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Transfer Paradox in a General Equilibrium Economy: a First Experimental Investigation

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Abstract: The transfer paradox, whereby a transfer of resources that influences the equilibrium price benefits the donor while harming the recipient, is a classic paradox in general equilibrium theory. This paper pursues an experimental investigation of the transfer paradox using a theoretical framework of a three-agent pure exchange economy that is predicted to have such a paradox. Two treatments were conducted. In the first treatment, there was one subject for each agent role in the experimental economy. In the other treatment, there were five subjects for each agent role (a total of 15 subjects) in the experimental economy. The experiment results indicate that a transfer of endowments among agents influenced the market clearing price, and consequently the donors benefited from this transfer, consistent with the competitive equilibrium theory. The equilibrium effects were strongest in the treatment with larger group size, resonating with the idea that having a larger number of market participants encourages them to behave competitively. Further, when given an option to make a transfer, the majority of the donor agents endogenously decide to adjust the endowment distribution. A detailed analysis found that the subjects' decisions to transfer were mainly driven by the equilibrium effects on prices, and their decisions were largely unaffected by their measured level of cognitive ability.

Keywords: experiments, transfer paradox, general equilibrium, equilibrium effects

JEL codes: C92, D51

1. Introduction

The transfer paradox in a general equilibrium economy is a well-known phenomenon in which an adjustment in endowments among agents may benefit the donors while harming the recipients. This paradox arises from the strong impact that the endowment transfer has on equilibrium prices.

The transfer paradox was first discussed in Leontief (1936), and has been extensively studied by a number of scholars in various fields, not only from a theoretical perspective, but also in applications to international economics, development economics, and public economics. Seminal contributions include

Samuelson (1947), Gale (1974), Aumann and Peleg (1974), Chichilnisky (1980, 1983), Polemarchakis (1983), Yano (1983), Bhagwati, Brecher and Hatta (1983), Leonard and Manning (1983), Safra (1984), and Rao (1992). As summarized by Turner (2016), this paradox can emerge in a regular equilibrium even in the simplest setup with two commodities and two agents, but only in unstable tâtonnement (Samuelson, 1947). In models with more than two agents, this paradox can also emerge in a stable equilibrium.

The transfer paradox offers many insights of real-world interest, such as the redistribution of incomes from high to low income groups within countries and aid flows across countries.[1] Yet the question as to whether the transfer paradox occurs in real human societies remains unclear. Unlike the rich body of theoretical research on the topic, surprisingly no attention has been paid to the paradox in a general equilibrium economy in the experimental literature. It is also almost impossible to explore the validity of the paradox using empirical data due to the difficulty in modeling the economic situation appropriately under controlled conditions. Thus, there is a clear advantage of bringing laboratory methods to bear, which enable us to control for potential confounds and causally study the transfer paradox.

This paper is the first experimental investigation regarding the validity of the transfer paradox in a controlled environment. The experiment is designed based on a three-agent pure exchange economy with two goods. Three agents have Leontief payoff functions whose preference parameters differ by the agent role. The three agents also differ by their initial endowment. Subjects submit their demand or supply schedules for trading, and their trading price in a given market is determined by market clearing (the trading quantity is determined by the market clearing price and their demand or supply schedules). Two research questions are examined. First, does an adjustment of endowments among agents influence the equilibrium price in line with the competitive equilibrium predictions, thereby potentially benefiting the donors and hurting the recipients? Second, if yes, can such a transfer of endowments be initiated by the agents endogenously?

The aggregate experimental data reveal that a transfer of endowments from one agent to another influences the market clearing prices as the competitive equilibrium theory would suggest. This results in the donor earning a higher payoff post-adjustment. Further, when given an option to make a transfer, the majority of the donor agents endogenously decide to adjust the endowment distribution. A closer analysis indicates that the mechanism through which transfer decisions work is via the equilibrium effects on trading prices and payoffs. Cognitive ability does not play an important part. These findings lend support to the predictive power of the competitive equilibrium theory and the possible existence of the transfer paradox in the real world.

The rest of the paper proceeds as follows: Section 2 describes the experimental design. Section 3 summarizes the results and Section 4 concludes.

[1] Some theorists explicitly modelled such real world situations (e.g., Chichilnisky [1980, 1983] for income distributions within a country).

2. Experimental Design

This study employed a standard simple framework discussed in the theoretical literature. A three-agent pure exchange economy is selected as the basis of experiments, since the transfer paradox is theoretically a rare phenomenon in a two-agent pure exchange economy (Turner, 2016).

To my knowledge, a challenge confronted in empirically exploring the transfer paradox in realistic setups proposed by prior influential papers, such as Chichilnisky (1980, 1983), is that the set of endowments and preference parameters that lead to a paradox is usually small even in a three-agent economy.[2] For example, in the three-income-group framework of Chichilnisky (1980, 1983), restrictive Condition (C.1) [Chichilnisky, 1980, page 509] must be satisfied. In addition, the sufficient condition, (C.3) [Chichilnisky, 1983, page 239], is also restrictive.

