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Biliana Alexandrova Kabadjova
Andreas Krause
Edward Tsang

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An Agent-Based Model of Interactions in the Payment Card Market*

Biliana Alexandrova Kabadjova[1], Andreas Krause[2] **, and Edward Tsang[1,3]

[1] Centre for Computational Finance and Economic Agents (CCFEA), University of Essex, Wivenhoe Park, Colchester CO4 3SQ, Great Britain, E-Mail: balexa@essex.ac.uk
[2] University of Bath, School of Management, Claverton Down, Bath BA2 7AY, Great Britain, E-Mail: mnsak@bath.ac.uk
[3] Department of Computer Science, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, Great Britain, E-Mail: edward@essex.ac.uk

Summary. We develop an agent-based model of the competition between payment cards by focusing on the interactions between consumers and merchants determining the subscription and usage of cards. We find that after a short period of time the market will be dominated by a small number of cards, even though there might not exist significant differences between cards and the market is fully competitive. In contrast to the existing literature we focus on the dynamics of market shares rather than equilibrium outcomes. Our results are consistent with observations from the market for payment cards.

Key words: Competition, two-sided markets, network externalities, agent-based modeling, multi-homing

1 Introduction

The market for payment cards - more commonly known as credit and debit cards - is dominated by two large competitors, Visa and Mastercard, while the remaining competitors, most notably American Express, Diners Club, Discover and JCB, have a significantly smaller market share. Over the last decade the dominance of the two main competitors has increased with Visa gaining a small advantage over Mastercard through the more widespread use of debit cards issued by Visa. Understanding the dynamics of the competition between payment cards is essential for any potential regulation of this market. In this paper we present a novel approach to modeling this

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** Corresponding author.

market for payment cards by using an agent-based approach focusing on the behavior of card holders and merchants rather than direct competition between payment cards via their fee structure.

The payment card market is a two-sided market in which for a successful transaction involving a card both participants have to hold the card (buyer/consumer) and accept the card as payment (seller/merchant), respectively. The benefits from holding (accepting) a specific card obviously depend on how often the card can be used. The more merchants (consumers) accept (hold) the card, the larger the benefits to the customer (merchant). The existence of these network externalities is an important aspect of the competition between different cards.

The main focus of the literature has for a long time been on the fee structure of payment cards, with the emphasis laid on the interchange fee. The interchange fee is the amount the bank of a merchant pays the bank of the consumer for each transaction with a card. The extensive literature in this field can generally be divided into models with only a single payment card, see e.g [1, 2, 3, 4], and those that allow for competition between payment cards, see e.g. [5, 6].

More recently a growing amount of literature has addressed the problem of multi-homing in payment card markets, i. e. consumers holding or merchants accepting more than one payment card. In this literature it has been shown that unless the costs of doing so are too high or too low, consumers or merchants might subscribe to different payment cards (multi-homing) [7]. Furthermore [8, 9] show that multi-homing is mostly observed by either consumers or merchants and [10] imply that multi-homing of merchants benefits consumers significantly more than the merchants themselves. [11] points out that the compatibility of payment cards is made less likely in the presence of multi-homing.

A common feature of these models is that they investigate equilibrium outcomes but ignore the dynamic paths towards these equilibria. In addition the underlying structure of the competition between merchants to attract consumers is in many cases not captured realistically. To this end we will develop an agent-based model of the payment card market which captures the competition by merchants for consumers as well as the competition between payment cards through decisions for adopting a card by consumers and merchants. Allowing the market to evolve over time we are able to observe the dynamics of our model and determine its properties through computer experiments.

The coming section introduces the basic set-up of the model elements and section 3 then describes the interactions between them. Section 4 evaluates the simulations of our model and section 5 concludes our findings.

2 Model elements

Our model consists of three key elements: merchants, consumers and the payment cards. As the focus will be laid on the interaction between consumers and merchants with the choice which payment cards to hold and accept determining the outcome, we do not consider the interchange fees as a relevant decision variable, but rather treat all fees as exogenously given. A justification for this approach can be deducted from [12] who finds that the degree of competition does not affect the relative fee structure but only the total level of fees.

2.1 Merchants

Suppose we have a set of merchants $\mathcal{M}$ with $|\mathcal{M}| = N_{\mathcal{M}}$ who are offering a homogenous good at a fixed common price and face marginal cost lower than this price. Eliminating price competition between merchants allows us to concentrate on the competition between payment cards and how the card choice affects merchants. The merchants are located at random intersections of a $N \times N$-lattice, where $N^2 \gg N_{\mathcal{M}}$. Let the top and bottom edges as well as the right and left edges of this lattice be connected into a torus.

2.2 Consumers

Consumers occupy all the remaining intersections of the above lattice. The set of consumers is denoted $\mathcal{C}$ with $|\mathcal{C}| = N_{\mathcal{C}}$, where $N_{\mathcal{C}} \gg N_{\mathcal{M}}$ and $N^2 = N_{\mathcal{M}} + N_{\mathcal{C}}$.

