No Risk is Unsafe:
Simulated Results on Dependability of Complementary Currencies

Kenji Saito*
Keio University

Eiichi Morino
Gesell Research Society Japan

Jun Murai
Keio University

Abstract

Efforts have been put for electronization of complementary currencies (alternative forms of monetary media) in the hope that it would reduce their operational cost. However, this paper argues that the problem is more inherent in the core design of MCS[7] (Mutual Credit System), the most common form of complementary currency today. By simulating a small world of 2,500 traders, we show that growing the number of free-riders in MCS has a paradoxical effect of increasing "welfare" (a "happiness" metric) of the community. Since there is no pressure to stop the growth of the bad users, it is difficult to sustain the soundness of the system without strong interventions from the operators of the system; we need alternatives to the alternatives.

We have proposed i-WAT[6] as an electronic descendant of the WAT System[10], a polycentric complementary currency using "WAT tickets" as its media of exchange. A simulation using the same model as above indicates that i-WAT users can sustain barter relationships even in the presence of free-riders by natural evasive actions to avoid risks.

1 Introduction

1.1 Complementary currencies

Economy is an important infrastructure of our world, based on which we can continue our lives and relationships. Yet money, which takes the central role in our daily exchanges, has caused a lot of problems because of its scarcity. *Complementary currencies*, or alternative forms of monetary media, have been proposed and tested around the world to achieve autonomy in the local economy even in short of money. There have been successful cases, such as experiments in Wörgl in 1932 (stamp scrip[8]), in Comox Valley in 1983 (LETS[9]) and in Ithaca since 1991 (Ithaca HOURs[4]). Many of these currencies fall into the category of MCS[7] (Mutual Credit System), in which participants freely credit one another, and the tradings are recorded in a single accounting system (Table 1).

*E-mail: ks91@sfc.wide.ad.jp

Table 1. Classification of currencies

	Centralized	*Not centralized*
Debt-oriented	MCS (LETS, Ithaca HOURs)	WAT, *i*-WAT
Labor-oriented	Stamp scrip	N/A

Many of the outcomes are short-lived, however, because centralized currencies are dependent on the qualities of their administrations. Many experiments owe their successes to their first administrations which are more adequately motivated. It would thus benefit the sustainability of economy if we could design an administration-free monetary system.

We proposed *i*-WAT[6] in year 2003 as such a currency usable on the Internet, based on the WAT System[10]. The WAT System is a real-life, polycentric complementary currency using *WAT tickets* as its media of exchange. A WAT ticket is like a bill of exchange, but without a specified redemption date or place. *i*-WAT implements the tickets electronically by exchanging messages signed in OpenPGP[1]. It has been put into practical use since June 2004.

1.2 Contributions of this paper

This paper quantitatively compares the effects of core designs of MCS, WAT and *i*-WAT currencies in the presence of whitewashers[2], a kind of free-riders who strategically leave and re-join the system with new identities.

In *debt-oriented currencies*, in which creation of an exchange medium implies that someone in the system is in debt (as opposed by the system itself being in debt in *labor-oriented currencies*), free-riding is when that someone manages without repaying the debt. It is so identified only when that someone leaves, because as long as they are in the system, their debt is in the record. Whitewashers re-join the system after free-riding, dealing with which we can investigate the effects of the misbehavior while maintaining the constant population in the system.

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2 MCS: Mutual Credit System

2.1 Concept

An MCS is an accounting system of exchange. When a member joins, the initial balance of their account is set to zero. The system allows negative balance to some extent, and values are transferred between accounts by subtracting an amount at one end and adding the same amount at the other, as two members participate in a trade.

2.2 Implementations

LETS (Local Exchange Trading System) is the most common example of MCS, which does exactly the above.

Many other currency systems can be viewed as different forms of MCS by appropriate transformations without changing their semantics. Ithaca HOURs, for example, issues paper notes of the unit "HOURS" when someone joins the system, which can be circulated within the region. This is transformed into an MCS by setting up a virtual account for each person involved in circulation of the notes, subtracting the amount which is worth the HOURS from the balance of the first person, and then transferring the amount to the accounts of those who are involved one by one.

2.3 Safety and risks

Theoretically, all accounts sum to zero in an MCS, which can be defined as the safety property of the system. However, maintaining this in practice is problematic.

