A blockchain application to the management of local complementary currencies

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Abstract

This paper proposes a theoretical setting to analyze the possibility of implementing a blockchain governance to local complementary currencies. The local currency that we capture is used to promote objectives such as short distribution channels, high quality products, and sustainable behaviors at the local level. Its viability relies on the ability of shops to support their involvement in the advantages derived from the use of the currency, on the interest of consumers in said advantages, and on the cost of the governance method used. The blockchain solution appears to be suitable in this specific setting that requires a substantial level of security and reproducibility. The model includes a control by the issuer or administrator of the currency of the advantages perceived by heterogeneous consumers. It also integrates the specifications of the blockchain (rewards of miners in a Proof-of-Work protocol, number of transactions per block) and their cost for the collectivity. Analytical results evaluate the conditions of sustainability of the system and numerical simulations from the model illustrate the diverse specifications of the trade-offs between the costs and advantages of such system for the population.

JEL Classification: E42, D91, L86, O31

Keywords: community currency, digitization, heterogeneous agents, payment system

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1. Introduction

Consumers' interests in environmental issues and short distribution channels have significantly developed since the 2010s. Food quality and product traceability are growing consumer concerns, along with the desire to limit the carbon footprint. However, despite the many food labels (organic, local produce, *etc...*) that exist, the average consumer is not capable of discerning the difference between the labels, let alone understand truly what each label means (Anstine 2007; Dahl 2010; Roitner-Schobesberger, Darnhofer, Somsook, and Vogl 2008). In particular, there is a growing tendency to propose organic products that come from usually very far away from their selling point. A local complementary currency which is used alongside the legal tender can be used as a signalling tool for 'quality goods' that are produced in a sustainable way and close to the consumption point. It does so by only allowing merchants who respect the quality charter of the currency, to reconvert their local currency into legal tender.

The security aspect of the local currency is ensured by the blockchain, which is also known as the mainstream technology behind crypto-currencies. The blockchain provides an impeccable level of security and traceability for transactions, and is designed to function in a decentralized way. Although its first applications are for crypto-currencies, the blockchain has developed beyond the financial sphere, and is now being used to improve the processes in multiple sectors including supply chain (Min 2019; Saberi, Kouhizadeh, Sarkis, and Shen 2019). In the case of alimentary supply chain, problems stemming from the traditional supply chain model which include the lack of information on the origins of products for consumers, call for alternative solutions like the governance of the food supply chain via blockchain (Casado-Vara, Prieto, De la Prieta, and Corchado 2018). In the same perspective, a local currency coupled with the blockchain can be used to signal the quality of products via their incentives system and highly secure technology. The issue of volatility does not exist in our case since the rate of exchange is one-to-one with legal tender, similar to some crypto-currencies that are pegged to the U.S. dollar (stablecoins) such as Tether (USDT) and USD Coin (USDC)[1]. We propose a model encompassing the interactions among consumers, shopkeepers, validators of the transactions (miners) in local complementary currency, and an administration of the system, studying the way of activation of such a local system of diffusion of 'quality products'. This theoretical model is followed by numerical simulations mimicking different scenarios of development of these interactions, in which the blockchain is used to govern a local currency system, or a network of local currencies across a number of cities.

[1] There are many other projects that aim to solve the volatility problem of crypto-currencies, like for instance Cryptobucks (Conley 2017)

2. The model

2.1 Agents

The local currency system associates four types of agents: n potential consumers, s shopkeepers, m potential miners (or validators) of the transactions, and an administration of the system which also issues digitally the complementary currency against legal tender and conditionally convert it back in legal tender at a fixed exchange rate. The administration determines a list of enforceable commitments binding the participating shops, related to the origin and nature of the products they sell and different ecological friendly attitudes (promotion of short distribution channels, of organic goods, of ethical products, participation to waste recycling, to various collective solidarity projects, etc.). The cost of commitments for the shops increases with the advantage they provide to consumers. Committed shopkeepers have the possibility to convert back in legal tender the complementary currency they receive in payment. Consumers interested in environmental protection and in promoting local and organic products can become clients of the committed shops and pay in complementary currency which is accepted only by shopkeepers able to convert it back in official currency. Payments in complementary currency are validated and settlements realized by the way of a blockchain using a proof of work like validation system. Miners/validators of the blockchain are interested in rewards associated to the validation process. Rewards are payed by the administration and funded by a conversion cost payed by consumers choosing to access to committed shops. The reliability of the validation system depends on the number of participating validators which itself depends on the level of rewards. Finally the administration maximizes welfare under the expression of total surplus.