Each consumer has a budget constraint that allows him in every time period to buy exactly a single unit of the good offered by the merchants. He will do so only by visiting a single merchant. The utility gained from the consumption of this good exceeds the utility from not buying the good and saving the money for later consumption. In order to obtain the good any consumer $c \in \mathcal{C}$ has to travel to a merchant $m \in \mathcal{M}$, where the distance of this travel is measured by the "Manhattan distance" $d_{c,m}$ between the locations on the lattice; the distance between two adjacent intersections is normalized to unity.

This distance imposes travel costs on consumers which reduces the attractiveness of visiting a merchant. As we will show below, consumers prefer card payments over cash payments. Let us for now assume that when deciding which merchant to visit the consumer has not yet decided which of the cards he holds will be used. In this case the more common payment cards the merchant and the consumer have, $\nu_{c,s}$, the more attractive a merchant becomes. From these deliberations we propose to use a preference function for consumer $c \in \mathcal{C}$ to visit merchant $m \in \mathcal{M}_c$, where $\mathcal{M}_c$ denote the set of merchants a consumer considers to go to:

$$\upsilon_{c,m} = \frac{\frac{\nu_{c,m}}{d_{c,m}}}{\sum_{m' \in \mathcal{M}_c} \frac{\nu_{c,m'}}{d_{c,m'}}}. \tag{1}$$

2.3 Payment cards

There exists a set $\mathcal{P}$ of payment methods with $|\mathcal{P}| = N_{\mathcal{P}} + 1 \ll N_{\mathcal{M}}$. The first payment method is the benchmark and can be interpreted as cash payment while all other payment forms are card payments. In order for a card payment to occur, the consumer as well as the merchant will have to have a subscription to the card in question.

For each unit of the good bought using a payment card, a merchant $m \in \mathcal{M}$ receives net benefits of $\beta_m \geq 0$. These benefits may include reduced costs from cash handling and differ across merchants, but are identical for all cards for a given merchant thus eliminating competition between payment cards arising from differences in benefits they are able to provide. Cash payments do not produce any net benefits.

Consumers also receive benefits from paying by card, but no benefits from cash payments. The benefits may arise from the delayed payment, insurance cover or cash-back options. These benefits consist of two elements, the first of which is common to all cards, but different across consumers $c \in \mathcal{C}$ with a uniform distribution on the range $b_c \in \left[\underline{b}, \overline{b}\right]$, where $0 \leq \underline{b} < \overline{b} < 1$. The second benefit is card specific and varies between consumers; it is also taken from a uniform distribution on the range $b_{c,p} \in \left[0, 1 - \overline{b}\right]$. Thus the total benefits to consumer $c \in \mathcal{C}$ using payment card $p \in \mathcal{P}$ is given by $b^*_{c,p} = b_c + b_{c,p}$. If $\overline{b}$ is close to 1 the payment cards are very homogenous to consumers and thus close substitutes; competition between payment cards will be reduced to their network effects, while for lower $\overline{b}$ the differences in the benefits between payment cards will affect the card choice more prominently. However, no card will have a systematic advantage over another card.

3 Interaction of elements

The three elements of our model are in constant interaction with the payment cards only being passive, while consumers and merchants make active decisions. The decisions by the merchants are limited to the choice of payment cards they subscribe to. The consumers, on the other hand, have to make decisions affecting the subscription to payment cards, which merchant to choose for their purchase and which payment card to use in a transaction.

3.1 Choice of merchant

Each consumer $c \in \mathcal{C}$ chooses a merchant $m \in \mathcal{M}_c$ with probability $\upsilon_{c,m}$ as defined in equation (1). The consumers will continuously update their beliefs on the number of common payments, $\nu_{c,m}$ by observing the number of common payments of all merchants they may visit. We restrict consumers to the five nearest merchants. In the case of several merchants having the same distance from a consumer the merchants are chosen randomly for the length of the experiment.

3.2 Choice of payment card

The consumer decides which payment card he wants to use. We investigate firstly a *random card choice*, in which he presents any of the cards he holds, and the merchants accepts (common cards), with equal probability. Secondly we allow for the *preferred card choice* in which consumers choose the common card which provides them with the highest benefits. If the merchant does not accept any card the consumer holds, the transaction is settled using cash payment.

