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Secondary Currency Acceptance: Experimental Evidence with a Dual Currency Search Model

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I examine, in a controlled, experimental laboratory setting, the acceptance of a secondary currency when a primary currency already circulates in an economy. The underlying model is an indivisible good / indivisible money, dual currency search model similar to that in Kiyotaki and Wright (1993) and Craig and Waller (2000). In such models, there are two pure Nash equilibria - total acceptance or total rejection of the secondary currency - and one unstable, mixed equilibrium denoted as partial acceptance. This mixed equilibrium is considered an artifact of the indivisibility of money and goods in the model and is often ignored. I find that when barter between good holders is allowed, the equilibrium tends towards total rejection. Conversely, when barter is prohibited, the equilibrium tends to- wards total acceptance. However, in both cases, the economies as a whole display partial acceptance of the secondary currency.

Keywords: Money, Search, Dual Currency, Experimental Economics, Repeated Games
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1 Introduction

[Bitcoin] has to have intrinsic value. You have to really stretch your imagination to infer what the intrinsic value of Bitcoin is. I havent been able to do it. Maybe somebody else can. - Alan Greenspan, Bloomberg, December 2013

The recent advent of decentralized, virtual or cryptocurrencies, such as Bitcoin, has raised many questions as to their possible impacts on traditional payment systems and the financial system in general. Underlying these questions is the fundamental concept of what defines money and what drives demand and acceptance of a medium of exchange. Modern monies evolved historically from commodity-backed monies into fiat monies, i.e. token[1] monies backed by government decree. Cryptocurrencies, essentially intangible electronic bits on a computer with no legal backing, complicate the issue as they are token money yet are not legal tender "for all debts, public and private." This begs the question as to why individuals and businesses are willing to accept such a secondary currency in exchange for goods and services given that generally-accepted fiat currencies already circulate in most, if not all, countries.

1.1 Secondary Currency History and Examples

In his 1933 book "Stamp Scrip", Irving Fisher claimed that in the face of a U.S. dollar shortage, presumably the result of hoarding, the introduction of a secondary currency might "prime the pump" of credit currency use and thus begin the end to the Great Depression. Fisher was particularly interested in

[1] I will generically refer to money with exchange value significantly above its component value as "token", and will refer to money backed by government decree as fiat money

stamp scrip which consisted primarily of private or community-issued token money that required the regular affixation of a marginally priced stamp that could be purchased from the issuer. This tax on currency use was intended to increase the velocity of money and thus spur business transactions and economic growth. While he cautioned that stamp scrip was no panacea, Fisher strongly believed that the use of a secondary currency would help overcome the shortage of fiat money during the Great Depression and the inability of barter to efficiently enable economic transactions.

Economic crises are often the genesis of secondary currencies that circulate along side, or in lieu of, a national fiat currency. During the severe recession in Argentina in 2002, individuals created local business associations that issued private currencies called "creditos" that circulated not only between members of an association, but also between different associations (Colacelli and Blackburn 2009). A similar phenomena occurred in Greece during its recent debt crisis when privately issued "TEMS" were used in lieu of Euros in response to wage cuts and unemployment (Donadio 2011). Even earlier in history, during small change shortages in Great Britain during the 1700s, privately minted coins circulated at values above that of their metallic content (Selgin 2008). Hyperinflations have also led to the endogenous adoption of foreign currencies, a recent example being the use of U.S. dollars and South African rand, among other foreign currencies, in Zimbabwe (Polgreen 2012).

However, not all secondary or multi- currency systems have been born of economic turmoil. In Scotland during the 18th century and the U.S. during the 19th century, a "free banking" system existed in which banks issued private notes, most often backed back by silver or gold. More recent examples include community currencies such as the Ithaca dollar in New York and BerkShares in Berkshire, Massachusetts. Internationally, currencies of neighboring countries are often accepted at par in border cities, a phenomena seen along the Canada - Minnesota border that has also spread to non-border states.[2].

In all of the above examples, individuals accept token money in exchange for goods or services rather than demand an existing fiat currency locally in circulation. Presumably this is done under the assumption that the token money would in turn be accepted in future exchange. While economists have developed multiple models to describe this phenomena - money search models being the most recent and arguably most often used - these models often make fundamental assumptions regarding agent choices that are not necessarily founded in actual human behavior. Particularly, early money search models such as Kiyotaki and Wright (1993) assumed agents would rationally optimize profits over a range of currency acceptance rates. More recent search models, such as those found in Trejos and Wright (1995, 1996) and Craig and Waller (2000) assume either "take it or leave it" offers by buyers or some form of Nash bargaining.

Controlled laboratory experiments with human subjects provide a systematic and methodological-based mechanism with which to test these behavioral assumptions. Though several researchers have conducted experiments testing the predictions and dynamics of single token and fiat currency money search models, I am not aware of any experimental research (with the possible exception of preliminary work undertaken by Janet Hua Jiang of the Bank of Canada and Cathy Zhang at Purdue University) that has specifically looked at economies with two token currencies, one of which is a priori generally accepted and another which is not. Therefore, I specifically address in my research the behavior of individuals

[2]While Canadian bank notes are typically not accepted in Minnesota, coins are, perhaps due to the visual similarity of Canadian and U.S. coinage and their relatively small exchange value.

in a dual currency economy in which a primary currency is by design generally accepted in exchange - and thus acts to a certain extent as a national fiat currency - and a secondary currency which individuals may decide to accept or reject in exchange for goods. Moreover, as the key friction addressed by money search models is the existence or absence of a double coincidence of wants, I compare two environments, one in which sellers may barter, and one in which they may not.

The structure of this paper is as follows. In Section 2, I will review the relevant literature, covering both theoretical models of secondary currency economies and related experimental work. In Section 3 I will describe in detail the underlying models upon which I based my laboratory experiments. Experimental procedures and design are discussed in Sections 4 and 5, respectively. This is followed by the experimental results in Section 6, and the conclusion.

2 Literature Review

Duffy (2012) succinctly breaks down much of the experimental work in monetary economics into two categories: money as a store of value and money as a medium of exchange.[3] Experiments based on search models all fall within the medium of exchange category, while experiments based on cash-in-advance ("CIA") and overlapping generations models ("OLG") predominantly fall into the store of value category. While some experiments have studied the emergence of money from the trade of different commodities (Duffy and Ochs 1999), others have focused on the impact of the introduction of a fiat money (Duffy and Ochs 2002, Deck et al 2006). However, few, if any, studies have explicitly considered multiple fiat monies, with

[3] I have not included experimental work on New Keynesian models, specifically money illusion, for reasons of relevance and brevity.

the exception of the open, general equilibrium economy in Noussair et al (2007) and Angerer et al (2010).

Brown (1996) and Duffy and Ochs (1999) are examples of earlier experimental research examining the 1st generation money search models that focus on commodity monies. The underlying model consists of three types of agents identified by the good they consume, $i = \{1, 2, 3\}$. However, type 1 produces good 2, type 2 produces good 3, and type 3 produces good 1. Hence, no double coincidence of wants naturally occurs. Each good has a different storage cost c, with $c_1 < c_2 < c_3$. Agents are randomly matched, and may trade their goods if mutually agreeable. If an agent trades for its consumption good, it consumes the good, gains utility, and then immediately produces its production good. In the above parameterization, type 2 should be willing to trade type 3 for good 1, good 1 having a lower storage cost, and in turn trade this for its consumption good in a match with a type 1 player. Thus, agents play a fundamental strategy in which they try to hold only the lowest cost good which becomes the de facto medium of exchange.

Duffy and Ochs (1999) utilized participant groups which consisted of a minimum of 2 players of each type (i.e. a minimum of $N = 6$), with equal numbers of each type, interacting in a computerized environment. Each session consisted of multiple games which in turn consisted of multiple rounds. At the beginning of a game, subjects were given an initial endowment of utility points. In a round, subjects were randomly matched and could trade goods and gain utility points by trading for and consuming their preferred good. A cost (in terms of utility points) was incurred to store a good until the next round. Another round occurred with a probability of 90%; otherwise, the game ended, subjects points were recorded and reset, and a new game began. This indirectly induced a 10% discount rate. Subjects, via the computer display, were able to see the round number, their point totals, the fraction of each type of player that held each type of good, and the probability of the game coming to an end. This information is considered common knowledge in the Kiyotaki and Wright (1989) framework.

In accordance with the underlying theory, in the standard parameterization described above, the type 1 (lowest storage cost) good was used as a medium of exchange and subjects almost always played this fundamental strategy. However, the researchers also tested a different set of parameterizations under which there is also a speculative strategy in which type 1 agents should trade their good to type 2 agents in exchange for good 3 (which has a higher storage cost) in order to trade for their consumption good with type 3 agents. In both Duffy and Ochs (1999) and Duffy (2002), subjects played the speculative strategy much less often than predicted. In an effort to evoke this strategy, the experimenters split the population unequally among the three types of players (i.e. 4/9 of the population were type 3 players) to make it more advantageous to speculate for the type 3 good. This, along with automating type 2 and type 3 players' decisions, improved the theoretical match, though the fundamental strategy was still played more often than predicted.