Polemarchakis (1983) developed a nice framework for a three-agent pure exchange economy in which the set of parameters that leads to a transfer paradox is not so restrictive. Kang and Rasmusen (2016) recently provided a very useful numerical example based on Polemarchakis (1983). The experimental design of this paper is built on these two papers.

2.1. The Experiment

There are two goods, numeraire (*x*) and iron (*y*), in an experimental pure exchange economy. Hereafter, ECU (experimental currency unit) and kg are used to refer to the units of numeraire and iron in the paper.[3] There are three types of agents, who each have the following Leontief payoff function (Polemarchakis, 1983):

$$u_i(x, y) = \min\{\lambda_i x, y\}, \text{ for } i = 1, 2, 3. \tag{1}$$

Hereafter, points are used to refer to the unit of an agent's utility throughout the paper. The agents have different preference parameters (λ_i), as described in Table 1. They also have different initial endowments so that Agent 1 (*i* = 1) can increase his or her payoff by buying iron, while Agent 2 (*i* = 2)

Table 1. *Experimental Parameters*

	The distribution of λ_i	Initial endowment	Competitive equilibrium
A: Before transfer	$\lambda_1 = 2, \lambda_2 = 1, \lambda_3 = 3$	$(w_1, w_2, w_3) = \left(\begin{bmatrix}100\\20\end{bmatrix}, \begin{bmatrix}20\\100\end{bmatrix}, \begin{bmatrix}0\\80\end{bmatrix}\right)$	$\left(p_y, \begin{bmatrix}x_1\\y_1\end{bmatrix}, \begin{bmatrix}x_2\\y_2\end{bmatrix}, \begin{bmatrix}x_3\\y_3\end{bmatrix}\right) = \left(1, \begin{bmatrix}40\\80\end{bmatrix}, \begin{bmatrix}60\\60\end{bmatrix}, \begin{bmatrix}20\\60\end{bmatrix}\right)$
B: After transfer		$(w'_1, w'_2, w'_3) = \left(\begin{bmatrix}80\\20\end{bmatrix}, \begin{bmatrix}40\\100\end{bmatrix}, \begin{bmatrix}0\\80\end{bmatrix}\right)$	$\left(p_y, \begin{bmatrix}x_1\\y_1\end{bmatrix}, \begin{bmatrix}x_2\\y_2\end{bmatrix}, \begin{bmatrix}x_3\\y_3\end{bmatrix}\right) = \left(0.2, \begin{bmatrix}60\\120\end{bmatrix}, \begin{bmatrix}50\\50\end{bmatrix}, \begin{bmatrix}10\\30\end{bmatrix}\right)$

Note: p_y is the price of iron (ECUs/kg).

[2] See also Rao (1992) to generalize the paradox by providing its necessary and sufficient conditions in a three-agent globally Walrasian stable economy.

[3] These terms were also used in the experiment sessions.

and Agent 3 (i = 3) can do so by selling iron (Kang and Rasmusen, 2016). At the onset of the experiment, subjects are randomly assigned a role – Agent 1, 2 or 3. The assigned role is fixed throughout the experiment.

As summarized in Table 1, the initial endowments of the three types of agents before any transfer takes place are: $(w_1, w_2, w_3) = \left(\begin{bmatrix} x_{1w} \\ y_{1w} \end{bmatrix}, \begin{bmatrix} x_{2w} \\ y_{2w} \end{bmatrix}, \begin{bmatrix} x_{3w} \\ y_{3w} \end{bmatrix}\right) = \left(\begin{bmatrix} 100 \\ 20 \end{bmatrix}, \begin{bmatrix} 20 \\ 100 \end{bmatrix}, \begin{bmatrix} 0 \\ 80 \end{bmatrix}\right)$. For the given preference parameters, Agent 1 can increase his or her payoff by giving away some ECUs to Agent 2, because such a transfer significantly decreases the equilibrium price of iron. The Appendix provides a simulation result for the detail. It indicates that the payoff of Agent 1 (the donor) is increasing with the size of transfer of ECUs (t), while conversely the payoffs of Agent 2 (the recipient) and Agent 3 (the third party) are decreasing with the size of transfer, provided that $t \leq 20$. A simple setup is desired since this is the first experiment study and also the transfer paradox is a counter-intuitive phenomenon. Subjects' behaviors in a laboratory are also usefully known to be heterogeneous. For these reasons, this study uses t = 20 in the experiment to make the payoff benefits of the transfer theoretically large to the donor subjects (Table 1). Subjects are unlikely to have prior knowledge about the paradox under study.

The experiment consists of two treatments, called S (Small Group treatment) and L (Large Group treatment). The group size is three and 15 in the S and L treatments, respectively. There are one Agent 1, one Agent 2 and one Agent 3 in each transaction group of the S treatment. By contrast, there are five subjects for each agent role in each interaction group of the L treatment. In many real-world settings, there are multiple donors and recipients, such as income groups, regions, or countries. Transfer decisions can be made collectively through international agencies as cross-country cooperation to fight poverty in developing countries or to combat an international crisis. The L treatment is therefore a step to increase the external validity of the experiment.