3.3 Consumer subscriptions

Consumers have in every period of time to decide whether to cancel a subscription to a card they hold and whether to subscribe to new cards. Every consumer $c \in \mathcal{C}$ keeps track whether a card he presented has been accepted or rejected. If card $p \in \mathcal{P}$ has been rejected by the merchant, he increases the score $\omega_{c,p}^{-}$ by one. With ω_c denoting the number of merchants visited, we assume that he cancels his subscription with probability

$$p_{c,p}^{-} = \frac{\exp\left(\frac{\omega_{c,p}^{-}}{\omega_c}\right)}{a + \exp\left(\frac{\omega_{c,p}^{-}}{\omega_c}\right)}, \tag{2}$$

where a accounts for the inertia of consumers to change cards. Similarly on every visit to a merchant he notices that he may accept another card the consumer does not possess, in this case he increases the score of the card he notices, $\omega_{c,p}^{+}$, by one. The probability of subscribing to this card is then given by

$$p_{c,p}^{+} = \frac{\exp\left(\frac{\omega_{c,p}^{+}}{\omega_c}\right)}{a + \exp\left(\frac{\omega_{c,p}^{+}}{\omega_c}\right)}. \tag{3}$$

3.4 Merchant subscriptions

Merchants keep track of all cards presented to them by consumers. Every time a card $p \in \mathcal{P}$ the merchant $m \in \mathcal{M}$ subscribes to is presented he increases the score of $\theta_{m,p}^{-}$ by one; and if he does not subscribe to the card, the score of $\theta_{m,p}^{+}$ is increased by one. He decides to subscribe to a new card with probability

$$\pi_{m,p}^{+} = \frac{\exp\left(\frac{\theta_{m,p}^{+}}{\theta_m}\right)}{\alpha + \exp\left(\frac{\theta_{m,p}^{+}}{\theta_m}\right)}, \tag{4}$$

where θ_m denotes the number of cards presented. Similarly he decides to cancel the subscription of a card with probability

$$\pi_{m,p}^{-} = \frac{\alpha}{\alpha + \exp\left(\frac{\theta_{m,p}^{-}}{\theta_m}\right)}, \tag{5}$$

where α represents the inertia to changes as before.

4 Computer experiments

Using the above model we conducted a number of experiments using the following fixed parameters settings: $N_{\mathcal{C}} = 1100$, $N_{\mathcal{M}} = 125$, $N_{\mathcal{P}} = 9$, $a = 8$, and $\alpha = 15$. We investigated the model over 1000 time periods and looked at the cases of $\underline{b} = 0.1$ and $\overline{b} = 0.2$ (heterogenous cards) as well as $\underline{b} = 0.8$ and $\overline{b} = 0.9$ (homogenous cards). However, as the choice does not depend on the size of the difference between cards in the preferred card choice, the results are not affected by these parameters, an inference which is confirmed in the experiments.

The initial card holdings of consumers and acceptances of merchants are determined randomly and every consumer as well as merchant can conduct a transaction using cash. The ability to conduct cash transactions is maintained throughout. Each consumer and merchant is allocated a random number of cards between zero and nine with equal probability and then obtains each card with equal probability. Thus the initial market share of each payment card is random. We also set $\theta_{m,p}^{-} = \theta_{m,p}^{+} = \omega_{m,p}^{-} = \omega_{m,p}^{+} = 0$.

4.1 Market shares

Our experiments using the above model reveal that the market quickly becomes dominated by a small number of cards. The dominance can be measured in terms of the fraction of transactions conducted using a specific card, figure 1, the fraction of consumers holding the cards as in figure 2 as well as the fraction of merchants accepting it, figure 3. In all cases we see that as a result of the net benefits of cards being positive, they drive out cash transactions nearly completely and only two cards survive in the long run. The figures shown throughout represent typical outcomes of our experiments; no attempts to calculate averages have been made as this would easily invalidate the outcome of individual results through inappropriate averaging.

While with a random card choice the elimination of cards is relatively slow, with preferred card choice it takes considerably less time until a small number of cards dominates with relatively stable market shares. The reason for this observation can be found in the fact that the consumer making preferred choices will continue to use a card consistently as long as he holds it, thus the dominance of cards emerges more quickly as random fluctuations are eliminated.

What we also observe from our experiments is the importance of the initial market share. We observe that those cards with the largest market share in the initial random distribution of cards are those dominating the market over time, with the order maintained. We see furthermore that two or more rarely three cards coexist for a long period of time, where the relative market shares are not changing significantly over time. Three or more cards only survive in cases where the initial market shares are sufficiently identical and large. Figure 4 shows the complete set of graphs for the case of three cards surviving in the market.

We find evidence that very slowly over time only the largest card will survive and thus obtain a monopoly. This process however is very slow and takes considerable time, well beyond the 1000 time periods investigated here. The reason for this very slow development can be found in the multi-homing we consider next.

4.2 Multi-homing

The second important result we obtain from our experiments is that consumers usually only hold a single card as shown in figure 5; only a small fraction of consumers actually hold two cards and only rarely three cards after the market has settled. In contrast to this, a sizable number of merchants accept two or even three cards, even after many time periods have elapsed, see figure 6. The reason for this observation is that merchants serve a large customer basis and thus more easily come into contact with consumers holding different cards, providing incentives for him to accept more than one card to increase their benefits from accepting card payments. This result is very much in agreement with the outcomes of the models in [8, 9] who in a very different setting also suggest that multi-homing will mostly be observed by either consumers or merchants. We find here with the above reasoning that merchants engage much more in multi-homing than consumers.