Subsequent experimental research considers the introduction of fiat money into an artificial economy. Duffy and Ochs (2002) follow the setup of their earlier 1999 work (3 types of players, 3 commodities with different storage costs, multiple games consisting of multiple rounds) but introduce a fourth good ("good 0") that has neither consumption value nor a storage cost. A fraction m of the population initially has good 0 in storage at the beginning of a game, and as good 0 is not consumed, this fraction is constant during a given game. Subjects' types are consistent throughout the session (i.e. they don't change between games), but at the beginning of each game, the initial endowment of money is randomized among types. The computerized environment again provided subjects with information on historical averages (within a game) as to which types of players held which type of goods. As theory suggests, good 0 was used as a medium of exchange as long as it had the lowest storage cost (i.e. was not dominated in rate of return), and was used much less frequently when it was costlier to store than at least one of the other goods.

Recent experimental research by Duffy and Puzzello (2014) tests a third generation search model similar to that of Lagos and Wright (2005) and Rocheteau and Wright (2005) in which both money and goods are divisible, and there are two sub-rounds. In a similar setup to Duffy and Ochs (2002) the first subround consisted of decentralized, random matching in which buyers could make take-it-or-leave it offers to sellers. The second subround consisted of a centralized, double auction market in which subjects could choose to either buy or sell goods[4]. The authors compare the results of this standard setup to an experiment in which subjects are not endowed with money, i.e. a gift economy. In this case, in the decentralized match, buyers request goods from sellers, and sellers provide goods presumably on the implicit promise that when the roles are reversed, the then sellers will reciprocate. Results in the money economy came close to, but were still below, the predicted efficient outcomes. However, in the gift economy, trade was significantly below that of predictions, suggesting that money plays a crucial role in coordinating exchange, particular as a memory mechanism.

Deck et al (2006) undertake an experiment to determine when the acceptability of a fiat money will collapse. Subjects were assigned one of three roles: type A or B who both consume and produce, or the role of a government, type G. In the first

[4]This second subround is in line with the theory in third generation search models, as it is needed (along with quasi-linear utility functions) in order to get tractable results, specifically to ensure that agents enter the decentralized subround with equal money holdings.

two experiments, types A and B were endowed with goods and tickets, and each consumed the others production good. As the basis for the experiment was a CIA model, direct barter was not allowed and subjects had to use tickets to exchange for goods in a double auction market. The authors tested scenarios in which payouts were 1) earned for both consumption and tickets holdings (commodity money), and 2) only for consumption (fiat money). In both cases, equilibrium prices and quantities were near the efficient levels predicted by the underlying model, though when the number of trading rounds in the fiat money scenario were reduced, prices tended to escalate above those predicted. In contrast, when a government capable of printing tickets and buying goods was introduced, prices quickly escalated and the resulting hyperinflation reached upwards of 2000% between trading periods. Hyperinflation was mitigated, however, when an exogenous money supply growth rule was put in place. In a similar experiment, Deck et al (2004) showed that when the government must follow a balanced budget rule, hyperinflation was also avoided.

As mentioned in the introduction to this section, the number of experimental studies on multiple fiat currencies is limited. Of note are Noussair et al (2007) and Angerer et al (2010). Noussair and co-authors Plott and Riezman modeled a large, multi-country economy in a general equilibrium setting in which there were three countries, each with its own currency; three types of traded goods; two non-tradeable inputs, labor and capital; and three types of agent roles: suppliers, producers, and consumers. Subjects in the experiment were assigned a nationality and played two roles, though they never produced a good they consumed. All goods and currencies were traded in centralized, double auction markets.[5]. In

[5]Understandably, this experiment is considered one of the most complex economies to be taken to the laboratory.

order to consume a good produced in another country, the good had to be imported, and in order to import a good, a subject had to first exchange her local currency for a foreign currency in the appropriate forex market. Strikingly, the quantities and prices traded in all markets ultimately converged quite closely to the theoretical predictions. However, as only one currency could circulate within a given country, the possibility of within borders, competing fiat currencies was not considered.

Angerer et al (2010) conduct an experiment in which participants issued "IOUs" that they could costlessly trade in a centralized clearinghouse. Subjects were endowed with 200 units of either good A or good B, and could issue up to 6000 IOUs. Utility was maximized by consuming 100 units of each good, though subjects could not consume their endowments. All units were placed for sale in a clearinghouse, and subjects bid on each good. The computerized clearinghouse determined the market clearing price and quantities, and all subjects received the same quantities. Each game consisted of 15 rounds of this process. The results for this baseline game were consistent with non-cooperative utility maximization, though the prices subjects offered for their own good were lower than expected. In a second treatment, the experiment allowed subjects to renege on their promises, i.e. after the clearinghouse bidding process, subjects did not need to deliver all 200 units. The resulting total units delivered were then distributed equally among subjects, and any withheld goods were counted towards that subject's consumption. In this treatment, delivery dropped considerably, averaging about 50 units out of subjects' 200 unit endowment. However, when a high enough non-delivery penalty was put in place, near-total delivery occurred.

3 Theoretical Background and Model

My experiment consists of two related goals: 1) to test the theoretical predictions of a dual currency search model in a controlled experimental setting, and 2) to determine whether or not the existence of barter impacts the acceptance of a secondary currency. The baseline model is a first generation, indivisible goods / indivisible money search model based on Kiyotaki and Wright (1993) that allows for barter, i.e. exchange between two good holders.

In the model, there are two currencies, primary and secondary, and nonperishable goods. Agents may be good holders, primary currency holders, or secondary currency holders with population proportions μ_g, μ_p, and μ_s, respectively, and $\mu_g + \mu_p + \mu_s = 1$. Each agent receives utility U from the consumption of a fraction x of goods but may never consume the good it holds. When an agent holding a good meets an agent holding one of the two currencies, a single coincidence of wants occurs with probability x and with symmetry, a double coincidence of wants occurs with probability x^2 when two agents holding goods meet. It is costless to store money and commodities, though there are currency-specific dividend returns y_i. The rate of time preferences is r.

Agents are randomly matched for bilateral trade with probability α. If an agent holding one of the currencies meets an agent holding a good meet, there is a possibility of trade. If trade does occur, the agent holding the currency receives the good, consumes it and earns utility U. This agent then produces a new good which the agent may trade in future matches. The agent that trades its good for the currency carries that currency into its next trading match.

An agent holding a good optimally accepts the primary or secondary currency with probability π_p and π_s (best responses), respectively. Agents holding a currency take the probabilities of an agent holding a good accepting either currency as given, and therefore these probabilities in the currency holder Bellman equations are denoted as Π_p and Π_s. Currency for currency trades are not allowed for the purposes of clarity, but including such trades does not affect the equilibrium results.

Let V_i represent the value function for agent i, where $i = g, p, s$ indicates that the agent is a good holder, primary currency holder, or secondary currency holder, respectively. The Bellman's equations are therefore:

$$rV_g = \alpha\mu_g x^2(U - V_g) + \alpha\mu_p x \max_{\pi_p} \pi_p(V_p - V_g) + \alpha\mu_s x \max_{\pi_s} \pi_s(V_s - V_g) \tag{1}$$

$$rV_p = y_p + \alpha\mu_g x\Pi_p(U + V_g - V_p) \tag{2}$$

$$rV_s = y_s + \alpha\mu_g x\Pi_s(U + V_g - V_s) \tag{3}$$

Equation (1) is the flow return to an agent holding a good. This return consists of three components. The first component of the right-hand side of the equation is the benefit from trading with another agent holding a good. This occurs with probability $\alpha\mu_g x^2$. The second component is the benefit from trading with a primary currency holder, which occurs with probability $\alpha\mu_p x$, assuming the agent holding the good decides to trade. The third component is the benefit from trading with a secondary currency holder, which occurs with probability $\alpha\mu_s x$, again assuming the agent holding the good decides to trade.

Equation (2) is the flow return to an agent for holding the primary currency. As currency trade is not allowed, the return consists of a dividend paid (or cost incurred) for holding the primary currency y_p plus the utility gain from trading with a good holder which occurs with probability $\alpha\mu_g x\Pi_p$, with Π_p taken as given by the agent holding the primary currency holder. Likewise, Equation (3) is the flow return to an agent for holding the secondary currency.

In order to motivate a secondary currency scenario in which the secondary currency circulates with partial acceptance, I follow Kiyotaki and Wright (1993) and assume that the primary currency is always accepted in trade: $\Pi_p = 1$. Therefore, $\Pi_p = 1 > \Pi_s > 0$ meaning that $V_p > V_s = V_g$. That is, the value of holding the primary currency is higher than the value of holding the secondary currency or a good, and agents are indifferent between holding the secondary currency and a good. For simplicity, dividend returns to currency are set to zero.

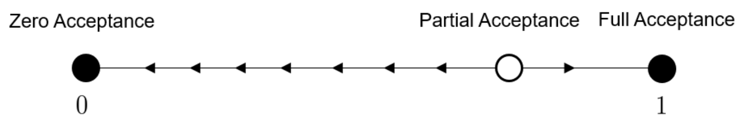
Solving for Π_s yields:

$$\Pi_s = \left(\frac{xr + x^2\alpha\mu_g + x\alpha\mu_p}{r + x\alpha(\mu_g + \mu_p)} \right) \tag{4}$$

This is the mixed strategy equilibrium. Therefore, there are three equilibria: partial acceptance of the secondary currency, total acceptance of the secondary currency, and total rejection of the secondary currency. It is important to note that it is often implicitly assumed that the agent-level symmetric mixed equilibrium is the same as an asymmetric equilibrium in which a fraction of the population of agents always accepts the secondary currency and a fraction does not. As Wright (1999) shows, this is not necessarily the case.