The experiment consists of three parts. Part 3 varies between the S and L treatments. Subjects are given instructions for each part separately at the onset of each part so that subjects have an opportunity to learn each environment, one by one. This would help reduce cognitive loads (see online supplementary materials for the instructions).

In Part 1, three or 15 agents interact with each other under the initial endowment conditions in each period without having an option to transfer (Table 1). At the onset of Part 1, in addition to the instructions, tables summarizing the relationship between buying or selling quantity of iron and payoffs are provided to subjects, in order to mitigate the difference in mathematical literacy among subjects.

In Part 2, three or 15 agents interact with each other on condition that 20 ECUs of money are forced to be transferred from Agent 1(s) to Agent 2(s), i.e., the endowment conditions after transfer (cf. Table 1). The transfer decreases the equilibrium price of iron from 1 ECU/kg to 0.2 ECUs/kg theoretically (also see the Appendix). The transfer is always implemented exogenously and without involving Agent 1s' decisions. As in Part 1, subjects are provided with tables that explain how their trading affects payoffs before Part 2 begins. As summarized in Table 1, this transfer theoretically benefits (hurts) Agent 1s (Agent 2s and 3s).

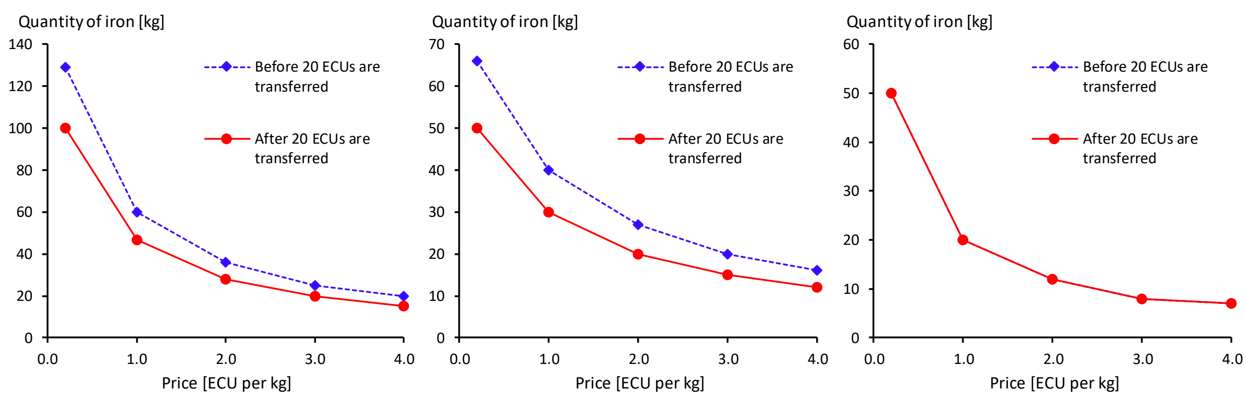
By comparing the market outcomes between Parts 1 and 2, the impact of the transfer on the market clearing price and payoffs can be examined without selection bias.[4] Subjects also gain experiences in both environments and of the transfer's possible effects.

In Part 3, Agent 1(s) decides whether to transfer 20 ECUs to Agent 2(s) before their interactions begin. After that, agents trade iron with each other under the selected endowment conditions.

Trading rule and detailed structure:

Trading is implemented based on the Clearinghouse (call market). There are five possible trading prices: 0.2, 1.0, 2.0, 3.0, and 4.0 ECU(s) per kg. At the onset of Part 1, Agent 1s decide how many kg of iron they want to buy for each possible price ("demand schedule," hereafter). Simultaneously, Agent 2s and 3s independently decide how many kg of iron they want to sell for each possible prices ("supply schedule," hereafter). These are the only decisions made by the agents in Part 1. Agent's competitive behaviors predicted by the theory can be found in Figure 1.

Figure 1. *Agents' Demand and Supply Schedules Predicted by the Competitive Market Theory*



(*a*) Agent 1's demand schedule (*b*) Agent 2's supply schedule (*c*) Agent 3's supply schedule

Note: The Agent 3's schedule is not affected by the forced transfer implemented in Part 2.