If one has a deficit on one's account in an MCS, the debt is owed to the rest of the members[3]. Therefore everyone shares the same averaged level of risks that the debt remains unpaid, which may lead to their indifference to the risks.

Sometimes, the expectation of the loss is compensated in the forms of maintenance fees, deposits or demurrages.

3 WAT/*i*-WAT currency system

3.1 The WAT System

3.1.1 Overview

The WAT System[10] is a complementary currency, in which a *WAT ticket*, a physical sheet of paper resembling a bill of exchange, is used as the medium of exchange. A lifecycle of a WAT ticket involves three stages of trading (or the *WAT Core*) as illustrated in Figure 1:

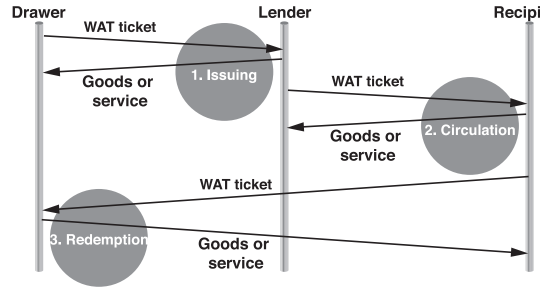

Figure 1. The WAT Core

Issuing A *drawer* issues a WAT ticket by writing on an empty form the name of the provider (*lender*) of the goods or service, the amount of debt, the present date, and the drawer's signature. The drawer gives the ticket to the lender, and in return obtains some goods or service.

Circulation The person to whom the WAT ticket was given can become a *user*, and use it for another trading. To do so, the user writes the name of the recipient, as well as their own, on the reverse side of the ticket. The recipient will become a new user, repeating which the WAT ticket circulates among people.

Redemption The WAT ticket is invalidated when it returns to the drawer.

3.1.2 Security

In case the drawer fails to meet their promise on the ticket, the lender assumes the responsibility for the debt. If the lender fails, the next user takes over. The responsibility follows the chain of endorsements (*security rule*). The longer the chain is, the more firmly backed up the ticket is.

3.2 *i*-WAT: the Internet WAT System

3.2.1 Overview

i-WAT is a translation of the WAT Core onto the Internet. In *i*-WAT, messages signed in OpenPGP (*i-WAT messages*) are used to implement transfers of an electronic WAT ticket (*i-WAT ticket*). An *i*-WAT ticket contains a unique number, amount of debt and public key user IDs of the drawer, users and recipients. Endorsements are realized by nesting PGP signatures over canonical XML expressions.

3.2.2 Changes from the WAT System

Upon translating the WAT Core onto the digital network, we have made the following changes from the state machine of a WAT ticket: 1) Trades need to be asynchronously performed. Intermediate states, such as waiting for acceptance or approval, are introduced, and 2) Double-spending needs to be prohibited. The drawer is made responsible for guaranteeing that the circulating ticket is not a fraud. This means that every trade has to be approved by the drawer of the involved ticket.

The semantics of this design and the trust model of *i*-WAT are discussed in detail in [6].

3.3 Safety and risks

The safety property of WAT/*i*-WAT is that the debt does not disappear without redemption.

There are apparent risks for a participant that the drawers of the acquired tickets go bankrupt, and by the security rule of the system, the debts are transferred up to the participant in question. This risk for a ticket is expressed as an expected cost C_n for the nth receiver of the ticket, where the probability of the drawer going bankrupt is p_0, that for the ith receiver is p_i, the cost of regaining trust after going bankrupt is CT_i, and the value of the ticket in concern is V:

$$C_n = (V \times (1 - p_n) + CT_n \times p_n) \times \prod_{i=0}^{n-1} p_i$$

To minimize this cost, some evasive actions are possible:

EV1 (elimination) Always try to use a ticket the partner has drawn if there is one, thus making sure that a ticket is eliminated whenever there is a chance.

EV2 (stretch) Always try to receive a ticket whose chain of endorsement is longer than those of others, thus making sure that n is reasonably large.

EV3 (matchmaking) Prefer selecting a partner from the drawers of acquired tickets, thus increasing the chance of eliminating a ticket.