As we see from figure 7, card usage of any surviving card is concentrated in distinct geographical zones which are generally not overlapping. It are those merchants located nearest to the edges of these zones who accept multiple cards in order to obtain benefits from all consumers wishing to use a card for payment. A small number of cash transactions occur in those cases where the merchant did not accept the card of the consumer. The willingness of merchants to subscribe to multiple cards is responsible for the fact that once the number of cards in the market is reduced to two or three they tend to co-exist for a considerable period of time. It is also not surprising that merchants are subscribing to multiple cards as the large number of transactions they conduct in every time period makes benefits of multi-homing much more important than for consumers. Given the multi-homing of merchants, consumers no longer have an incentive to hold multiple cards.

This result is not in contrast to [10] who find that most of the benefits of multi-homing by merchants goes to consumers. Although consumers obtain the majority of benefits from the multi-homing of merchants by not having to subscribe to multiple cards or relying on non-beneficial cash transactions, the large number of consumers each merchant interacts with, provides him with sizeable benefits of multi-homing. These larger benefits to each individual merchant induces him to subscribe to multiple cards, a situation similar to the production of public goods.

Although the network externalities reduce the number of cards in the market quickly, it is the multi-homing of merchants that prevents a single card from obtaining a monopoly quickly. Thus competition between cards and the subsequent dominance of a single card is limited due to multi-homing.

4.3 Discussion

On first sight the above results on multi-homing seem not to be realistic as undoubtedly a large number of consumers have more than two credit cards in their possession. It has, however, to be noted that this in part refers to cards issued by different financial institutions rather than different card organizations, such as Visa or Mastercard. As any of these cards are accepted equally, we treat them here as a single card in our model. This aggregation of cards in the real world would reduce the number of cards held significantly and make our result much more realistic. Furthermore, [13] finds empirically that although consumers may possess several different cards, they in many cases only use one of these cards regularly, which would be very much in line with the results from our model.

Another source of payment cards are store cards which are only accepted by the issuing store. We excluded such cards from our model as they cannot be used with different merchants and thus do not have the same network effects. They could nevertheless present competition to payment cards.

In light of the above comments we can observe that the results we obtained are at least approximately realistic. Despite a competitive market with cards not differing from each other we observe the coexistence of two or three credit cards dominating the market very quickly, while at least for some time at the beginning of the experiments a number of less important credit cards survives. As this reflects quite well the current market situation noted in the introduction, our model suggest that we should expect even more consolidation of the market in the future.

The parallel existence of two or more cards is equivalent to the equilibrium [14] obtain in their model when the costs of substitution between networks, i.e. changing subscriptions, is low relative to the network externality. Given the multi-homing of merchants the costs for consumers of switching cards is negligible, fulfilling the conditions for this equilibrium. Given the geographical zones it would be on the other hand very costly for merchants to give up either multi-homing close to the boundaries or switch cards within the zones.

The main deviation from reality is the emergence of very distinct geographical zones of card usage which is clearly not replicated in reality. Although differences exist in the market shares of payment cards across countries, they are significantly less pronounced than in our model. [13] finds a correlation between the cards held by consumers and acceptance by merchants, leading to a certain degree of regional concentration of card usage through a local interaction loop, but the regional differences are by no means as distinct as we find in our model.

However, we did only allow consumers to visit the five nearest merchants and ignored any consumers traveling longer distances, e.g. for consumers being on holidays or business journeys. Including such long-distance travel into our model, such as the inclusion of small-world effects in the network structure, might actually change the results of our model and need to be explored in more detail. It is a widely accepted fact that the network topology can have significant impact on the outcomes of any dynamics using its structure. [15] provides an example for the different outcomes of a repeated prisoner's dilemma played on various types of networks and it is reasonable to expect similar differences in our model.

5 Conclusions

We provided an agent-based model of the market for payment cards where the interaction between merchants and consumers drove the decision to subscribe to a payment card and subsequently the market shares. We found that the market quickly becomes dominated by a small number of payment cards operating in distinct geographical markets and multi-homing of merchants emerged.

This novel approach to model the payment card market yielded additional insights into the dynamics of the market which conventional models with their emphasis on equilibrium outcomes cannot provide. It became clear that the multi-homing of merchants enables the survival of a small number of payment cards, despite the presence of network externalities. The emergence of multi-homing prevents the quick appearance of a monopolistic market with only a single card surviving, thus preserving competition between cards.

A large number of extensions can be thought of to improve the model further and make it more realistic. The importance of the information set on which consumers and merchants base their decisions has already been shown in [16]. As was already mentioned above it would further be of interest to evaluate the importance of the network topology for the results in our model. Enabling payment cards to react to changes in their market shares through giving different net benefits to consumers and merchants as an incentive to subscribe to the card and actually use it, might provide further insights into the dynamics of the payment card market.