Once all agents have completed the demand/supply schedules, a series of interactions begin in their session. There are four periods in Part 1. The structure of each period is identical: first, subjects are randomly assigned to an interaction group of three so that the group has one Agent 1, one Agent 2 and one Agent 3 in the S treatment (a group of 15 so that the group has five Agent 1s, five Agent 2s and five Agent 3s in the L treatment). After that, the trading price is determined by the market clearing condition as in the Clearinghouse. That is, the computer calculates the difference between (a) the total quantity of iron Agent 1(s) wants to buy and (b) the total quantity of iron Agent 2(s) and 3(s) want to sell in that

[4] The terms "market clearing price" and "equilibrium price" are used interchangeably in the paper.

group, for each possible price (i.e., 0.2, 1, 2, 3 or 4 ECU(s) per kg). The price that minimizes the difference (i.e., equates the demand and the supply as close as possible) will then be implemented for trading. Ties are broken by the computer at random.[5] Subjects are informed of the market clearing price, their trading outcome and own payoffs at the end of the period. The demand and supply schedules completed at the outset are used for all four periods within this part. A given period's outcome does not affect the grouping process in the following period. It is worth noting that the trading outcomes may be affected by a specific group's composition. Subjects can experience average market outcomes in their own sessions by allowing them to interact with others four times under random matching.

Part 2 proceeds exactly the same as Part 1, except that the initial per-period endowments are given by: $(w'_1, w'_2, w'_3) = \left(w_1 - \begin{bmatrix}20\\0\end{bmatrix}, w_2 + \begin{bmatrix}20\\0\end{bmatrix}, w_3\right) = \left(\begin{bmatrix}80\\20\end{bmatrix}, \begin{bmatrix}40\\100\end{bmatrix}, \begin{bmatrix}0\\80\end{bmatrix}\right)$. Agent 1s complete demand schedules, while Agent 2s and 3s complete supply schedules – see Figure 1 for the agents' competitive behaviors predicted by the theory. These scheduled are used for transactions in each of the four periods in this part.

In Part 3, subjects also have initial endowments as in Part 1. However unlike in Parts 1 and 2, at the onset of this part, Agent 1(s) have an option to give away 20 ECUs of money to Agent 2(s) (i.e., Agent 1(s) can change the endowment conditions from those in Part 1 to those in Part 2). While the transfer decision is made unilaterally in the S treatment, it is based on majority voting by five Agent 1s in the L treatment (Table 2).[6] This part proceeds as follows: at the beginning of Part 3 subjects are randomly assigned to an interaction group of three (15) in the S (L) treatment, immediately followed by the transfer decision by Agent 1(s). Once Agent 1(s) has made the transfer decision, the agents in a given group are informed of the transfer outcome, and then complete the demand or supply schedules (dependent on their role). The trading price and quantities are then implemented based on the market clearing condition, as already discussed. To reduce the complexity of the design, there is only one period in Part 3.[7] In order to make the stake in Part 3 comparable to those in Parts 1 and 2, the conversion rate between points and pounds sterling is set four times higher in Part 3 than in the first two parts.[8]

It is worth noting that an alternative way to design the experiment would have been to let agents

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[5] The quantities of iron Agent 1s buy, and Agent 2s and 3s sell will be determined by the schedules they have already completed and the market clearing price. For example, if the amount Agent 1(s) wants to buy is larger than or equal to the sum of the amounts Agent 2(s) and 3(s) want to sell, then Agent 2(s) and Agent 3(s) can sell the exact amounts they want to sell. Agent 1(s) then buys the total quantity supplied in the S treatment (each Agent 1 buys $100q_{1,i}/Q_d$ [%] of the quantity supplied, where $Q_d = q_{1,1} + q_{1,2} + q_{1,3} + q_{1,4} + q_{1,5}$, in the L treatment).
[6] A transfer will be implemented when at least three Agent 1s support the transfer.
[7] If there were more than one period, Agent 2s and 3s might encounter Agent 1s who wish to transfer 20 ECUs in some periods, and Agent 1s who do not wish to do so in other periods. We would then have required subjects to complete demand or supply schedules for the two regimes (one for the Part 1 regime and the other for the Part 2 regime).
[8] 100 ECUs are exchanged for 1.5 and 6.0 pounds sterling in Parts 1 to 2 and Part 3, respectively.

Table 2. *Summary of Treatments*

Treatment:	Transfer process in Part 3	# of sessions	# of subjects
S (Small Group)	Agent 1 in a group decides unilaterally.	4	72
L (Large Group)	Five Agent 1s vote (majority voting).	4	120
Total		8	192

Note: Each session in the S (L) treatment has 18 (30) subjects.

trade with each other using double auctions. For example, Gode, Spear and Sunder (2004) showed experimentally that under a double auction mechanism, trading prices converge to the competitive equilibrium price predicted by the standard theory in a two-good, two-agent pure exchange economy. Similarly, a multi-unit double auction format could be used in the present study' setup. As this study is the first to test the transfer paradox, however, a double auction mechanism was not used because the volatility of the trading prices was quite large (Gode, Spear and Sunder, 2004). High volatility is problematic for the aim of this paper, because the transfer paradox is a subtle effect, counter-intuitive to subjects. The impact of such volatility is arguably small if the simple call market is instead used.