4 Simulation model

4.1 The world

The world consists of a set of participants U such that $|U| = 2500$, set of materials (of equal values) M such that $|M| = 100$, and a manufacturer function f such that $f : U \mapsto M$. The manufacturers are evenly distributed, and approximately equal number of participants $u \in U$ manufacture a material $m \in M$, which they can trade with others.

The participants form a network $<U, K>$ where K is an acquaintance relation such that $K \subset U \times U$. It is assumed that the relation is symmetric: xKy always implies yKx. Initially, the population forms a scale-free network, whose properties are shown in Table 2.

Table 2. Initial properties of the small world

Number of unreachable pairs	0
Mean distance (in hops)	4.18
Maximum distance (in hops)	7

Table 3. Common parameters

Maximum debt	10.0
Maximum active trades per round	3
Production rate pr_m for all $m \in M$	3.0
Consumption rate cr_m for all $m \in M$	0.1
Probability to search the 2nd hop for a partner	0.2

Time is abstracted as a series of rounds. There is a special variable t of type integer to denote a round.

4.2 Production and consumption

The amount of material m owned by participant u at time t is denoted as R_t^{mu}. It is defined that u is satisfied with m at time t if $R_t^{mu} \geq 1.0$. Each material can have its own production and consumption rates, denoted as pr_m and cr_m, respectively. But for the purpose of this paper, these are one set of constants as shown in Table 3.

The initial amount (as it may vary during the round) R'^{mu}_{t+1} for time $t + 1$ is calculated as follows:

$$R'^{mu}_{t+1} = R_t^{mu} \times (1.0 - cr_m) + Z$$

where $Z = pr_m$ if $f(u) = m$, and $Z = 0$ otherwise.

4.3 Currencies

Currencies are valued by the amount of materials.

Each participant u has an account in an MCS, whose balance at time t is denoted as B_t^u.

Every participant u can use WAT/*i*-WAT currencies. A_t^u is the set of tickets u has acquired by time t, and D_t^u is the set of tickets u has drawn by time t. Every ticket $k \in A_t^u$ or $k \in D_t^u$ is considered to be a sequence of endorsers, where the drawer and lender are denoted as k_0 and k_1, respectively. Thus for every $k \in D_t^u$, it holds that $k_0 = u$.

4.4 Welfare

Welfare W_t^u is a value representing how well the participant u has spent their lives in the world up to time t.

$$W_t^u = \sum_{i=1}^{t} \sum_{m \in M} min(R_i^{mu}, 1.0)$$

The goals of the currencies are twofold: 1) to maximize the welfare of participants, and 2) to minimize the variability in the distribution of welfare in the world.

4.5 Balance

Balance $B_t'^u$ is a value representing the purchasing power of the participant u at time t. Each participant can purchase materials as long as their debt (negative part of the balance) does not exceed the predefined maximum value.

$$B_t'^u = \sum_{a \in A_t^u} value(a) - \sum_{d \in D_t^u} value(d) + B_t^u$$

For the purpose of this paper, uses of MCS accounts and WAT/*i*-WAT tickets are mutually exclusive.

4.6 Trades

An *active trade* is to purchase 1.0 of a partner's manufactured material. The condition for a successful trade for a participant u and their partner u' is $R_t^{mu'} \geq 1.0 \wedge R_t^{mu} < 1.0$ where $f(u') = m$. The maximum number of active trades allowed to a participant in a round is predefined.

A *passive trade* is to vend a material by the request of a partner. There is no limit in the number of passive trades.

4.7 Bankruptcy

At the end of a round, a participant may go bankrupt if their debt is equal to or greater than the limit, by a predefined probability p. This probability is called *bankruptcy rate* throughout this paper, but the actual probability p' for any participant to go bankrupt during a simulation is dependent on the probability p'' for their debt to reach the limit.

$$p' = 1 - \prod_{i=1}^{t} (1 - p \times p'')$$

The procedure for a bankruptcy of a participant u at time t is as follows: 1) Remove all (u, x) and (x, u) from the acquaintance relation K, 2) Add (u, x) and (x, u) to K for a random partner x, 3) Set $B_t^u = 0$ (the debt becomes inaccessible), 4) Empty D_u after adding k to D_x for all $k \in D_u$ and $x = k_1$, and remove u from k (the security rule), and 5) Empty A_u after removing k from D_x for all $k \in A_u$ and $x = k_0$ (treated as redemption).