Moreover, this mixed strategy equilibrium is evolutionarily unstable. Starting at the mixed equilibrium Π_s^*, a slight increase in the fraction of agents accepting the secondary currency, Π_s will cause an explosion to the full acceptance equilibrium. Likewise, a small decrease in Π_s will cause a degeneration to the full rejection equilibrium. This is displayed stylistically in Figure 1. It is this evolutionary process I explore in the experimentally laboratory setting.

Figure 1: Evolutionary Dynamics of Secondary Currency Acceptance



The model for the no barter treatment is similar to the model above but more closely follows Colacelli and Blackburn (2009) in their field research on creditos systems in Argentina. Repeating value equations (2) and (3) from above and using the same notation, the model is:

$$rV_g = \alpha\mu_p x \max_{\pi_p} \pi_p(V_p - V_g) + \alpha\mu_s x \max_{\pi_s} \pi_s(V_s - V_g) \tag{5}$$

$$rV_p = \alpha\mu_g x\Pi_p(U + V_g - V_p) \tag{6}$$

$$rV_s = \alpha\mu_g x\Pi_s(U + V_g - V_s) \tag{7}$$

Equation (5) is the return to an agent for holding a good which consists of only two components versus three as barter is not allowed. The first component of the right-hand side of the equation is the benefit from trading with a primary currency holder, which occurs with probability $\alpha\mu_p x$ assuming the agent holding the good does decide to trade. The second component is the benefit from trading with a secondary currency holder, which occurs with probability $\alpha\mu_s x$, again assuming the agent holding the good decides to trade.

Setting $\pi_p = \Pi_p = 1$ to indicate that the primary currency is always accepted and noting that $\pi_s = \Pi_s$ in equilibrium, a mixed strategy equilibrium for secondary currency acceptance exists when

$$\Pi_s = \frac{x\alpha\mu_p}{r + x\alpha(\mu_g + \mu_p)} \tag{8}$$

Comparing the barter to no barter equilibria:

$$\Pi_{s,barter} = \frac{xr + x^2\alpha\mu_g + x\alpha\mu_p}{r + x\alpha(\mu_g + \mu_p)} > \frac{x\alpha\mu_p}{r + x\alpha(\mu_g + \mu_p)} = \Pi_{s,nobarter} \tag{9}$$

The partial equilibrium, which is an unstable source in the evolutionary sense, is higher in the barter economy than in the no-barter economy. Therefore, in order for a secondary currency to circulate in a given economy, ceteris paribus, the fraction of good holders that accept the secondary currency in an economy in which double coincidence of wants (barter) may occur must be higher than the fraction of good holders that accept the secondary currency in an economy with only single coincidence of wants (no barter) may occur. This suggests that a secondary currency is more likely to circulate in an economy with no barter versus in an economy in which barter may occur.

4 Experimental Procedures

The subject pool consisted of University of California Santa Cruz undergraduate students, and subjects only participated in one session consisting of one treatment. Sixteen subjects were recruited for each session plus six extras. Subjects had no prior experience with the experiment and participation was voluntary. The experiment was computerized using zTree software (Fischbacher 2007) on a Linux platform and was run in the Learning and Experimental Economics Projects at UC Santa Cruz.

At the beginning of each experimental session, subjects were provided with written instructions (see "Supplementary Materials" for copies of the instructions). After the instructions were read, subjects used their computer workstations to answer multiple questions (also available in "Supplementary Materials") to test their knowledge of the experiment.[6] Once all subjects successfully completed the quiz, they played four practice rounds to ensure they understood the rules and the computer interface.

Four sessions of each treatment (barter and no barter) were run for a total of eight sessions. Sessions typically took between 45 minutes to one hour. During the session, subjects were not allowed to communicate with each other or use cell phones, tablets, laptops, or other electronic devices. At the end of the session, subjects were given their cash payout consisting of a $7.00 showup fee plus a performance component dependent on their actions during the experiment. When sessions were overbooked, sixteen subjects from the total number of subjects that showed up were randomly selected to participated in the session. Those who were turned away still received the $7.00 showup fee. See Table 1 for details on the sessions and payouts.

5 Experimental Design

In the experiment, subjects were initially endowed with one of three items: a red ticket (the primary currency), a blue ticket (the secondary currency), or a non-perishable good. All subjects were matched in every period, equivalent to $\alpha = 1$. Subjects earned 1 point by trading with another subject for a good they could

[6]During pilot testing sessions of the experiment, subjects were given the opportunity to provide written feedback on the instructions. The large majority of the feedback indicated that the instructions were clear and understandable.

Table 1: Session Summary

Session	Treatment[1]	Sequences	Periods	Total Payout [2]	Avg. Payout
1	B	9	108	$225.25	$14.07
2	B	13	101	$224.75	$14.05
3	B	14	106	$246.25	$15.39
4	B	9	102	$227.25	$14.20
1	NB	9	108	$196.50	$12.28
2	NB	13	101	$188.50	$11.78
3	NB	14	106	$194.00	$11.88
4	NB	9	102	$196.25	$12.27

1. Treatment B = Barter, Treatment NB = No Barter
2. Does not include payouts to overbooked subjects.

consume, and subjects could not consume a good with which they were endowed or already held. With probability x subjects could consume the good of their trading partner, assuming the partner held a good. Thus, the single coincidence of wants was x, and in the treatment in which trade (barter) was allowed between two good holders, the double coincidence of wants was x^2. In the treatment in which trade between two good holders was not allowed, effectively $x^2 = 0$. Each point earned translated into $0.25 that went towards the subjects' cash payouts at the end of the experiment.

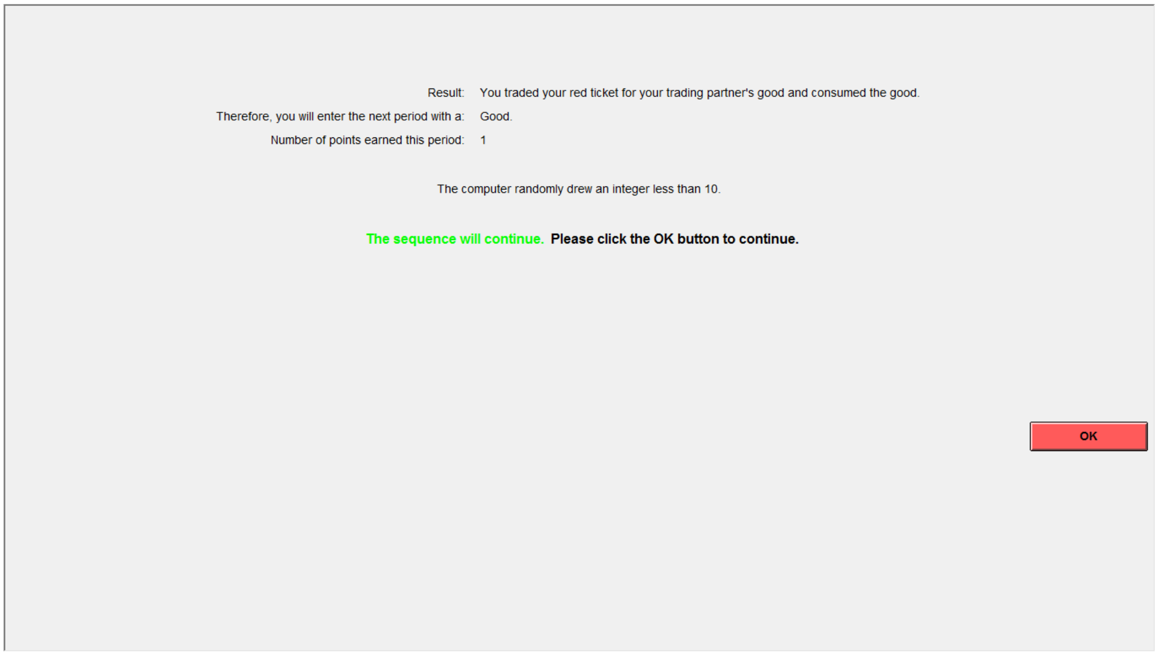
A single coincidence of wants of $x = 0.80$ was used in all sessions and treatments. All subjects were informed, both in the instructions and all computer screens, that there was an 80% probability that when they were matched with a good holder, they could consume that good holder's good. Subjects were also informed that the computer would randomly draw a number over a uniform distribution [0, 1] and that if the number was less than or equal to 0.80, the computer would determine there was a single coincidence of want. If the number drawn was greater than 0.80, the computer would determine there was not a single coincidence of want. For clarity, subjects were asked to think of a 10-sided die. If a 1, 2, 3, 4, 5, 6, 7, or 8 was rolled, the subject could consume his or her trading partner's good. If a 9 or 10 was rolled, the subject could not consume his or her trading partner's good, and therefore no trade was possible.

In order to induce a discount factor, subjects were informed that the experiment was broken down into a number of sequences, or supergames, that in turn were broken down into an indefinite number of trading periods. Each sequence consisted of at least one trading period, and continued with a new period with probablity β and ended with a probablity of $(1 - \beta)$. Time permitting, when a sequence ended, a new sequence would begin. Importantly, for the first period of each sequence, subjects were randomly endowed with a new item, as determined by the computer, regardless of the item that they held in the last period of the previous sequence. At the end of each period, on the results screen (see Figure 2), subjects were told whether or not a new period would begin, and if not, what item they would carry into the first period of the next sequence.