2.2. Additional Tasks

Subjects' decisions to transfer may require high levels of cognitive ability. To control for this in the data analyses, three measures of cognitive ability are elected from subjects. First, subjects are asked to answer the Cognitive Reflection Test – CRT hereafter – consisting of three questions (Frederick, 2005) immediately after the main trading experiment.[9] Following this task, subjects are also asked to engage in a beauty-*p* contest in their sessions (Nagel, 1995). Responses to the beauty-*p* contest can be used to control for subjects' strategic sophistication. Finally, in the exit questionnaire at the end of the experiment, subjects are asked to answer their college entrance exam mathematics grade (A-level grade in the United Kingdom). The exit questionnaire also asks for demographic information about gender and academic majors (e.g., economics, arts).

3. Results

The experiment was conducted at the Centre for Experimental Economics laboratory in the University of York. Solicitation messages were sent through *hroot* (Bock, Baetge and Nicklisch, 2014) to all eligible subjects in the database, and a total of 192 undergraduate students there voluntarily participated in the experiment (Table 2). The experiment, except the instructions and payoff tables, was programmed using the zTree software (Fischbacher, 2007). Subjects were given enough time to review

[9] The CRT measures subjects' ability to analyze and correct initial intuitive responses (i.e., System 2 thinking).

the payoff tables and also to ask questions to the experimenter.

This section begins in Section 3.1 by discussing the effects of transfer on market clearing price and payoffs. Then, Section 3.2 explores how Agent 1s made their transfer decisions in Part 3 using the data at the individual level.

3.1. The Impact of Transfer in the Lab

The main research questions in this paper are two-fold: whether a transfer of money from Agent 1 to Agent 2 influences equilibrium outcomes consistent with the transfer paradox; and whether Agent 1 voluntarily makes such a transfer when given the option in Part 3.

Market clearing prices:

We find evidence from both treatments to support that subjects' demand and supply schedules elicited in the laboratory were roughly consistent with competitive behaviors.

For the S treatment, Figure 2 shows aggregate demand and supply schedules based on the median of subjects' responses to each price level.[10] The excess demand is zero when the price is greater than 1 ECU/kg in Part 1. By contrast, it is zero when the price is less than 1 ECU/kg in Part 2 (where 20 ECUs were forcibly transferred from Agent 1 to Agent 2). This pattern holds also for Part 3, for which the price at which excess demand is zero is lower when 20 ECUs were transferred from Agent 1 than otherwise.

Figure 3 reveals similar patterns for the L treatment. In order to make the demand and supply schedules comparable to the S treatment, the schedules were depicted based on the median of each agent type's set of responses to a given price level. The figure shows that the market clearing price is 1 ECU/kg in Part 1 or in Part 3 where 20 ECUs were not transferred from Agent 1s to Agent 2s. However, the price is 0.2 ECUs/kg in Part 2 or in Part 3 where the 20 ECUs were transferred. Thus, these market clearing prices for the L treatment are indeed in line with those predicted by the competitive equilibrium theory (Table 1).

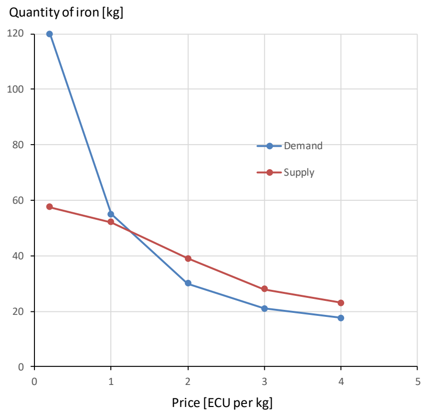
In sum, both Figures 2 and 3 suggest that the transfer decreases the market clearing price as the theory predicts, whether the transfer of money is forced or is endogenously decided by Agent 1s. One may wonder how frequently Agent 1s actually made the transfer in Part 3, given the option to do so. This is the second research question of the paper. The data show interestingly that 58% and 50% of Agent 1s did make the transfer by themselves in Part 3 in the S and L treatments, respectively. This suggests that the transfer paradox phenomenon can indeed be initiated by human decision-makers.

Result 1: *(a) Median agents' demand and supply schedules were roughly consistent with the competitive equilibrium prediction. The realized market price was lower after, rather than before, 20 ECUs were*

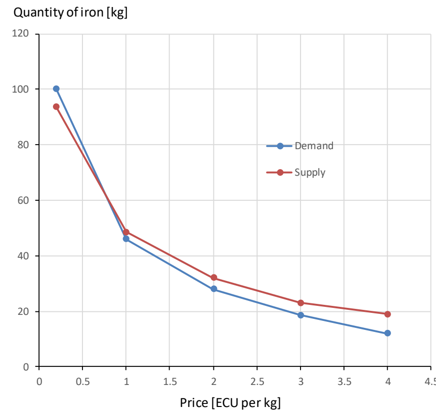
[10] The median is used to study the overall patterns because the raw data indicate strong heterogeneity in individual schedules, as will be discussed later (see also Figures S.1 and S.2 in the supplementary materials).

transferred from Agent 1(s) to Agent 2(s). (b) At least half of Agent 1s endogenously chose to transfer money to Agent 2s in Part 3.