Shopkeepers

There are s various and heterogeneous shops (mini-market, food-store, fishmonger, clothing shop, drugstore, bookstore, hairdresser, pub, restaurant, etc.) able to commit or not to the chart proposed by the administration. Committed ones have in counterpart the possibility to access the retro-conversion of the complementary currency in legal tender. Their choice to accept or not complementary currency in payment depends on the additional income and costs generated by commitments. When a shopkeeper decides to accept the complementary currency in payment, its excess income is given by the number of new clients n^* it attracts, each one being supposed to consume one unit of "quality" good or service at a fixed price equal to 1 by convention. The cost to commit increases quadratically with the advantages provided to consumers. It also depends on idiosyncratic components differing from one shopkeeper to another (it is easier to serve a beer locally brewed in Munich than in Lisbon, and as hard to sell local electronic components in both cities).

The excess profit π_k of shopkeeper $k, (k = 1, 2, \ldots, s)$ accepting the complementary currency in payment is given by expression (1):

$$\pi_k = n^* - (c_1 k + c_2 a^2) \tag{1}$$

where n^* figures the number of consumers using the complementary currency in payment, and c_1k and c_2a are respectively the idiosyncratic and the common components of the cost to commit $(c_1 > 0, c_2 > 0)$.

2.1.1 Consumers

There are n potential consumers who use or not the complementary currency according the content of the chart proposed by the administration. Their utility as clients of the committed shops increases with the level of commitment of the shops, but decreases according the transaction fees they have to pay to convert the legal tender int complementary currency They are differentiated by their sensibility to the excess price of "quality" goods and services of the committed shops, by the limitations in terms of variety of "quality" goods and services, or by other disadvantages of committed shops compared to their competitors (including hypermarkets) offering "normal" goods and services. The differential of utility of consumer i, $(i = 1, 2, \ldots, n)$ when it chooses to pay a given variety of goods/services using complementary currency is given by expression (2):

$$u_i = a(1 - t) - i\tau \tag{2}$$

where t relates to the rate of conversion of legal tender in complementary currency and τ to the idiosyncratic opportunity cost associated to the use of the complementary currency.

2.1.2 Miners

The m potential miners/validators can use their interconnected computers to activate a blockchain able to validate transactions in complementary currency. The payment of validators is determined by a "proof of work" contest: the computational power of computers determines also the miners' probability to win the unit reward r associated to each block which includes l transactions. Computational powers are uniformly distributed on the segment $[\underline{j}, \bar{j}]$. When the time devoted to validation and other opportunity costs are considered, the number of effective participants in the blockchain depends on the amounts of rewards. The expected gain for a given block of the miner endowed with the computational power j (or miner j) is given by expression (3):

$$\pi_j = \left(\frac{jr}{\sum_{j^*}^{\bar{j}} j} - \theta \right) \frac{n^* s^*}{l} \tag{3}$$

where j^* figures the marginal participating miner, *e.g.* the miner for which the expected profit exactly vanishes, the first term in the parenthesis representing the gross expected gain of miner j given its equipment and the level of rewards, and θ its opportunity cost.

The potential miners decide to participate in the blockchain as soon as their net expected profits are positive.

2.1.3 Administrator of the currency

The administrator of the complementary currency charges a rate t to each unit conversion of legal tender in complementary currency, and converts back for free the complementary currency of committed shopkeepers into legal tender. It determines the content of the chart (the level of commitments) a. The conversion tax t funds the miners' activity. Indirectly, the blockchain activity then determines the conversion tax t when the administrator budget constraint is balanced as written by equation (4):

$$n^* s^* \left(t - \frac{r}{l} - c_3 \right) = 0 \tag{4}$$

where s^* figures the number of committed shops and c_3 a unit operational cost of the administration.