For all sessions and treatments, the discount factor β was set to 0.90. Therefore, subjects were informed that there was a 90% probability that the current sequence would continue with a new period, and a 10% probability that the sequence would end. Similar to determining single coincidence of want, subjects were asked to think of rolling a 10-sided die, and when a 1, 2, 3, 4, 5, 6, 7, 8, or 9 was rolled, the sequence would continue with a new period, and if a 10 was rolled, the sequence would end. In addition, subjects' trading screens displayed a chart of the cumulative probability of the sequence ending within 1 to 10 periods from the current period (see Figure 3). The trading screen also displayed the cumulative blue ticket acceptance rate for the sequence.

In the underlying model, the rate of time preference r rather than the discount

Figure 2: Results Screen



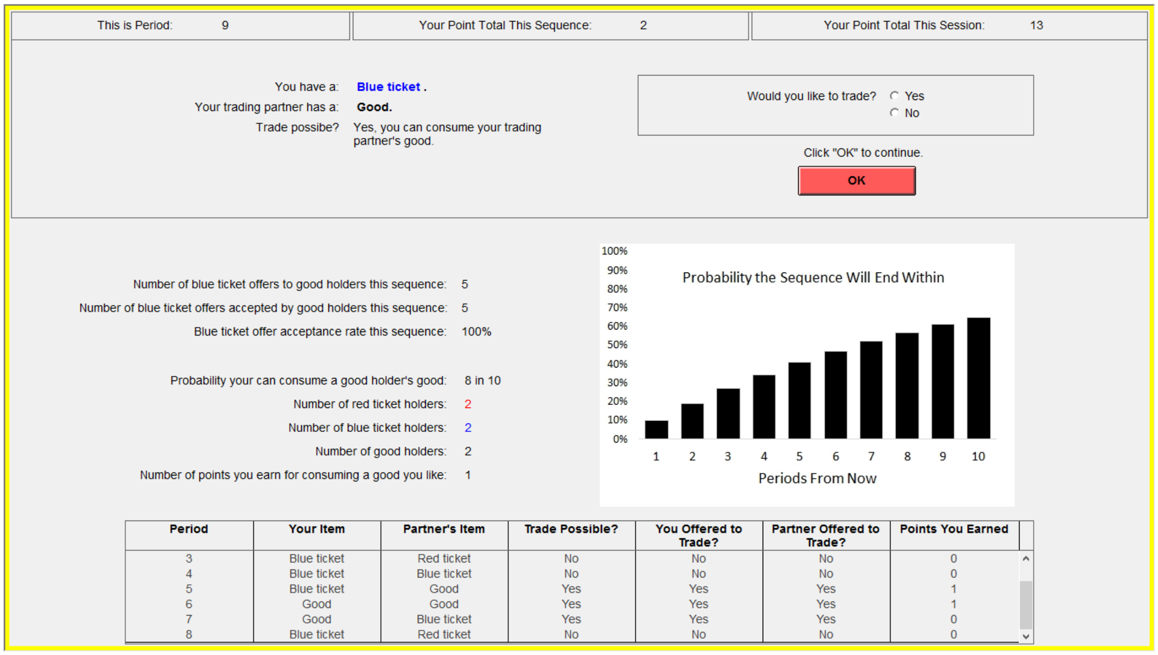
factor β appears. For determining the mixed strategy equilibrium, r is therefore calculated as:

$$r = \frac{1-\beta}{\beta} \approx 0.11 \tag{10}$$

The number of periods in each sequence were randomly determine by the computer in advance of the beginning of a session, and was unknown to the subjects [7]. The number of sequences in a session was capped to limit the total number of trading periods to approximately 100 for time considerations. Again, this was unknown to the subjects. In order to ensure comparability of treatments, the number of sequences and periods for the first sessions of the barter treatment and no barter treatment were held the same, likewise for the second sessions of the barter treatment and no barter treatment, etc. See Table 2 for the number of

[7]An R script using the "runif" command was used for the random number generation.

Figure 3: Main Screen



sequences and periods for each session.

Table 2: Ending Period Number of Each Sequence

	Sequence #													
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Session 1	10	24	37	51	65	70	73	74	108	-	-	-	-	-
Session 2	4	11	12	13	24	28	31	37	43	48	59	85	101	-
Session 3	11	12	18	21	38	42	43	65	69	79	88	89	90	106
Sessoin 4	5	8	17	18	43	56	57	79	102	-	-	-	-	-

1. Corresponding sessions for the barter and no barter treatments have equivalent sequences

In a trading period, subjects were randomly and anonymously matched with another subject - their trading partner for that period. If the rules of the experiment allowed (described below), the matched pair was offered the opportunity to trade the items they held. If trade occurred, the subject that traded for a good would "consume" that good, earn one point and then produce a new good that was carried into the next period, assuming the sequence continued. The subject that received a ticket in trade would carry that ticket into the next period, again assuming the sequence continued. If both subjects in a pair held a good and were able to trade and chose to do so, they would both consume the good for which they traded, earn one point, and produce a new good to be carried into the next round of the sequence. If subjects could not trade, they would carry their current good into the next period if the sequence continued.

As noted previously, at the beginning of each sequence, subjects were endowed with one of three items: a red ticket (the primary currency), a blue ticket (the secondary currency), or a good. For all sessions and treatments, there were 4 red ticket holders, 4 blue ticket holders, and 8 good holders.[8] Subjects were then matched in pairs of two, and if the rules of the game allowed, were offered the opportunity to trade. To summarize:

- If a ticket holder is matched with a good holder, and the ticket holder can consume the good holder's good (there is a single coincidence of want), the ticket holder may offer to trade items.
- If a good holder is matched with a red ticket holder, the computer will automatically accept an offer to trade on behalf of the good holder.
- If a good holder is matched with a blue ticket holder, the good holder may decide whether or not to trade with the blue ticket holder.
- Barter Treatment: If two good holders are matched, and both matched trading partners can consume the others good (i.e. there is a double coincidence

[8] I was limited by the number of available work stations available in the lab.

of wants), each may offer to trade. Trade only occurs when both matched subjects agree to trade.

- No Barter Treatment: If two good holders are matched, they may not trade.

Subjects made trading decisions before knowing the decision of the subject with whom they were matched.

Given the above parameter settings, the barter and no barter models give predictions as to the mixed strategy equilibrium. Specifically:

Barter

$$\Pi_s = \left(\frac{xr + x^2\alpha\mu_g + x\alpha\mu_p}{r + x\alpha(\mu_g + \mu_p)} \right) = \frac{0.8 * 0.11 + 0.8^2 * 1 * 0.5 + 0.8 * 1 * 0.25}{0.11 + 0.8 * 1(0.5 + 0.25)} = 0.86 \tag{11}$$

No Barter

$$\Pi_s = \frac{x\alpha\mu_p}{r + x\alpha(\mu_s + \mu_p)} = \frac{0.8 * 1 * 0.25}{0.11 + 0.8 * 1(0.5 + .025)} = 0.28 \tag{12}$$

These predictions for the mixed strategy equilibria, being evolutionarily unstable, also act as thresholds for determining in which direction blue ticket acceptance rates should move. For example, in the barter economy, if the fraction of subjects accepting blue tickets is at any point below 0.86, the model predicts that the acceptance rate will eventually degenerate to zero. Likewise, if the fraction of subjects accepting blue tickets is at any point above 0.86, the model predicts that the acceptance rate will explode to 1, i.e. 100% acceptance. As the no barter partial acceptance equilibrium (0.28) is lower, the likelihood of full acceptance in the no barter economy is higher, and for full rejection, lower.

6 Experimental Results

This sections presents the findings from the two treatments described above. Findings include both within and between treatment analysis at an individual, session, and treatment level. Specifically, I analyze the difference in acceptance rates between the two treatments, changes in acceptance rates over the course of a session, and subjects' individual patterns of acceptance and rejection of the secondary currency.

Finding 1. *Secondary currency acceptance rates were higher in the no barter treatment versus the barter treatment.*

The underlying theory predicts that it is more likely that a secondary currency will be accepted when barter is not possible. Though secondary currency acceptance rates were positive in both treatments, acceptance rates were considerably higher in the no barter treatment. Table 3 displays, for each session, the cumulative acceptance rates of blue ticket offers broken down into three time periods: 1) acceptance rates for the first 25 offers, 2) acceptance rates for subsequent offers, and 3) total acceptance rates across the entire session. A Wilcoxon Mann-Whitney non-parametric test of all four sessions of each treatment for each of the three time periods indicates that the no barter treatment had significantly higher blue ticket acceptance rates in all cases (p-value = 0.021 in all three cases). See Table 4 for a summary of the Wilcoxon results, including comparisons of sessions split by first half versus second half.