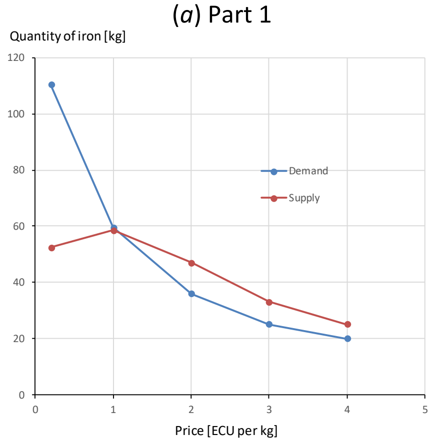
Figure 2. *Median Aggregate Demand and Supply Schedules in the S treatment*



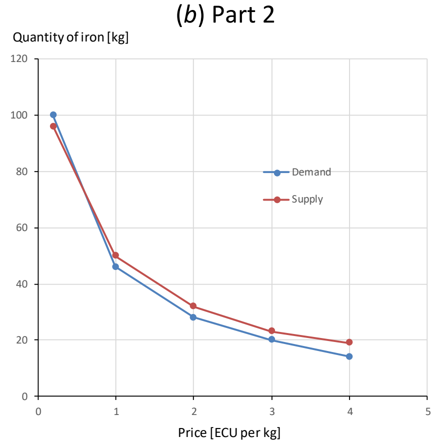
(*a*) Part 1



(*b*) Part 2



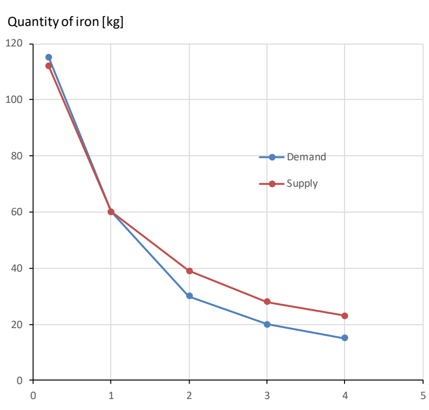
(*c*) Part 3 (Not Transferred)



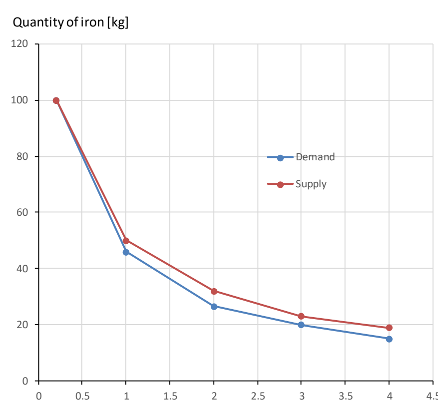
(*d*) Part 3 (Transferred)

Notes: The quantity demanded for each price is the median of all responses made by Agent 1s, while the quantity supplied for each price is the sum of the median Agent 2 and the median Agent 3 responses, in a given panel.

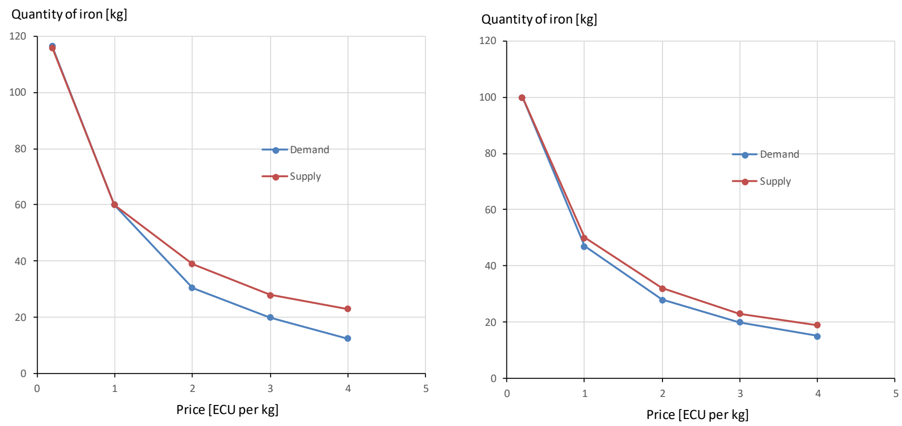
Figure 3. *Median Aggregate Demand and Supply Schedules in the L treatment*



(*a*) Part 1



(*b*) Part 2



(*c*) Part 3 (Not Transferred)#　　　　(*d*) Part 3 (Transferred)

Notes: The quantity demanded for each price is the median of all responses made by Agent 1s, while the quantity supplied for each price is the sum of the median Agent 2 and the median Agent 3 responses, in a given panel. # The excess demands per Agent 1 were 0.5 kg and 0 kg when the prices are 0.2 ECUs/kg and 1 ECU/kg, respectively (as there are five Agent 1s per group, the excess demand is 2 kg per group when the price is 0.2 ECUs/kg).