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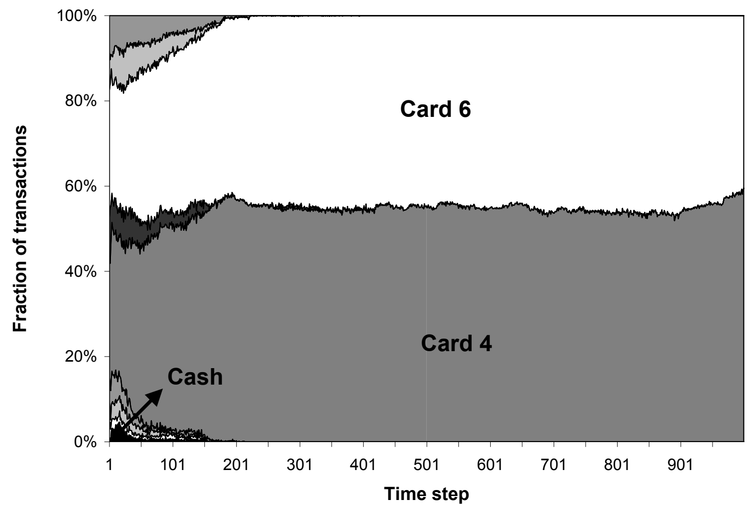
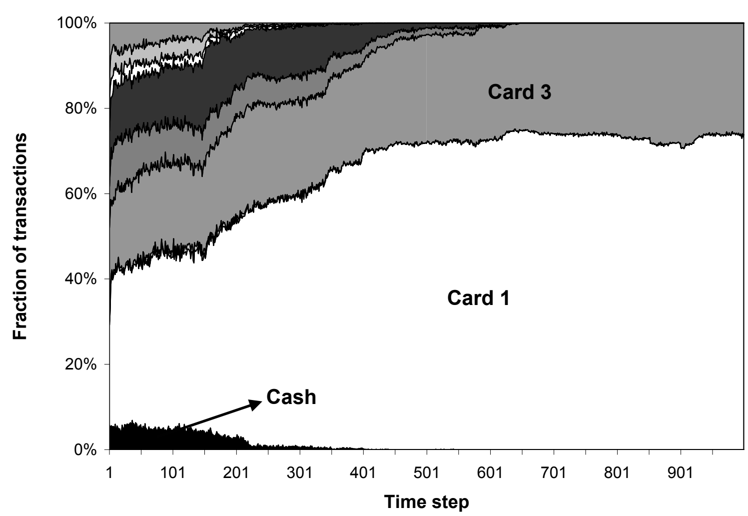
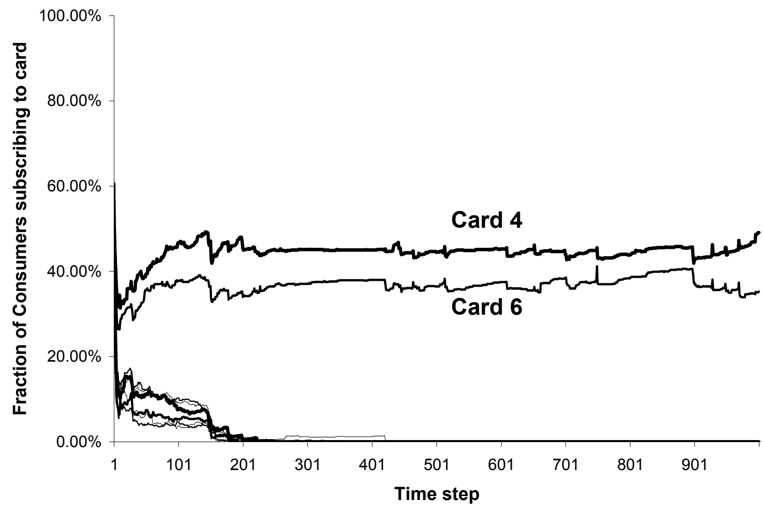


(a) Preferred card choice.



(b) Random card choice.

Fig. 1. Fraction of transactions of each payment method evolving over time for a typical run.