A graphical depiction of this results is displayed in Figure 4. In the graph, the horizontal axis is the cumulative number of blue ticket for good offers made, while the vertical axis is the cumulative number of such offers accepted. The black line

Table 3: Blue Ticket Acceptance Rates

Treatment, Session	# of Periods	Average over Periods		
		First 25	Remaining	Total
B, S1	108	0.48	0.23	0.26
B, S2	101	0.52	0.36	0.38
B, S3	106	0.44	0.59	0.57
B, S4	102	0.56	0.26	0.30
B Avg		0.50	0.36	0.39
NB, S1	108	0.80	0.90	0.88
NB, S2	101	0.72	0.72	0.72
NB, S3	106	0.72	0.80	0.79
NB, S4	102	0.72	0.74	0.74
NB Avg		0.75	0.80	0.80

B = Barter, NB = No Barter

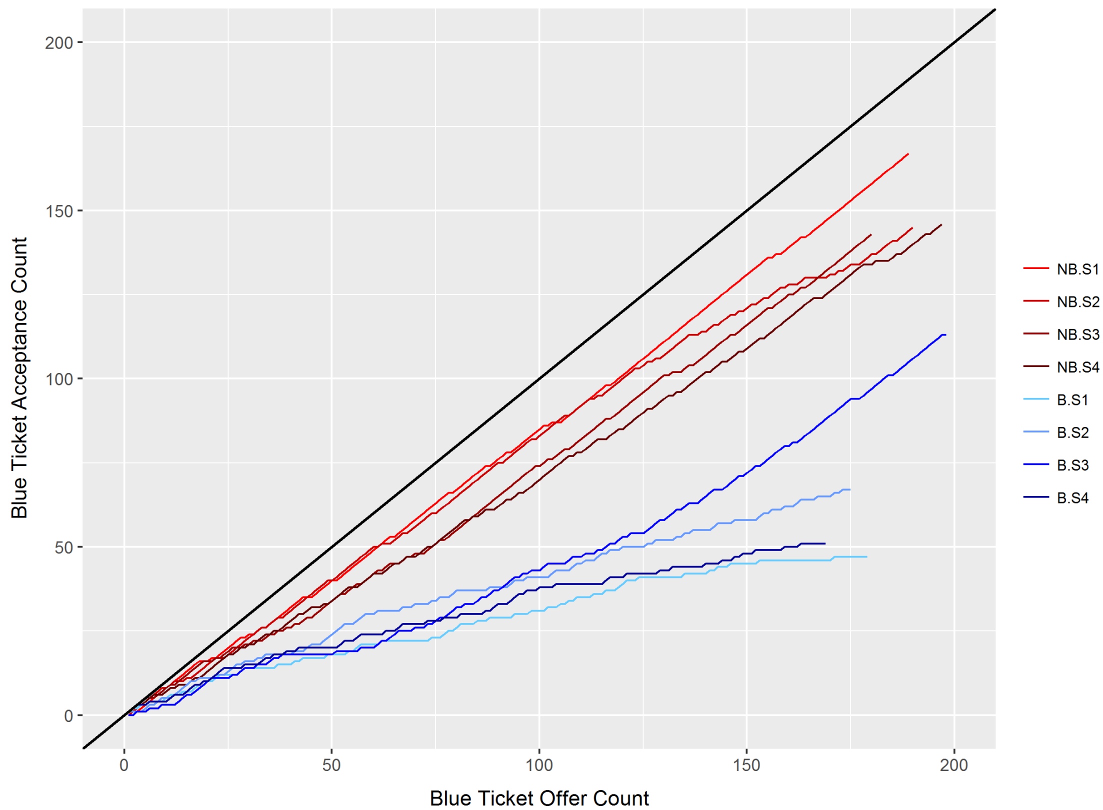
Table 4: Barter vs. No Barter Mann-Whitney Mean Comparisons

Periods	Acceptance Rate Comparison	P-Value
1st 25	No Barter > Barter	p=0.021
Post 25	No Barter > Barter	p=0.021
1st Half	No Barter > Barter	p=0.021
2nd Half	No Barter > Barter	p=0.043
All	No Barter > Barter	p=0.021

represents a hypothetical session in which all blue ticket offers are accepted. Blue ticket acceptance in the no barter treatment sessions (red), are all higher than the barter treatment sessions (blue) and this divergence occurs early, evident before the 25th blue ticket offer in each session. This suggests that, in aggregate, subjects were willing to risk trading a good for a secondary currency without enforceable acceptance as trading options were limited given the inability to barter.

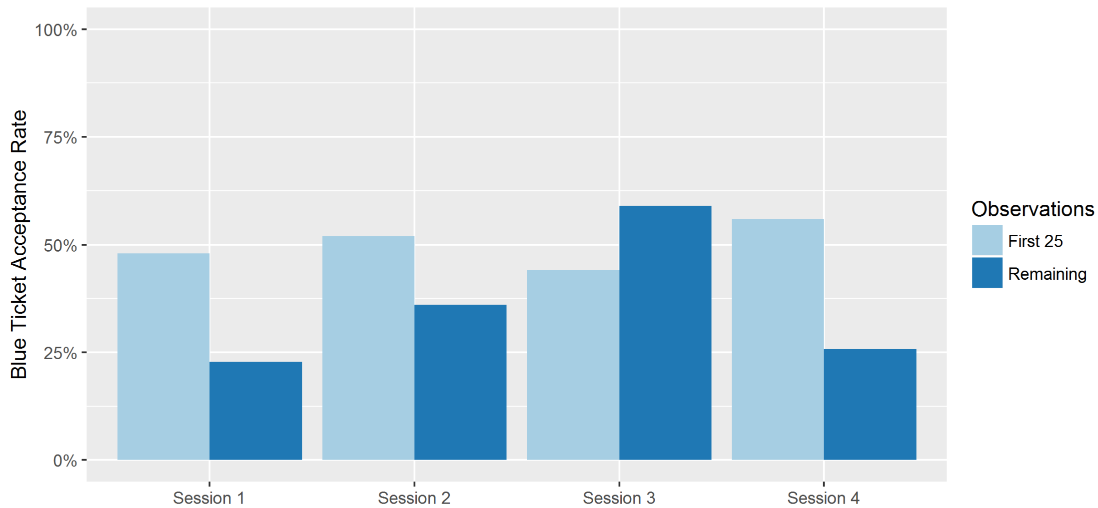
Finding 2: *Subjects were initially willing to "test the waters" and accept blue tickets in exchange for goods, though this willingness dissipates relatively quickly in the barter treatment.*

Figure 4: Cumulative Blue Ticket Acceptance Rate



Again referring to Figure 4, with the exception of session 3, barter treatment sessions show a distinct leveling off of blue ticket offer acceptances over time, suggesting a certain amount of learning by subjects. A Wilcoxon Mann-Whitney non-parametric tests does not find a statistically significant difference between the average acceptance rates in the first 25 offers versus the subsequent offers for the barter treatment sessions (p=0.127). However, excluding session 3 the same test does suggest a significant difference (p=0.050). Further evidence of this phenomena is apparent in the bar graph in Figure 5 which visually shows the difference in acceptance rates before and after the 25th blue ticket offer. The underlying evolutionary theory suggests a reason for this behavior, as the higher unstable mixed strategy equilibrium in the barter model requires fewer subjects unwilling to accept a secondary currency to cause a degeneration to the 100% rejection equilibrium.

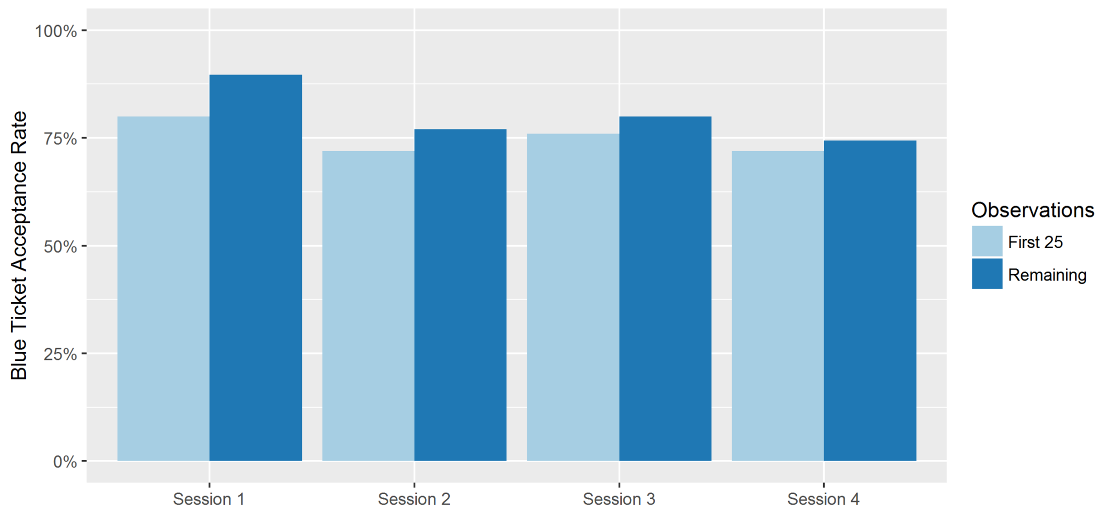
Figure 5: Acceptance Rates by Period: Barter



Notedly, a similar pattern is not evident in the no barter sessions. While Figure 6 suggests subjects in aggregate slightly increased their willingness to accept blue ticket offers, a Wilcoxon Mann-Whitney non-parametric tests does not find a statistically significant difference between the average acceptance rates in the first 25 offers versus the subsequent offers (p=0.189). This fits with both the theory and the behavior observed in the barter treatments: a portion of subjects are initially willing to accept the secondary currency, but as the mixed strategy equilibria is lower in the barter treatment, a relatively smaller group of subjects accepting the currency is needed to push the equilibrium towards full acceptance.

