the system, the hidden cost to pay for virtually eliminating credit risk. Interbank money markets had new reasons to operate at an accelerated rate. Given the financial volumes at stake, central banks started in the last ten years to model RTGSs, with a special interest in understanding how to keep the structure stable and functioning even under extremely difficult conditions (stress test, Hellqvist and J. Koskinen, 2005).

2 Alternative modeling strategies and advantages of the agent-based approach in payment systems simulation

The RTGSs encourage strategic behaviors of the participants, that could decide to postpone a payment either because the necessary liquidity is too expensive or because they expect incoming payments (which might even fail to materialize at the "right" time). This is why "internal queues" can be stacked, often unknown to the central bank that acts as system manager. Such behaviour is individually rational but might result in "bad" equilibrium outcomes and compromise the general efficiency of the system. Another relevant feature is the necessity of a money market where commercial banks exchange liquidity and decide to sell or buy funds after assessing their current and expected liquidity levels and the interest rate charged in the market. Central banks play a role that goes beyond their regulatory and supervisory function, since they also provide liquidity both on a regular and an exceptional base (lender of last resort). All these elements form a setting in which the interplays among the single elements are complex and not easily amenable to stylised analytical frameworks. The agent - based approach, where complexity emerges from the single agents' interplays (Wolfram, 1994 and Goldstein, 1999) is particularly suitable in such a context, if the interest is understanding the underlying decisional processes and their consequences. An alternative modeling approach could consider payment lists to settle during the day as the only input. The only behaviour modeled is that of a central processor trying different settlement rules, assessed by the analysis of some performance measures (typically the total amount of liquidity used, the average delay, the number and values of payments processed in the chosen time unit, etc.). Such an approach is highly focused and tailored to the needs of payment system designers, for whom the complex factors dictating single agents' micro choices are not relevant (see Glaser and Haene, 2007 and Heijimans, 2007).

3 The current version of SLAPP model and some basic results

A small-scale agent-based model of an RTGS system was first developed, with the aim of understanding the basic interactions and the aftermath of an unforeseen extreme event (Arciero *et. al.*, 2009). An extended model is now being developed and will be able to deal with real payment data and handle a large number of banks. The model, now available as a prototype, is built around the Swarm Protocol (Minar *et al.*, 1996). The protocol rigorously defines a structure for simulations, based on a discrete-event philosophy, where multiple agents are represented by an object-oriented representation. Seminal concepts are those of the set of agents as a collection ("swarm") endowed with an activity schedule, as well as that of an observer running the model with a schedule to produce graphical representations, reports, etc. The clock of the observer can be different from that of the model and this feature enables watching the simulation results with a flexible choice of the time frequency. Swarm is therefore a tool for representing agent-based simulation models independent of the actual implementation tool (Terna, 2009). Swarm has been written with the Python programming language[1], which creates all the model elements as instances of classes. In the model, commercial banks are the agents that move between two worlds: one is the representation of a RTGS system, the second is a market for short - term liquidity where agents exchange funds at a price represented by an interest rate. For the moment, agents enter the market as buyers or sellers with predefined probabilities chosen at the beginning of the simulation. Two different behaviours can be simulated into the money market: in the first agents decide at what price buying/selling liquidity according to the most recent price quoted in the market, whereas in the alternative scenario the reference price is the most favourable one so far practised (respectively the lowest one if the agent is looking for liquidity, the highest one if the agent is selling liquidity). If an input dataset containing data of payment settled on a RTGS is provided to the model, together with the single payment settlement time, such a time can be artificially put forward or back, in order to perform "what if" analyses under different distributions of payment delays. Agents can also by partitioned into two groups, the first composed by payers who do not tend to delay too much, the other containing those who pay later. In a first exercise the system has been tested with payment data corresponding to an entire day of activity in March 2008 on the Italian RTGS system, with around 50 banks regulating directly their payments (the system is tiered so that the smaller banks participate only indirectly in the system). The model produces a rich set of output datasets enabling the analyst to trace all that has happened throughout the simulation time and perform the model validation (Windrum *et al.*, 2007). The following figure 1 shows the patterns of the cumulated

[1]Python is an easy to learn dynamic object-oriented programming language that enables many kinds of software development. It also provides strong support for integration with other languages and tools and is also endowed with extensive standard libraries. Transparency is the main attractive feature of its coding structure (Python official web site, 2008).

amount of payments settled during the simulated day, together with the corresponding cumulated overall liquidity borrowed on the monetary market.