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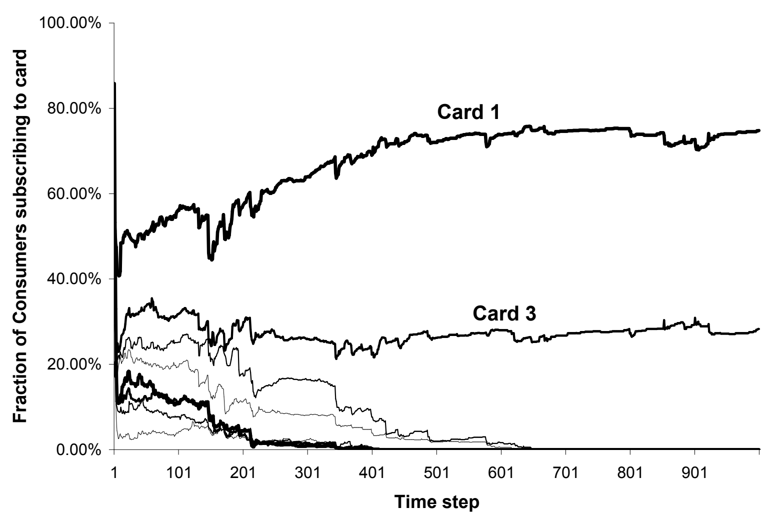
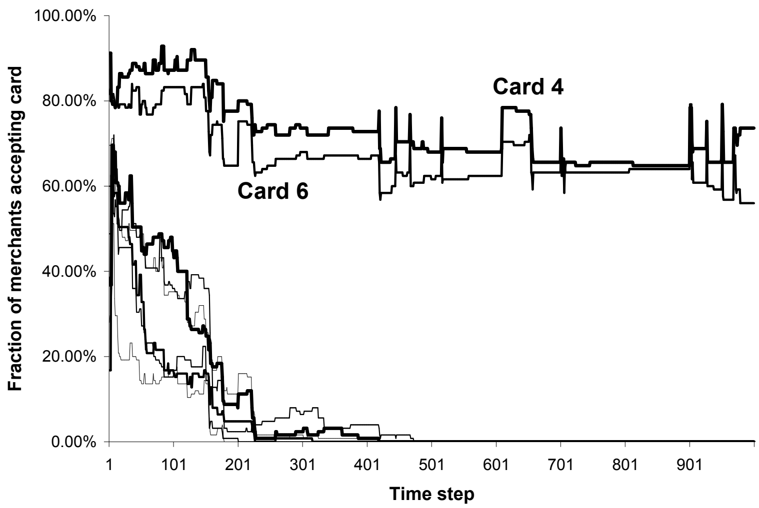
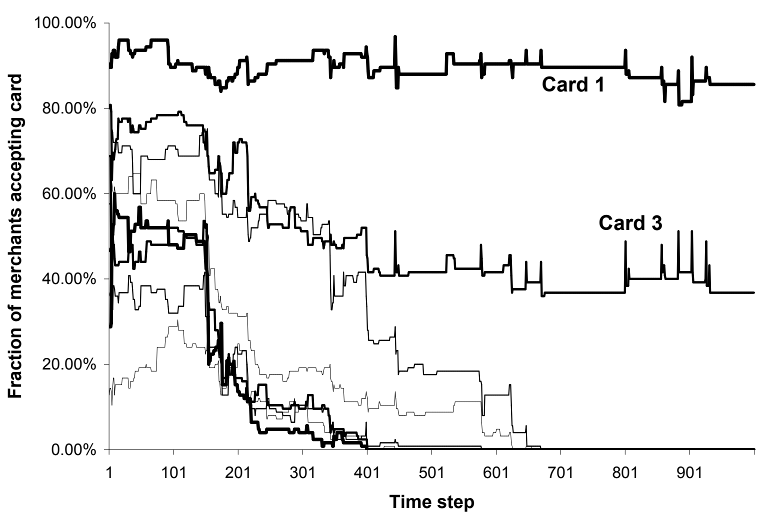


(b) Random card choice.

Fig. 2. Fraction of consumers subscribing to a given card evolving over time for a typical run.

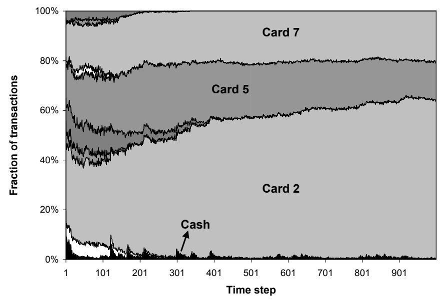


(a) Preferred card choice.

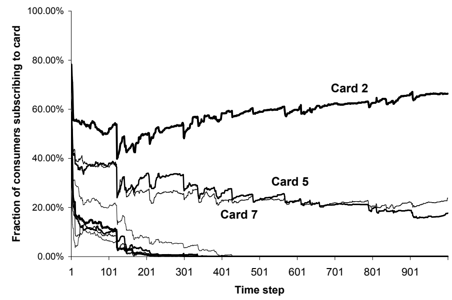


(b) Random card choice.

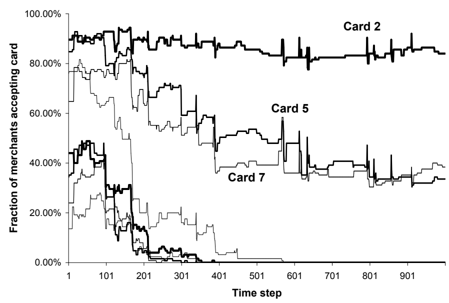
Fig. 3. Fraction of merchants accepting a given card evolving over time for a typical run.