Finding 3: *Subjects who have previously had a blue ticket offer rejected are less likely to subsequently accept blue ticket offers, particularly when barter is not*

Figure 6: Acceptance Rates by Period: No Barter



possible.

In order to determine whether previous experience with having a blue ticket offer rejected impacted subjects' future decisions as good holders, I ran multiple random-effects probit regressions, the results of which are displayed in Table 5.[9] In the regressions, the dependent variable is whether or not a subject accepted a blue ticket offer in exchange for his or her good (0 = reject, 1 = accept). *Barter* is a dummy variable for the treatment (0 = no barter, 1 = barter), and *NewSequence* is a dummy for whether or not the offer occurred at the beginning of a new sequence (0 = no, 1 = yes). *RejectCumul* is the cumulative number of blue ticket offer rejections the subject received during the current sequence prior to making a decision whether or not to accept such an offer, and $RejectCumul * Barter$ is an interaction term. *RejectSeq* is a dummy variable indicating whether or not the subject had a blue ticket offer rejected during the current sequence prior to

[9]Following Duffy and Puzzello (2014), I use the gllamm package for Stata 12 to estimate the regressions, with robust standard errors clustered at the individual and session level.

making a decision whether or not to accept a blue ticket offer regardless of the number of times such a rejection occurred (0 = no, 1 = yes). $RejectSeq * Barter$ is also an interaction term.

The results in Table 5 suggest that previous experience did impact subjects' decisions as to whether or not to accept blue tickets in exchange for their good. Both the binary rejection and cumulative rejections variables were significant and negative, suggesting that having a blue ticket offer rejected in turn reduced the likelihood that a subject would accept a blue ticket offer in the same sequence. Moreover, the impact of a rejection was larger in the barter treatment, as indicated by the statistically significant and negative results for both rejection - barter interaction terms. There was no indication of a reset effect at the beginning of a sequence, nor of changes in decision making behavior due to the length of the session as both the new sequence and period coefficients were insignificant.

Finding 4: *All three strategies - always accept a blue ticket, always reject, or mix - were evident in all treatments. However, the always accept strategy was most common in the no barter treatment, and the mixed strategy predominated.*

While the underlying money search model does not explicitly assume or predict agent learning, the evolutionary dynamics suggest that as a subject learns whether or not other subjects will accept a secondary currency, the subject will adjust his or her behavior accordingly. In Figures 7 to Figure 10, I compare, by treatment and session, individual subject decisions as to whether or not to accept a blue ticket in exchange for a good. The horizontal axis is the period number, the vertical axis is the individual subjects (in no specific order), and the vertical black lines demarcate the end of a sequence. A blue circle indicates the subject accepted a blue ticket offer, and an orange triangle indicates the subject rejected a blue ticket

Table 5: Probit Regression of Blue Ticket Acceptance

	Accept = 1, Reject = 0			
	(1)	(2)	(3)	(4)
Barter	0.023	0.040*	0.015	0.038
	(0.024)	(0.024)	(0.026)	(0.029)
NewSequence	-0.048	-0.048	-0.049	-0.050
	(0.056)	(0.056)	(0.055)	(0.055)
Period	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
RejectCumul	-0.210***	-0.122***		
	(0.036)	(0.016)		
RejectCumul * *Barter*		-0.154***		
		(0.059)		
RejectSeq			-0.394***	-0.229***
			(0.067)	(0.067)
RejectSeq * *Barter*				-0.290***
				(0.101)
Constant	-0.060	-1.208***	0.000	-0.060
	(0.010)	(0.034)	(0.030)	(0.034)
Observations	13,344	13,344	13,344	13,344
Log Likelihood	-3429.095	-3427.386	-3425.195	-3421.605

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

offer. The top chart in each figure shows the results from the barter treatment, and the bottom chart shows the results from the no barter treatment.

One noticeable pattern consistent with the aggregate findings mentioned above is that in the barter treatments, individual subjects often (though clearly not always) appear to initially be willing to accept blue tickets, but after a few trades, revert to rejecting all such future offers. Clear examples of this behavior are subjects 7 and 11 in Figure 7a; subjects 7, 8, 10, 12, and 13 in Figure 8a; and subjects 3, 6, 8, 10, and 15 in Figure 10a. Again, session 3 of the barter treatment is an outlier with no subjects clearly displaying this learning behavior (Figure 9a).

However, there are also several subjects in the barter treatments who rejected all, or almost all, blue ticket offers from the beginning of the session, examples being subjects 4, 15, and 16 in Figure 7a; subjects 9 and 16 in Figure 8a; subject 8 in Figure 9a; and subjects 2 and 8 in Figure 10a. Presumably, these subjects have "chosen wisely" and therefore experience no incentive to change their behavior. In contrast, there are relatively few subjects who played a pure strategy of complete acceptance, subject 13 in Figure 7a, subject 15 in Figure 9a, and subject 15 in Figure 10a being the only example. In this last case, the subject only had three blue ticket offers so may not have had enough experience to persuade a change in behavior.

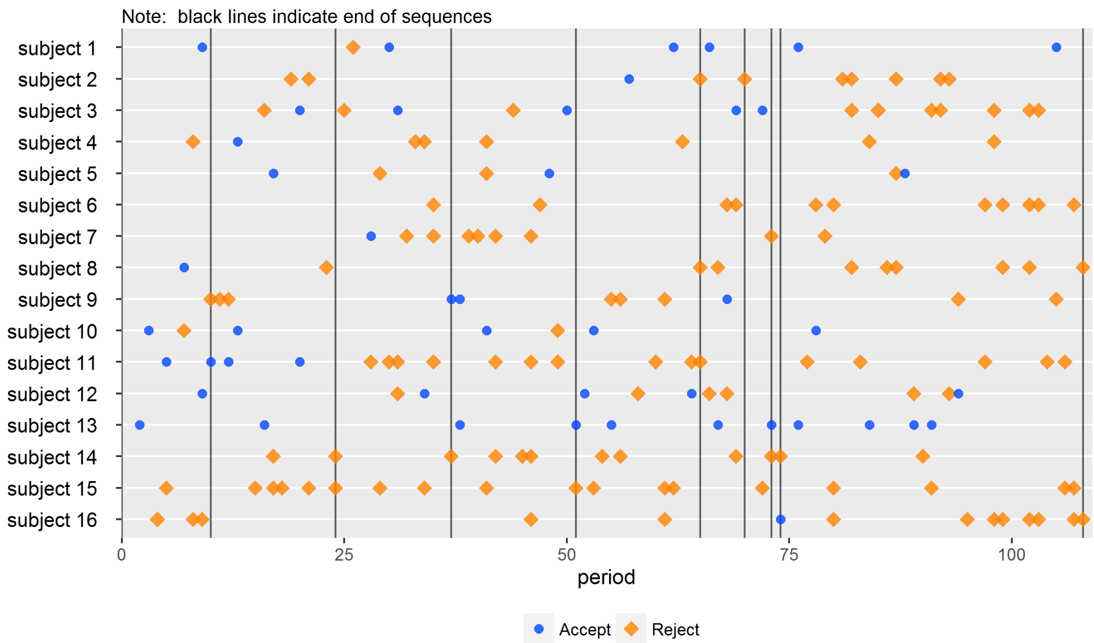
The remaining subjects in the barter treatment sessions display varying degrees of mixed strategy behavior. Some subjects, such as subject 2 in Figure 7a appear to have played a pure strategy of always reject with a temporary "testing of the waters" but in the middle of the session rather than the beginning. In general, a subject deciding to play a mixed strategy may be the result of a multitude of factors, such as experiencing only sporadic rejection of their own blue ticket offers and therefore not clearly identifying the general aggregate trend, attempting to signal to other players to accept blue tickets, or possibly not fully understanding the strategic choices faced.

The most noticeable trends among subjects within the no barter treatment sessions were the number of subjects who played a strategy of always accepting a blue tick offer. Subjects 1, 12, 13, and 14 in session 1 (Figure 7b); subjects 1, 9, 12, 13, and 14 in session 2 (Figure 8b); subjects 1, 2, 9, 13, and 15 in session 3 (Figure 9b); and subjects 5, 7, and 8 in session 4 (Figure 10b) chose this strategy. Moreover there we 18 subjects across the four no barter sessions that predominantly played an always accept strategy who, early in the session, rejected a blue ticket offer one or two times. While the remaining subjects played mixed strategies, most of these subjects more often than not chose to accept blue ticket offers.

A possible explanation for this behavior in the no barter treatment is that subjects realized the strategy that maximizes welfare is for everyone to always accept blue ticket offers. Thus, in both treatments subjects initially attempted to play this strategy. However, in the no barter treatment, since good-for-good trades may not occur, subjects needed to have a ticket of either color for trade to be possible. Therefore, the incentive to defect when others defect was significantly mitigated, consistent with the evolutionary dynamics of the theoretical model.