Given that the amount of reward r is given by the validation market[2], the administrator finally determines the level of commitment a^* maximizing the welfare (5) of the members of the community (consumers and member-shops), given its budget constraint (4):

$$W = s^* a n^* (1 - t) - s^* \tau \left(\sum_0^{n^*} i \right) + s^* n^* - c_1 \left(\sum_0^{s^*} k \right) - c_2 s^* a^2 \tag{5}$$

2.2 Sequence of actions and solution concept

The interactions among agents and the control of actions by the administration can be presented in a sequential way. The sequence is then as follows:

- At the beginning of the period, the administration determines the content of the chart a in order to maximize welfare (5) under the budget constraint (4), using rational expectation of other agents actions given parameters c_1, c_2, c_3, τ, l and the value of r given by the market.
- At stage 2, potential member-shops choose to sign or not the chart (and to accept or not the complementary currency in payment).
- At stage 3, potential users choose to adopt or not the complementary currency and to become or not clients of the member-shops.
- At stage 4, potential miners choose to participate or not in the blockchain.

The solution concept is the subgame perfect equilibrium of the previous sequence in which in each period agents choose the best action to maximize respectively welfare, profits, utilities and validation expected gains. It is solved in a backward way.

[2] Miners participate to various blockchains which for a given size of blocks places the administrator in a price taker position relatively to the amount of r.

3. Solution of the model

3.1 Fourth stage of the game

Lemma 1. *The effective number of miners is* $\bar{j} - \frac{1}{2} + \frac{r}{\theta} - \frac{\left(4r(r-\theta)+\theta^2(1+4\bar{j}+4\bar{j}^2)\right)^{1/2}}{2\theta}$. *This number increases with the level* r *of rewards.*

Proof: The expected profit of the threshold miner j^* vanishes in expression (3). Among the two roots, and given that $r \geq 3\theta$ is a necessary condition to have at least 2 participants in the blockchain, the relevant solution is $j^* = \frac{1}{2} - \frac{r}{\theta} + \frac{\left(4r(r-\theta)+\theta^2(1+4\bar{j}+4\bar{j}^2)\right)^{1/2}}{2\theta}$, from which is deduced the number of miners $\bar{j} - j^*$.

From Lemma 1, are deduced the following remarks:

- Given the opportunity costs of miners, the number of active miners only depends directly on the amount of rewards and not on the level of commitment of shopkeepers and the level of circulation of the complementary currency.
- Given the administration 'budget constraint' (4), the amount of rewards has also an indirect influence on conversion costs t and on the level the number of transactions in complementary currency, and finally determines also the number of blocks and the profit π_j of each miner.

Indirectly, from their effect on the conversion tax, the blockchain technology and the level of rewards have then an influence both on the number of consumers using complementary currency and on the number of shopkeepers accepting it in payment.

3.2 Third stage of the game

The third stage of the game corresponds to the determination of the number of consumers using the complementary currency, given the level of commitment of shopkeepers a^* and the amount of conversion fees t.

Lemma 2. *The effective number of complementary currency users among consumers is* $n^* = \frac{a(1-t)}{\tau}$. *This number increases wit the level of commitments of shopkeepers and decreases with the conversion fees.*

Proof: The threshold complementary currency user i^* vanishes expression (2), i.e. $i^* = \frac{a(1-t)}{\tau}$. Given the form of (2), $n^* = i^*$, equality from with is derived the first part of the lemma. The second part is immediate from the study of n^*.

3.3 Second stage of the game

The second stage of the game corresponds to the determination of the number of the shops s^* which sign the chart and accept the complementary currency. This number depends on the level of commitments a previously proposed by the administration of the currency, and on the value of their profit function (1).

Lemma 3. *The effective number of shopkeepers accepting the complementary currency is* $s^* = \frac{a(1-t-ac_2\tau)}{c_1\tau}$*. This number decreases with* t*. It first increases then decreases with* a*.*

Proof: The threshold shopkeeper k^* vanishes expression (1), i.e. $k^* = \frac{a^*(1-t-ac_2\tau)}{c_1\tau}$. Given the form of (1), $s^* = k^*$. The second part is the consequence of expression s^* form.