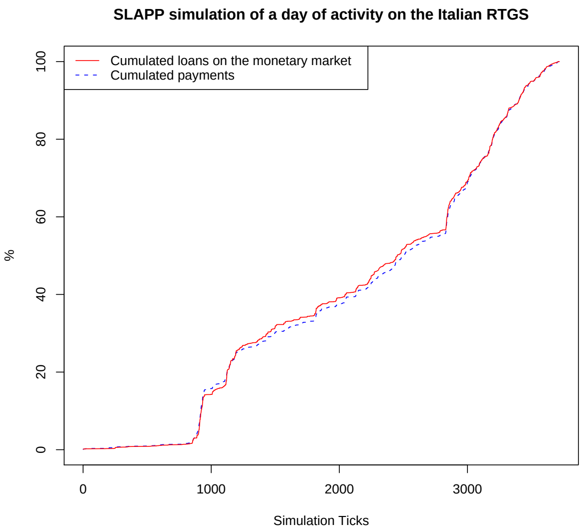

Figure 1: SLAPP simulation of a day of activity on the Italian RTGS system. Cumulated percentage amounts of payments (blue dashed line) and monetary market loans (red line).

The first indicator is a kind of throughput rate of the system (Markose *et al.*, 2006). In this simple scenario, the agents are settling payments and lending/borrowing liquidity with similar frequency, although we do not know what fraction of the payments are covered by loans. A heavy utilisation of the money market might be a clue of stress in the system: a possible indicator for that is the ratio between cumulated loan and payment amounts (see also Galbiati and Soramaki, 2008). This last indicator is shown in figure 2, where we can see that the percentage of the payment amounts settled through loans is quite stable around a mean value of 48.5 percent after a more variable pattern in the simulation burn-in.

4 A look at the mechanisms regulating payment internal queues

As mentioned before, one of the fundamental parts of the model is represented by the treasurer's decisional process. The aim of the bank is to settle

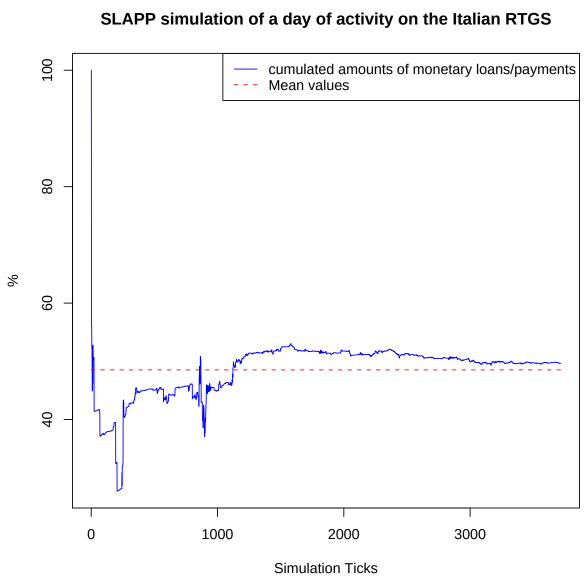

Figure 2: SLAPP simulation of a day of activity on the Italian RTGS system. Ratio between cumulated amounts of monetary market loans and payments.

the requested payments as soon as possible while at the same time controlling the amount of liquidity available. The tuning mechanisms are: the possibility of accessing the monetary market and the rules for scheduling the internal queues. In this section, we show some aggregate evidence of the actual scheduling rule based on data collected from a leading Italian bank. The data correspond to three working days, selected so as to constitute a relatively homogeneous sample. For each payment included in the dataset, information on origin, settlement time, the amount and typology area is available.

In a typical day a treasurer usually manages a huge number payments of small size and a relative small number of large amounts. However, these few transactions represent the bulk of the total amount, with the first quantile corresponding to 62% of the total volume, for instance.

The treasurers tend to stack the incoming payment requests and to release them once their number exceeds a certain threshold. Hence the major part of the requests is settled in few time-frames, rather than continuously in time. Figure 3 shows the time distribution of the number of settled payment in the three days.

We also can gather from the same graph that a such queuing policy produces time-frames in which payments are released that are not evenly spaced during

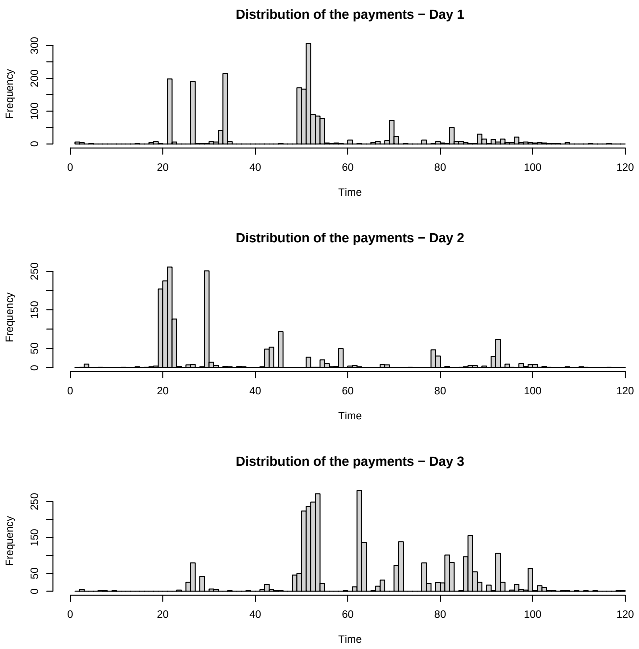

Figure 3: In the panels are plotted the numbers of payments settled in bucket of five minutes in three different days.

the day, since their actual time location can also depend on some payment that cannot be deferred. Figure 4, featuring the time distribution of incoming and settled payments, provides a clearer insight of the decisional rule.