In other words, u resets their relationships with others, and starts again.

5 Simulation scenarios and results

5.1 Mass-market MCS

5.1.1 Mass-market partnership

Participants choose their partners randomly from the whole population. The acquaintance relation K is not altered.

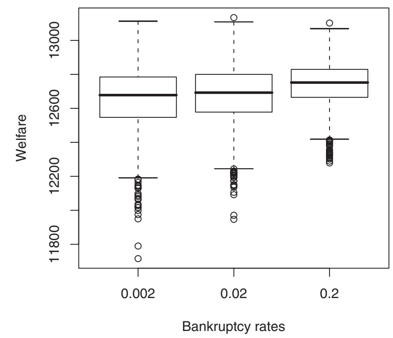

Figure 2. Mass-market MCS

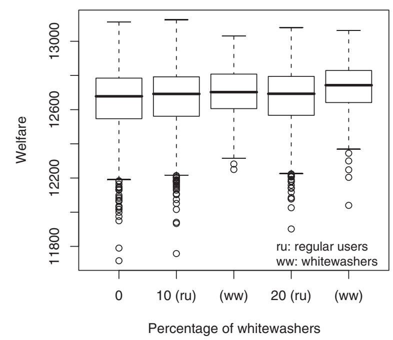

Figure 3. Mass-market MCS w/ whitewashers

5.1.2 Welfare distributions and bankruptcy rates

Figure 2 shows box-and-whisker plots of the welfare distributions after 500 rounds in the simulated mass-market MCS with different bankruptcy rates. A box-and-whisker plot shows the median as a thick line, and a box is drawn around them to cover first and third quartiles. Small circles represent values that are extreme.

The plots show that although the upper extreme gets lowered as the bankruptcy rate grows, the median welfare increases and the variability decreases, suggesting that the currency gets closer to achieving its goals. This paradoxical result is explained by a consequence of bankruptcies (and re-joining the system); the participants regain the purchasing power that they were deprived of. This new supply of currency while the population remains constant indicates that they share higher level of debt than before, but the fact is not obvious because their welfare increases.

5.1.3 Welfare distributions with whitewashers

Whitewashers are represented as a group which has higher bankruptcy rate (0.2) than that of regular users (0.002).

Figure 3 shows box-and-whisker plots of the welfare distributions in the simulated mass-market MCS with different

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ratios of whitewashers to the whole population.

The plots show that whitewashers are always at better welfare levels, and having more whitewashers has slightly better effects on the welfare of regular users; this indicates that there is no pressure within the system to stop the increasing number of bad users.

5.2 Small-world MCS

5.2.1 Small-world partnership

A mass-market MCS is costly to operate because participants need to be provided information on the whole population to search for their prospective partners. Once a partner is found, there is also a difficulty in communicating with someone they do not know. Partners should be more easily found among one's acquaintances.

In *small-world partnership*, participant u chooses their partner randomly from $\{x|(u,x) \in K\}$ in most cases, or from $\{x|(u,z) \in K \wedge (z,x) \in K\}$ by a predefined probability. In the latter case, (u,x) and (x,u) are added to K if the trade was successful and they are not already in K; the number of prospective partners increases as they continuously participate in trades.

We have discovered that there is a positive correlation between the number of trade partners and resulted welfare, which can be used to punish whitewashers in a small-world MCS; they need to start again with a small set of prospective partners every time they go bankrupt, and their levels of welfare are predicted to be less than those of regular users.

5.2.2 Welfare distributions and bankruptcy rates

Figure 4 shows box-and-whisker plots of the welfare distributions in the simulated small-world MCS with different bankruptcy rates.

The plots show that although there are more participants with lower levels of welfare as the bankruptcy rate grows, the median welfare still increases.

5.2.3 Welfare distributions with whitewashers

Figure 5 shows box-and-whisker plots of the welfare distributions in the simulated small-world MCS with different ratios of whitewashers to the whole population.

The plots indicate that the punishment is in working for whitewashers, but the regular users may still be indifferent to the increasing number of bad users.

5.3 The WAT System

5.3.1 Preconditions

Participants choose their partners by small-world partnership, and all evasive actions (EV1∼3) are implemented.