Figure 7: Blue Ticket Acceptance Decisions: Sessions 1

(a) Barter Treatment



(b) No Barter Treatment

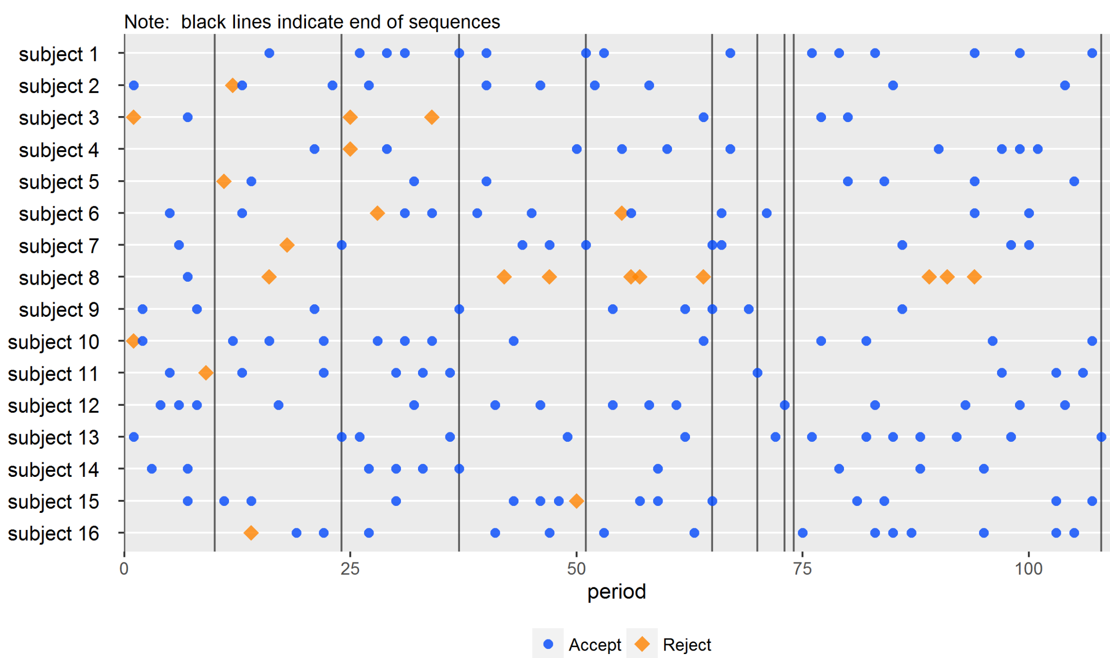
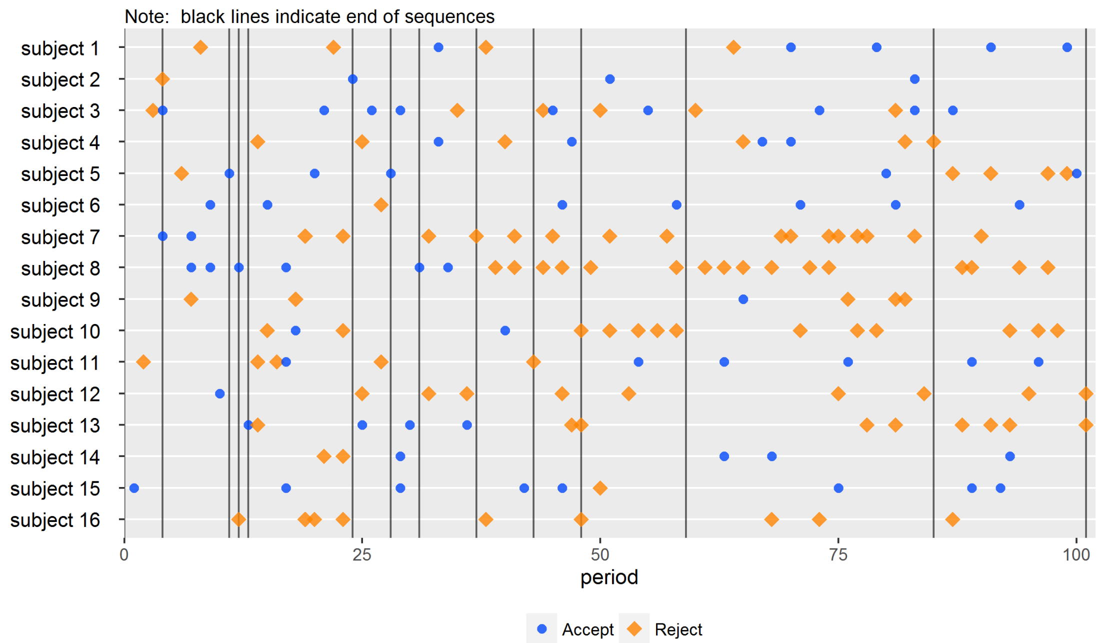


Figure 8: Blue Ticket Acceptance Decisions: Sessions 2

(a) Barter Treatment



(b) No Barter Treatment

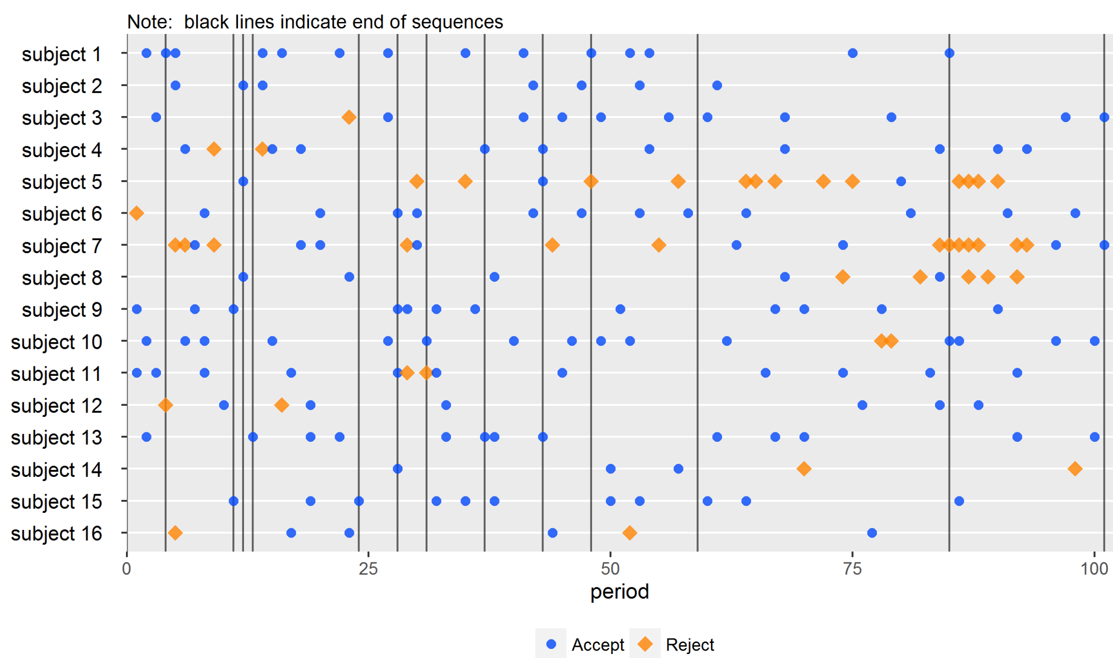
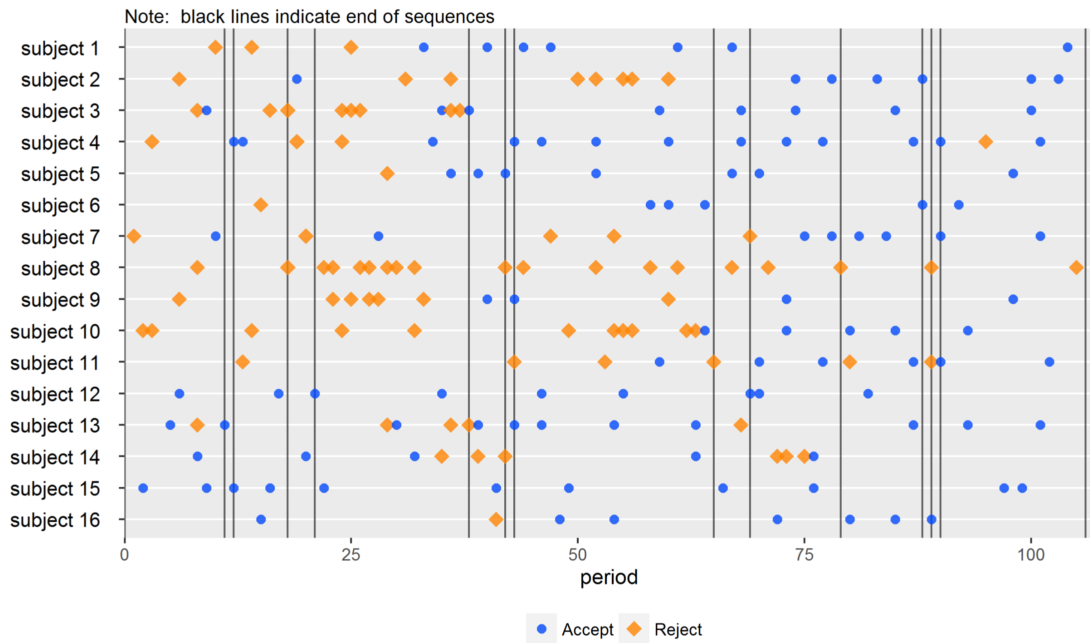