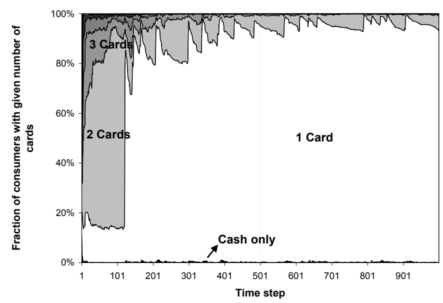
(a) Market share by transactions.



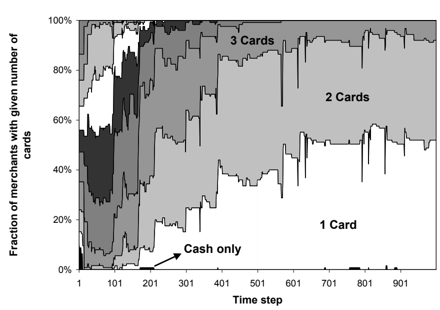
(b) Market share by consumers subscribing to cards.



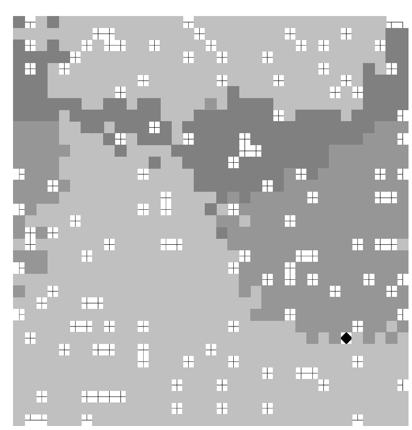
(c) Market share by merchants accepting the cards.



(d) Multi-homing of consumers.

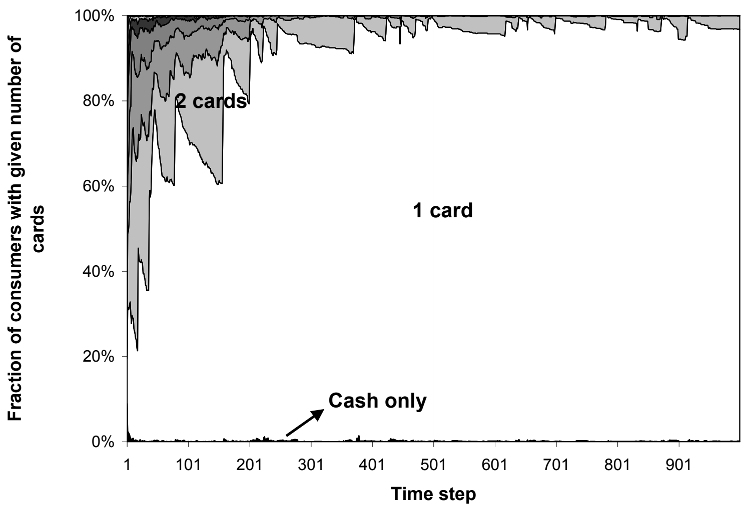


(e) Multi-homing of merchants.

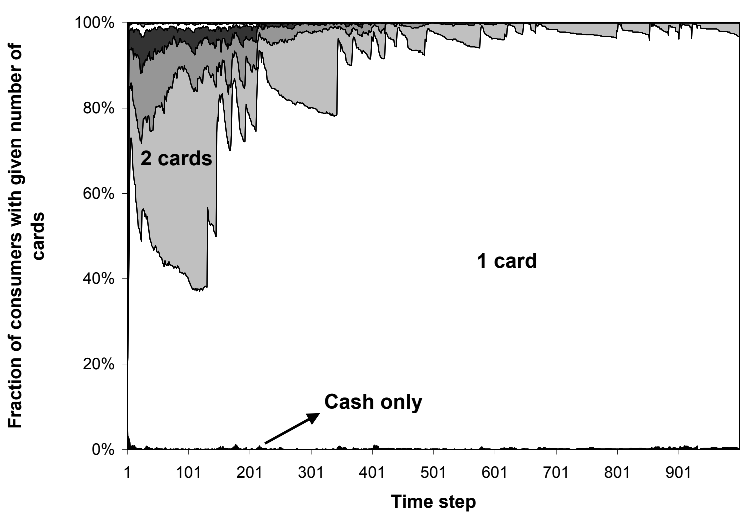


(f) Regional use of payment cards.

Fig. 4. Example of an experiment in which three cards survive.