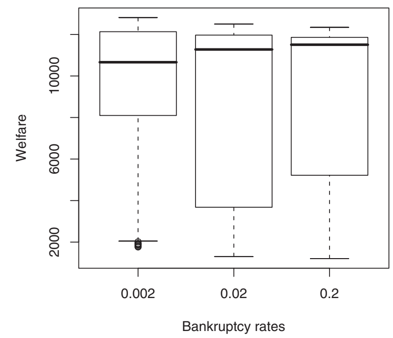


Figure 4. Small-world MCS

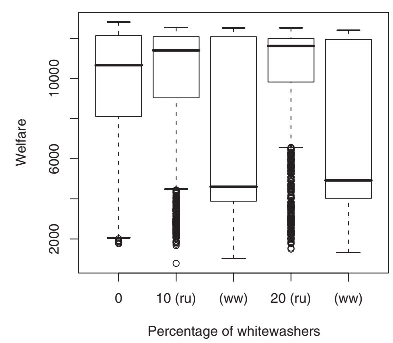


Figure 5. Small-world MCS w/ whitewashers

5.3.2 Welfare distributions and bankruptcy rates

Figure 6 shows box-and-whisker plots of the welfare distributions in the simulated WAT System with different bankruptcy rates.

The plots show that the distribution of welfare drastically changes as the bankruptcy rate grows, which is attributed to the security rule where everyone has a chance of taking over the past partners' debt.

5.3.3 Welfare distributions with whitewashers

Figure 7 shows box-and-whisker plots of the welfare distributions in the simulated WAT System with different ratios of whitewashers to the whole population.

The plots indicate that regular users are slightly affected by the growing number of whitewashers.

5.4 Comparative study on *i*-WAT

5.4.1 Preconditions

A participant u chooses their partner u' by small-world partnership. If the trade was successful with a ticket k and $(k_0, u') \notin K$, then (k_0, u') and (u', k_0) are added to K.

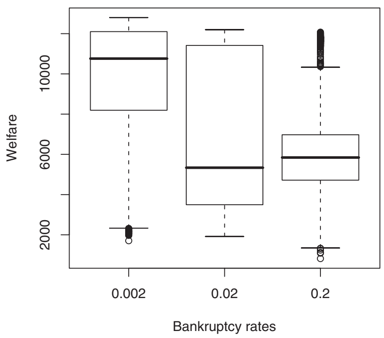


Figure 6. The WAT System

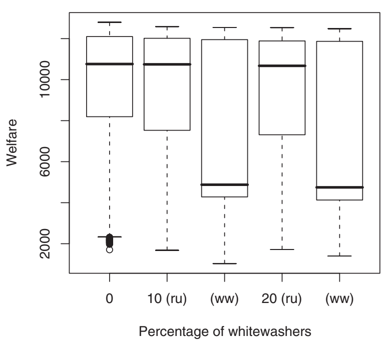
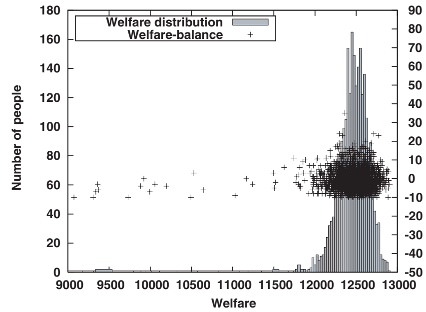
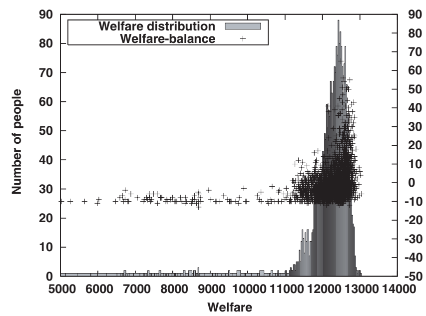


Figure 7. The WAT System with whitewashers



	i-WAT users	*Placebo users*
Mean welfare	12461	12403
Median welfare	12487	12537
SIQR	113.5	175.6
Bankruptcy	28	62

Figure 8. *i*-WAT (bankruptcy rate: 0.002)



	i-WAT users	*Placebo users*
Mean welfare	12153	12175
Median welfare	12331	12393
SIQR	248.5	286.3
Bankruptcy	124	125

Figure 9. *i*-WAT without evasive actions (1)

This is to be compatible with the semantics of *i*-WAT trust model, in which the drawers of tickets are always responsible for validating trades.