It is interesting to observe that the number of participating shops increases with the level of commitment as far as the good effect on the latter dominates the bad effect on shopkeepers' costs.

3.4 First stage of the game

Finally, once determined the level of conversion taxes $t = \frac{r}{l} + c_3$ of legal tender in complementary currency from expression (4), the welfare maximizing value of a^*, can be derived from expression (5) where the values of n^* and s^* are expressed as obtained in Lemmas 2 and 3.

Proposition 1. *Under the mild condition* $c_2\tau^2 < \left(1 - \frac{r}{l} - c_3\right)^2$*, there exists a positive value of* a^* *maximizing welfare.*

Proof: Given expression (5) and Lemmas 2 and 3, the welfare is a polynomial expression of degree 4, continuous in the whole range of definition of a. Its term of highest degree is positive. It has then in general two local mimima and one single local finite maximum. The expression vanishes for $s = 0$, which corresponds to two different values of a, namely $a = 0$ and $a = \frac{(1-t)}{c_2\tau}$. It first derivative in a is negative for $a = 0$ which means that it becomes negative for small values of a. A sufficient condition in which it becomes positive is when the two components of W, namely $W = s^*an^*(1-t) - s^*\tau\left(\sum_0^{n^*} i\right)$ and $W = s^*n^* - c_1\left(\sum_0^{s^*} k\right) - c_2s^*a^2$ are positive, which corresponds respectively to $a > \frac{\tau}{1-\frac{r}{l}-c_3}$ and $a < \frac{1-\frac{r}{l}+c_3}{c_2}$, which summarizes in the condition $c_2\tau^2 < \left(1-\frac{r}{l}-c_3\right)^2$. When this condition is observed, and given the form of w and its values when $s^* = 0$, a maximum of W exists for positive values of a^*, s^* and n^*.

The condition of the proposition could be easily commented. The left part of the inequality $c_2\tau$ refers to the cost of commitment for shopkeepers, and to the heterogeneity of consumers related to the opportunity costs when they choose to be clients or not of committed shops, while the right part of the expression refers to the costs of the validation system, namely the rewards paid to the blockchain which activates the system. It then exists a positive level of commitment maximizing welfare if opportunity costs of consumers and commitment costs of shopkeepers are not too high when compared to the cost of activating a blockchain.

3.5 Simulation results

We present in this section numerical illustrations able to capture different levels of extension of the network of agents paying in local complementary currency and using it as a way to disclose committed stores.

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4
c_1	0.75	1	1.5	2
c_2	2	1.5	1	0.5
c_3	0.7	0.5	0.4	0.3
r	0.1	0.075	0.05	0.01
l	20	20	20	20
τ	0.015	0.01	0.0075	0.005
a^*	7.05	24.72	59.67	209.79
W	15 995.2	4 707 180	135×10^6	$15\ 826\times10^6$
n^*	142	1 227	4 754	29 349
s^*	51	310	795	3672
n^*/s^* in %	35.44	25.27	16.73	12.51

Table 1: Simulation results of each stage of adoption of the local currency project

The four columns of Table 1 could be interpreted as different stages of adoption of the complementary currency. Scenario 1 may depict an early stage of the project characterized by an important opportunity cost of adoption by users (τ), high rewards for miners (r), high costs for the administration (c_3) and for the merchants to be engaged in the advantages provided by the local currency (c_2). The subsequent scenarios may depict the further adoption stages of the project respectively in evolution with our variables, with scenario 4 being the latest stage in which the project has reached its maturity and the possibility of a network of multiple local currencies governed by a blockchain has become a reality.

The four figures below show the evolution of the total welfare (blue curve, left y-axis), the number of shops accepting the local currency (purple curve in the bottom most position, right y-axis), and the number of users (straight purple line) for each scenario of table 1.