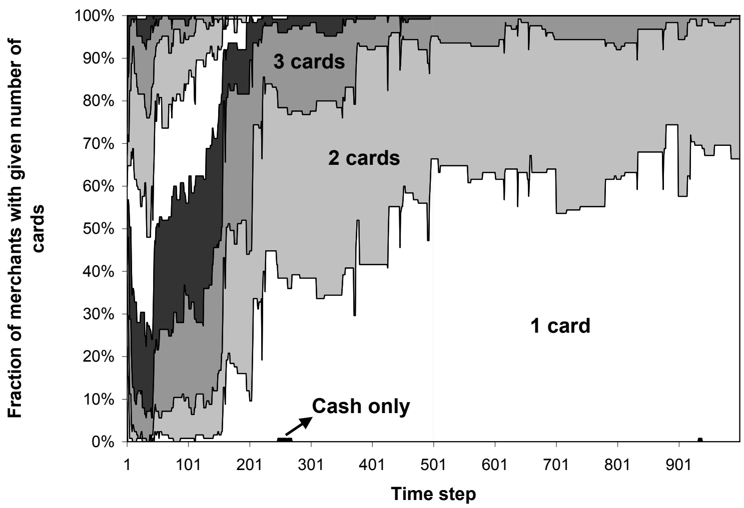


(a) Preferred card choice.

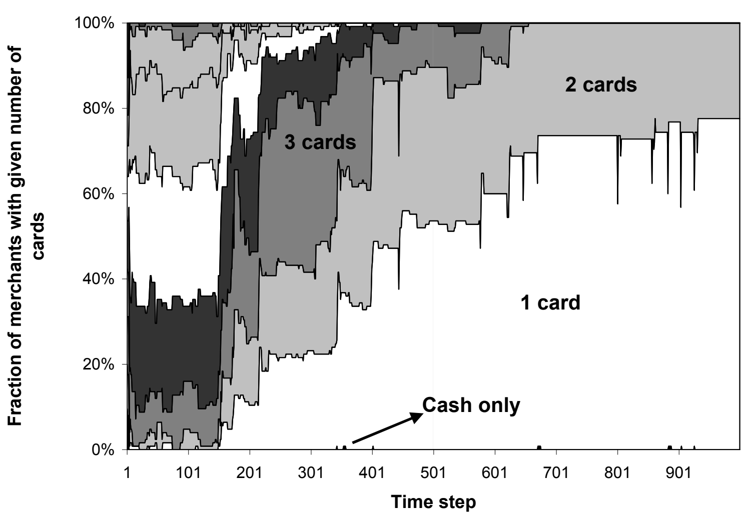


(b) Random card choice.

Fig. 5. Multi-homing of consumers evolving over time for a typical run.

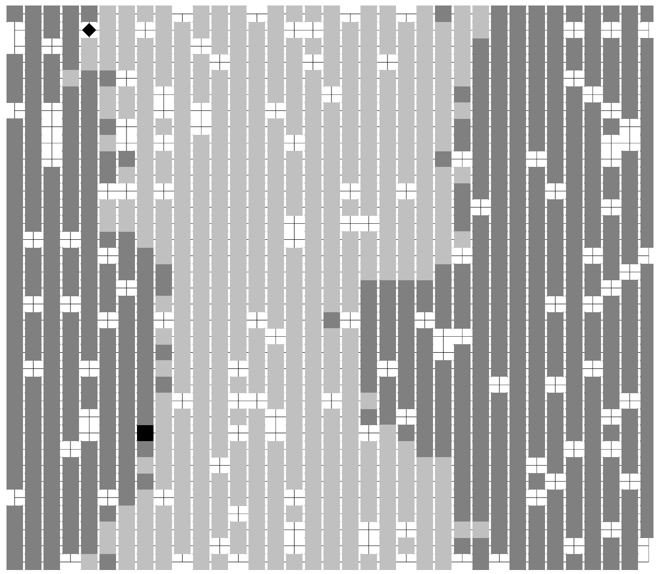


(a) Preferred card choice.



(b) Random card choice.

Fig. 6. Multi-homing of merchants evolving over time for a typical run.



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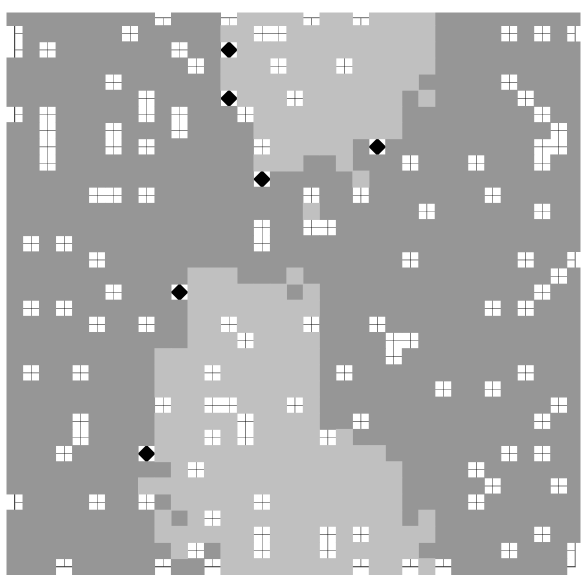

(b) Random card choice.

Fig. 7. Regional use of payment cards by consumers after 1000 time steps. Different colors denote different cards, empty cells the location of merchants and a rhombus the use of cash.