Every simulation is compared with *placebo* cases where instead of adding the drawer k_0, a randomly chosen participant is added to the set of the receiver's acquaintances; this makes the effectiveness of *i*-WAT trust model independently measurable from the effects of growing population.

5.4.2 Base results

Figure 8 shows the welfare distribution and the scatter plot of welfare-balance in the simulated *i*-WAT with the bankruptcy rate of 0.002. The scatter plot shows that purchasing power is not affected by the level of welfare for majority of participants.

Figure 9 shows the plots for the same settings, but without evasive actions; they select the tickets to use on a first-in, first-out basis. The scatter plot shows a slight positive correlation between welfare and purchasing power. Evasive actions seem to have an effect of removing the correlation.

Figure 10 shows what happens if the bankruptcy rate is raised to 0.02 while the evasive actions remain uninstalled.

5.4.3 EV1 (elimination)

Figure 11 shows the effect of EV1 (elimination), which is added to the previous settings.

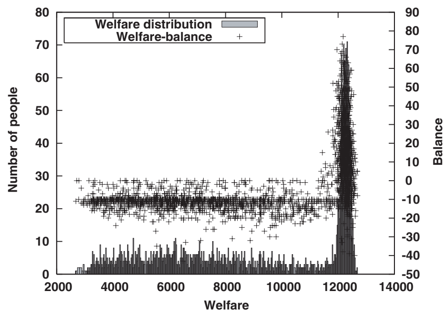
Comparison with the placebo case indicates that this action is particularly effective with the *i*-WAT trust model.

5.4.4 EV1 + EV2 (stretch)

Figure 12 shows the effect of EV2 (stretch), which is added to the previous settings.

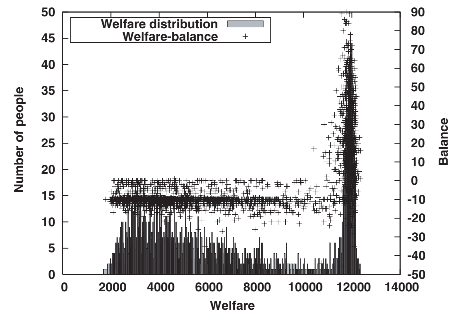
The plots show that this action is only a local optimization (because the participants *are* exposed to more risks without it), and it has an overall negative effects on welfare, its distribution and the number of bankruptcies. It is even more so for real *i*-WAT than the placebo case.

This should be attributed to the tendency that redemption is deferred, which makes the participants stay longer in the state of being in heavy debt.



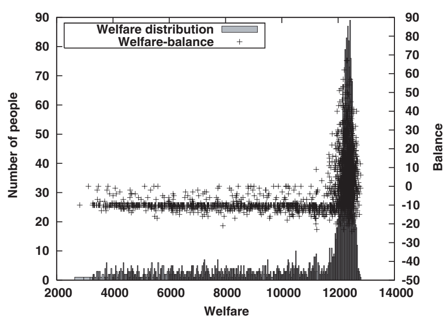
	i-WAT users	*Placebo users*
Mean welfare	9259	9437
Median welfare	10080	10692
SIQR	2957.9	2942.3
Bankruptcy	7616	7881

Figure 10. *i*-WAT without evasive actions (2)



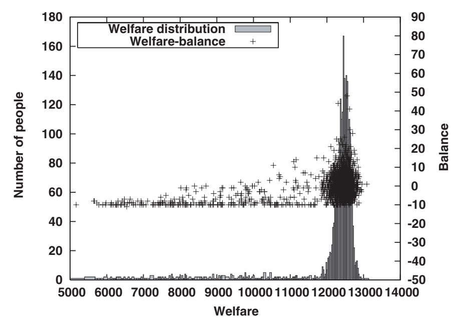
	i-WAT users	*Placebo users*
Mean welfare	7142	9462
Median welfare	6119	10723
SIQR	3900.0	2932.6
Bankruptcy	11046	7692

Figure 12. *i*-WAT with EV1 and EV2



	i-WAT users	*Placebo users*
Mean welfare	10704	9448
Median welfare	12169	10986
SIQR	1424.4	2933.3
Bankruptcy	4308	7884

Figure 11. *i*-WAT with EV1



	i-WAT users	*Placebo users*
Mean welfare	12105	11536
Median welfare	12456	12470
SIQR	139.6	238.8
Bankruptcy	916	2390

Figure 13. *i*-WAT with EV1, EV2 and EV3

5.4.5 EV1 + EV2 + EV3 (matchmaking)

Figure 13 shows the effect of EV3 (matchmaking).