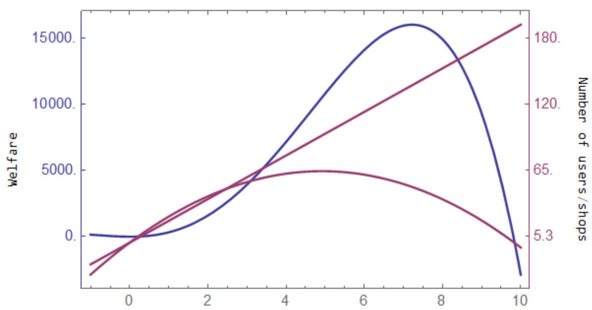

Figure 1: Scenario 1

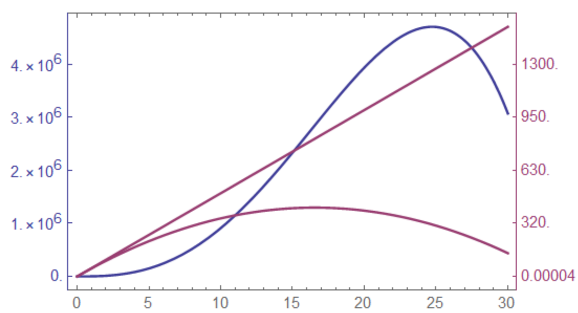

Figure 2: Scenario 2

Despite important differences in the level of adoption and use between cases, and mild (visual) nuances in the range of positivity of W close to $a = 0$[3], the same observations are

[3] In reality, these nuances are for the most the consequence of the difference of scale among the 4 cases.

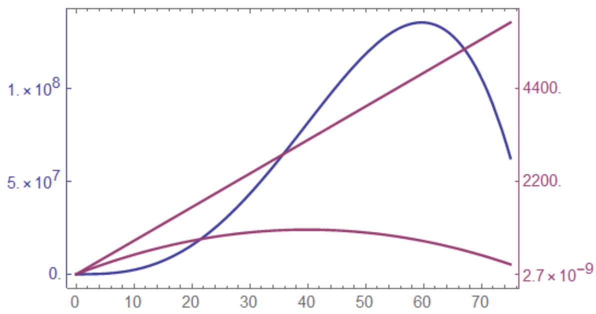

Figure 3: Scenario 3

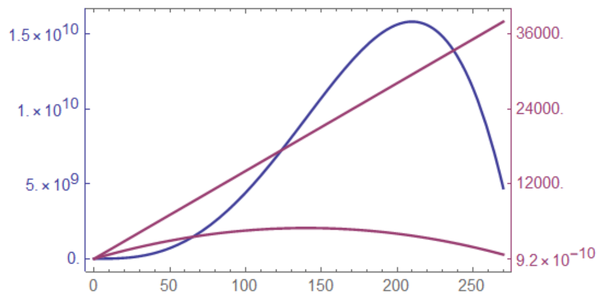

Figure 4: Scenario 4

made in every situation: the number of consumers increases linearly with a, the number of involved shops reaches a maximum before total welfare, and ends up having a negative influence on the latter, until making it vanishing. Only changes the size of users' network and the gain in term of welfare. The amount of rewards r plays a role in the success of the experience, as part of the costs, but the other costs (opportunity costs of consumers, commitment costs of shopkeepers) are also decisive in the success of the experience.

4. Conclusion

In general, achieving mainstream adoption is the objective of a currency. Conversely, in the case examined in this paper, the adoption should be restricted to a limited number of shops to enforce the role of the local complementary currency as a signaling tool. In this sense, the local complementary currency does not position itself as a 'rival' to the legal tender. The increasing need for security and viability for a payment system in a world where technology is advancing at a fast pace calls for alternative solutions that are easily reproducible across spaces and cities. The blockchain seems to be one of the solutions to this problem. Our model and its simulation results showed that a local complementary currency or a network of local complementary currencies governance via blockchain is feasible in many circumstances. It is in line with rational behavior of agents, and comes at a low cost, if not nearly no cost, for the collectivity. Two prominent examples of blockchain applications are the Monnaie Léman[4] in France and Switzerland, and MonedaPAR[5] in Argentina (Orzi, Porcherot, and Valdecantos 2021). The digitization of local currencies via blockchain is gaining momentum as more projects are adopting the solution and we expect this trend to continue growing rapidly in the next few years.

[4] https://monnaie-leman.org/le-leman-concretement#electronique

[5] https://monedapar.com.ar

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