Market clearing payoffs:

The effects of transfer on payoffs are quite sensitive to the discrete nature of price realization, despite Result 1. Recall that there were only five possible trading prices in the experiment (= 0.2, 1.0, 2.0, 3.0 or 4.0 ECUs/kg).

In the S treatment, the market clearing price realized was 1 ECU/kg in both Part 1 and Part 2 according to the subjects' median behaviors, hence not leading to perverse effects of transfer in aggregate between the exogenous parts. Using the median demand and supply schedules in panels *a* and *b* of Figure 2 and the agents' payoff formulas, a calculation finds that the payoff of the median Agent 1 decreased through the forced transfer in Part 2, while the payoffs of the median Agent 2 and Agent 3 each increased (Figure 4.*a*.*i*). This implies that the transfer acts hurt donors, but benefited recipients and third parties.

Nevertheless, a beneficial effect of transfer for donors was observed in Part 3 of the S treatment. As in Part 1, the market clearing price was 1 ECU/kg when Agent 1 did not make the transfer in Part 3 (panel *c* of Figure 2). However, the price was exactly at the midpoint between 0.2 ECUs/kg and 1.0 ECU/kg when the transfers were made endogenously (panel *d* of Figure 2).[11] The payoff of the median Agent 1 increased by the transfer, while the median Agent 2 and Agent 3 each received lower payoffs, according to the payoff formulas (Figure 4.*a*.*ii*). Hence, in Part 3, the transfer paradox emerged.

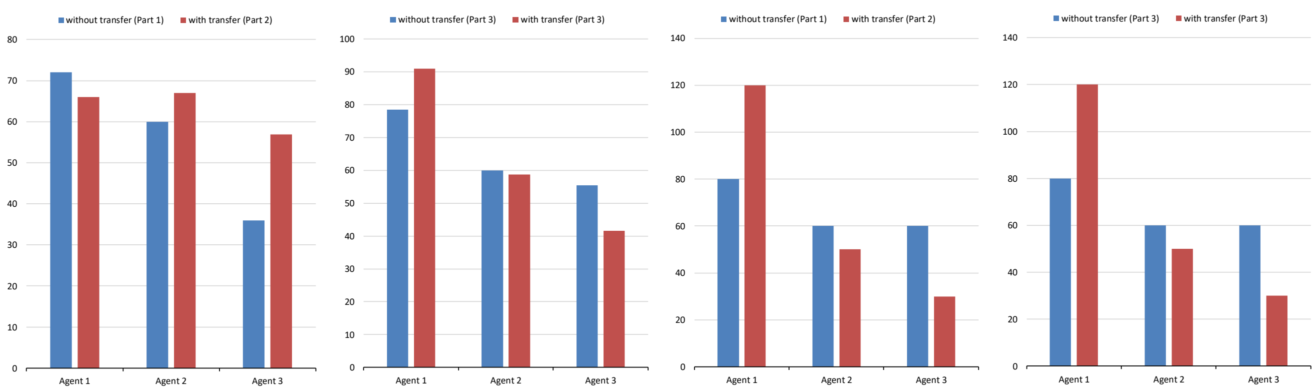
A transfer paradox was witnessed among the median agents in the L treatment (Figure 4.*b*). The comparatively stronger result may be due to the larger group size, whereby theoretically encouraging agents to behave more competitively (recall that the impact of each agent's schedule on the market

[11] The excess demands were 4.0 and -4.0 kg when the prices were 0.2 and 1.0 ECU(s)/kg, respectively

price is 6.7% = 1/15×100% only). As discussed, the market clearing price was 1 ECU/kg for Part 1 and 0.2 ECUs/kg for Part 2 in the L treatment (panels *a* and *b* in Figure 3). A calculation based on the median demand and supply schedules in Figure 3 and the agents' payoff formulas finds that (a) the median Agent 1 received 80 ECUs in Part 1, but 120 ECUs in Part 2, while (b) the median Agent 2 and Agent 3 received 60 ECUs and 60 ECUs in Part 1, but 50 ECUs and 30 ECUs in Part 2, respectively.

Similar effects were likewise observed among the median agents in Part 3 of the L treatment. As shown in panels *c* and *d* of Figure 3, the market clearing price was 0.2 ECUs/kg when Agent 1s collectively transferred 20 ECUs to Agent 2s, while it was 1 ECU/kg when they did not do so. A calculation finds that as in Part 1, the median Agent 1 in the transfer group received 120 ECUs, while the median Agent 1 in the no-transfer groups received 80 ECUs. The median Agent 2 and 3 in the non-transfer groups (transfer groups) received 60 ECUs (50 ECUs) and 60 ECUs (30 ECUs), respectively.

Figure 4. *Median Agents' Payoffs Based on Figures 2 and 3*



(*i*) Parts 1 and 2 (*ii*) Part 3 (*i*) Parts 1 and 2 (*ii*) Part 3

(*a*) S treatment (*b*) L treatment

Note: Payoffs in the S (L) treatment were calculated based on Figure 2 (Figure 3) and Equation (1).