Adding this action has a positive impact overall, especially with the *i*-WAT trust model.

5.4.6 Effects in total

Figure 14 and Figure 15 show box-and-whisker plots of the welfare distributions in the simulated *i*-WAT with different bankruptcy rates and with different ratios of whitewashers to the whole population, respectively.

i-WAT shows very small variability for the majority of regular users, and they are slightly affected when the number of whitewashers grows.

Figure 16 shows box-and-whisker plots of the welfare distributions in the simulated *i*-WAT with and without evasive actions, and with different ratios of whitewashers to the whole population. Those plots show regular users only.

The plots indicate that those evasive actions out of self-interest can contribute to decreasing the number of bankruptcies and raising the overall welfare.

6 Discussion

Part of this work can be seen as a confirmation by a computational method of what R. Douthwaite said[3]: "... the whole weakness of a LETS system is that nobody ever specifies how quickly you're going to repay that debt back to the group and nobody ever chases you."

WAT/*i*-WAT do not specify the timing of redemption either, but two out of three evasive actions investigated in this work has a direct effect of accelerating redemptions. This acceleration is spontaneously enforced out of self-interest of the participants.

Some may question how drawing tickets can be regulated while WAT/*i*-WAT are totally decentralized, and how people would receive such risky tickets in the first place.

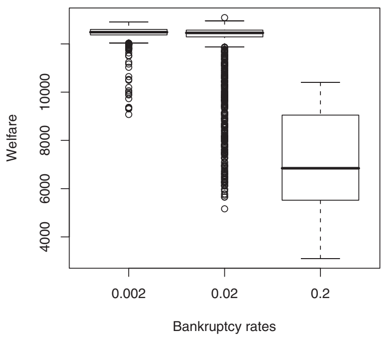


Figure 14. ***i*-WAT**

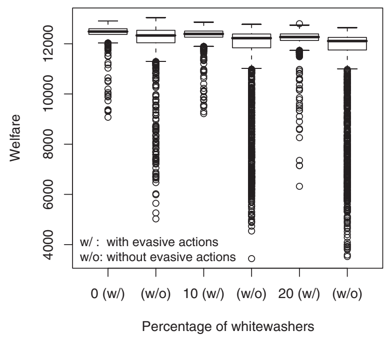


Figure 16. ***i*-WAT with whitewashers (2)**

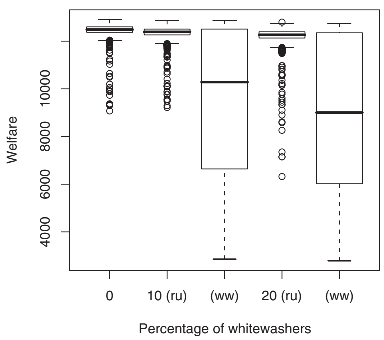


Figure 15. ***i*-WAT with whitewashers (1)**

To answer the former question, a distributed query method to achieve the regulation is discussed in [5]. For the latter question, WAT/*i*-WAT has already been in practical use, and we are to further deploy the currency systems in real life.

7 Conclusions

This paper quantitatively compared the effects of core designs of MCS, WAT and *i*-WAT currency systems in the presence of whitewashers by simulations.

We showed that the design of MCS is especially problematic in the case participants can freely choose their trade partners from the whole population. Although choosing partners within one's own network of acquaintances has an effect of punishing those who try to exploit the system by whitewashing, other users may remain indifferent to the growth of such bad users.

The security rule of the WAT/*i*-WAT makes the risks apparent to the participants, motivating them for evasive actions out of self-interest which has positive effects to the community.

We showed that linkage with drawers, introduced for detection of double-spending in *i*-WAT, has also positive overall effects to the community.

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