Figure 9: Blue Ticket Acceptance Decisions: Sessions 3

(a) Barter Treatment



(b) No Barter Treatment

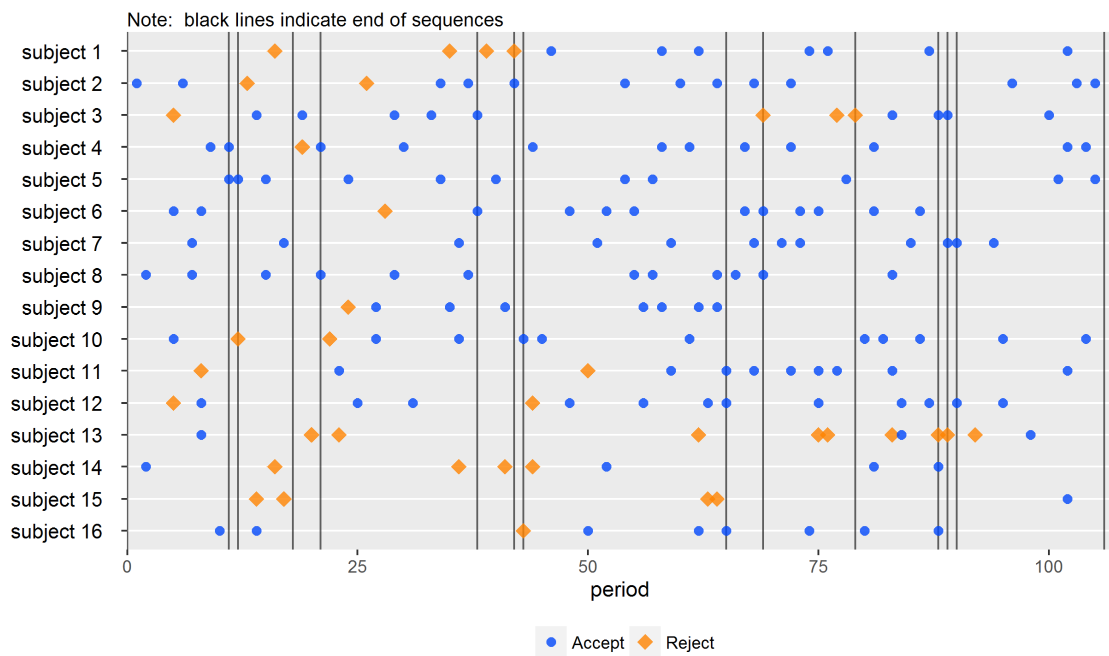
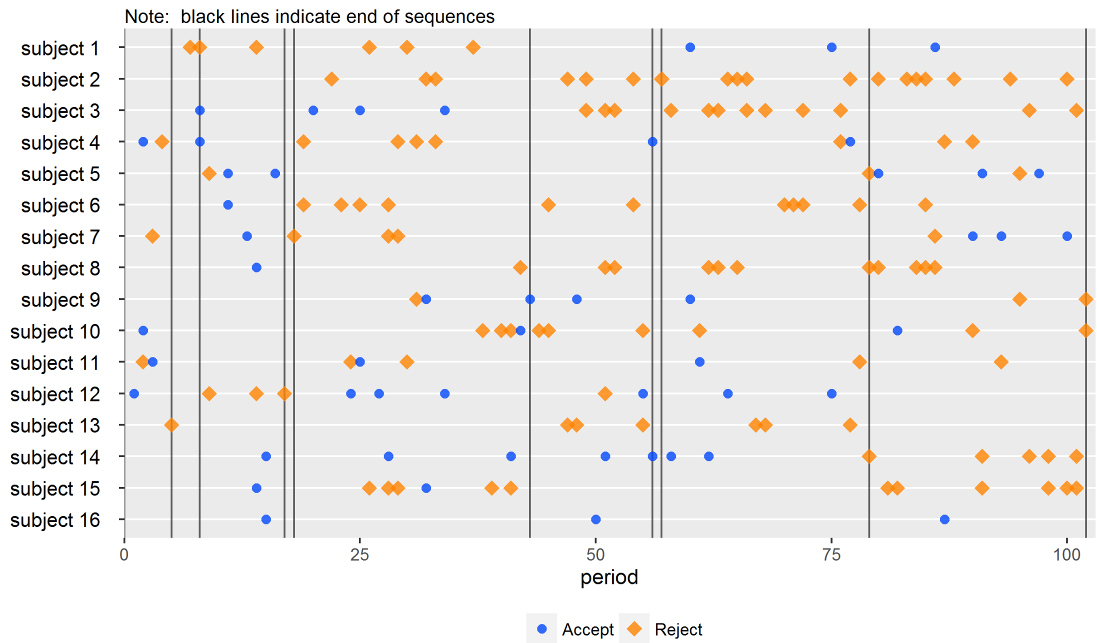
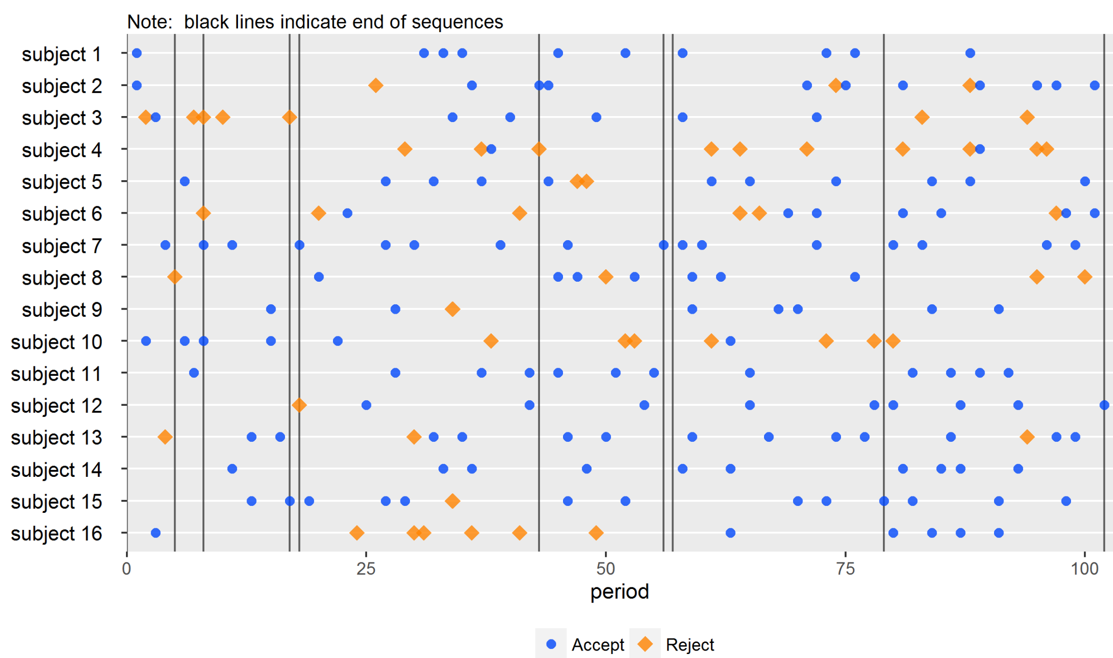


Figure 10: Blue Ticket Acceptance Decisions: Sessions 4

(a) Barter Treatment



(b) No Barter Treatment



7 Discussion

For a currency to become a generally accepted medium of exchange, people must believe that if they accept the currency in trade, they will in turn be able to trade the currency for goods or services in the future. For a commodity or commodity-backed money, the value of the money outside of exchange encourages this belief. However, with token money, generating general acceptance is more complicated, as beliefs about acceptance may unravel: if people believe no one will accept the money in the future, they are not willing to accept the money in the present, a process that becomes a self-fulfilling prophesy. When an existing, generally accepted medium of exchange already exists, the need to accept a new money is greatly reduced, thus further complicating the acceptance dynamic.

In this paper, I analyze this dynamic by testing a dual currency, money search model in a controlled laboratory setting. I find that even when a fully accepted currency already exists an economy, a secondary currency may still be readily accepted. Moreover, this acceptance is significantly higher when barter does not exist, highlighting the benefit of money in overcoming a lack of a double coincidence of wants. In contrast, in an economy in which barter does exist, acceptance of a secondary currency does exhibit the potential to unravel.

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Supplementary Materials

Quiz Questions

1) At the end of a period, what is the chance that the sequence will continue with a new period?

__ 0 in 10

__ 1 in 10

__ 2 in 10

__ 3 in 10

__ 4 in 10

__ 5 in 10

__ 6 in 10

__ 7 in 10

__ 8 in 10

__ 9 in 10

__ 10 in 10

2) If you meet a good holder, what is the chance that you can consume the good holder's good?

__ 0 in 10

__ 1 in 10

__ 2 in 10

__ 3 in 10

__ 4 in 10

__ 5 in 10

__ 6 in 10

__ 7 in 10

__ 8 in 10

__ 9 in 10

__ 10 in 10

3) Which color of ticket is always accepted by the computer on a good holder's behalf when it is offered in trade for the good holder's good? __ blue __ red

4) Which color of ticket may be accepted or rejected by a good holder when offered in trade for the good holder's good? __ blue __ red

5) When you enter a new sequence after completing a previous sequence, do you keep your item from the previous period? __ yes __ no

Instructions

Below are the instructions first for 1) the barter treatment and then 2) the no barter treatment.