The large part of payment requests arrives in the first part of the day and is also settled in large batches before the afternoon, without taking into account the consequence of possible delays. On the contrary, payment requests arriving in the evening are settled more quickly, mainly because of the constraint that they should be settled before the 6 p.m. deadline.
If the simulation uses real payment requests, they also include their actual settlement time, whereas the time when the treasurer becomes aware of their existence is unknown. In this preliminary version of the model this critical piece of information is therefore imputed by subtracting from the settlement time a random delay, drawn from an uniform distribution.
In a future development, the time of the arrival of the payment request will be generated more akin to the empirical evidence: the delay will be

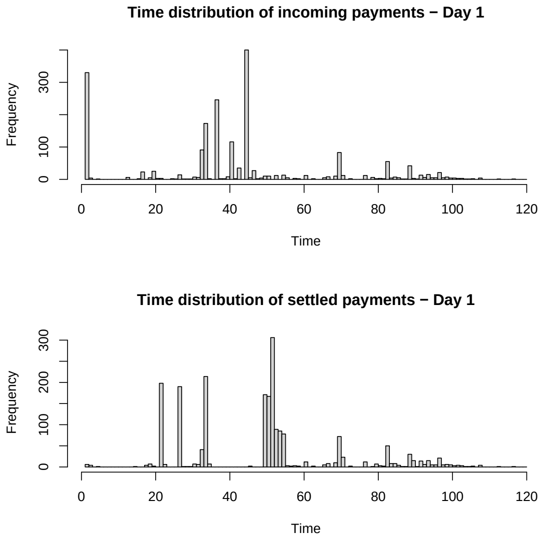

Figure 4: Top panel: time distribution of the payments entered in the internal queued. Bottom panel: time distribution of the payments settled. Time span 120 buckets of five minutes

approximated by a finite mixture of truncated normal distribution[2]. This choice is justified by the natural ability of the finite mixture of adapting to multimodality, a peculiar characteristic of the empirical delay distribution.

Figure 5 shows a good fit, even if we remark that this complex modelling is just an intermediate step. The final aim is to collect the treasurer's behavioural rules in a structural model that connects settled payments to some exogenous variables such as incoming payment requests, needed and available liquidity and total amount of payments to be settled, so that the delay will no longer be an exogenous variable. Elements such as treasurer's expected liquidity and propensity for strategic behaviour in internal queue scheduling, in order to generate profits, will also be encompassed.

[2]The pdf of a finite mixture for the delay Y_t can be define as:

$$f_{Y_t} = \sum_{i=1}^{3} \pi_i f_{X_i},$$

where $X_i \sim TN(\mu_i, \sigma_i)$ is the i^{th} component of the mixture and π_i is the corresponding weight. In our case, the value of vector of parameters is fixed by using a calibration method, but, otherwise, it can be easily estimated with an EM algorithm (Dempster *et al.*, 1978).

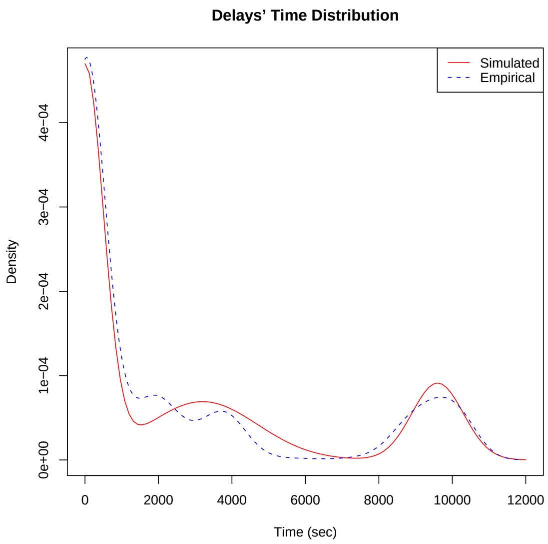

Figure 5: In the graph are plotted the empirical (blue dashed line) and the simulated (red line) time distribution of the delays.

5 Conclusions

The present paper illustrates the utilisation of agent-based modelling for the simulation of payment systems. The main novelty of the approach is the application of the Swarm protocol through the Python language. The flexible programming structure of Python enables the user to create an easily upgradable and extendable model that is presently able to handle large-scale simulation scenarios with hundreds of banks and real streams of payment requests, to be settled through a stylised representation of a RTGS system. The model also features a monetary market as a source of funding for the agents short of the necessary liquidity to face payment obligations. The model is endowed with a rich set of outputs enabling the researcher to perform all the usual efficiency analyses of a payment system and will be extensively enhanced in the current year, with an emphasis on modelling treasurers' behaviours.

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