Result 2: *Consistent with the transfer paradox hypothesis, a transfer of 20 ECUs from Agent 1s to Agent 2s benefited Agent 1s, but hurt Agent 2s in the L treatment. Such a paradox was also observed among the agents in Part 3 of the S treatment.*

Individual heterogeneity:

A closer look at individuals' demand and supply schedules indicates substantial heterogeneity in responses across treatments (see Figures S.1 and S.2 in the supplementary materials). Many subjects seemingly exhibited strategic behavior, attempting to influence the market clearing prices.[12]

[12] One may argue that these behaviors happened due to some subjects' limited cognitive ability. This is less likely, however, since subjects were given detailed payoff tables that summarize the relationship between traded quantity of iron and payoffs in the experiment in addition to the instructions (Section II of the supplementary materials).

First, certain subjects' willingness to buy or sell did not decrease significantly as the trading price rises in the schedules, unlike the competitive market theory prediction (Figure 1). This was the case for 41.7% (47.5%) of Agent 1s, 87.5% (62.5%) of Agent 2s and 75.0% (32.5%) of Agent 3s in at least one out of the three parts in the S (L) treatment.[13] Interestingly, such behaviors by the Agent 2s and 3s were stronger in the S than in the L treatment. This again resonates with the idea that having a larger number of market participants encourages them to behave competitively.

Second, some buyers (Agent 1) indicated that they would not buy anything when the purchase price is the highest. Likewise, some sellers (Agent 2 or 3) indicated that they would not sell any amount if the price is the lowest. This also contradicts agents' competitive profit maximization behaviors visible from the instructions and payoff tables distributed to the subjects. According to Figures S.1 and S.2, 37.5% (47.5%) of Agent 1s, 45.8% (32.5%) of Agent 2s and 33.3% (17.5%) of Agent 3s exhibited such responses in at least one out of the three parts in the S (L) treatment.[14]

Due to random matching (Section 2), the level of independent observations is the session. Each session's median demand and supply schedules are reported in Figures S.3 and S.4 of the supplementary materials. These schedules differ substantially by the session due to the large heterogeneity at the subject level.[15] In support of a main part of Result 2, however, the median Agent 1s benefited from forced transfers in two out of four sessions in the S treatment (panel A of Figure S.3), and in three out of four sessions in the L treatment (panel A of Figure S.4). The increase in the median Agent 1's payoffs through transfer is significant if data from all eight session are used (p = .0479, one-sided t test).[16] Moreover, the minimum trading price, 0.2 ECUs/kg, was realized in four out of eight sessions in Part 2, but it was only observed once in Part 1, parallel to Result 1. Beneficial effects on the donors' payoffs were seen also for endogenous transfers in Part 3 in three out of four sessions in the S treatment (panel B of Figure S.3).

As will be addressed in the next sub-section, the diverse demand and supply schedules are useful for the purpose of this paper, since they make it possible to explore Agent 1s' motives for their transfer decisions in Part 3. Such heterogeneity, however, also means that trading outcomes in any

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[13] The percentage differences between the S and L treatments are significant for Agent 2s and 3s (two-sided p = .0313 and .0010, respectively, according to two-sample tests of proportions), but not significant for Agent 1s (two-sided p = .6518).

[14] These percentages are not significantly different between the S and L treatments according to two-sample tests of proportions (two-sided p = .3656, .2230, and .1045 for Agent 1s, 2s and 3s, respectively).

[15] Some median schedules did not monotonically decrease as the price increased. There were also cases where the median demand schedule did not intersect with the median supply schedule in some sessions.

[16] The change in the median Agent 2's payoff through transfer is not significant unlike Figures 2 and 3 (p = .1669, one-sided t test). Importantly, however, this test result and Result 2 mean that Agent 2 did not benefit from the transfer. One-sided tests were used when comparing the effects of transfer since the theory predicts a specific direction. The null hypothesis is that the transfer does not benefit (does not hurt) the donor (recipient). In these tests, sessions were used as the unit of independent observations.

period largely depend on group composition; hence, realized trading prices likely differ substantially dependent on the identity of Agent 1. This interpretation in fact turned out to be correct in the data. Table S.1 in the supplementary materials reports the distribution of realized trading prices subjects experienced. Unlike the aggregate result reported in Figures 2 and 3, any trading price was possible in the experiment, dependent on a subject's match. Nevertheless, importantly, the price 0.2 ECUs/kg was significantly more likely to occur in Part 2 than in Part 1 in both the S and L treatments (Table S.1), in statistical support of Result 1 and Figures 2 and 3.

Result 3: *(a) Individual demand and supply schedules were heterogeneous. (b) A large number of subjects, whether buyers or sellers, exhibited seemingly strategic behaviors. As a result, (c) each of the five prices was realized, dependent on the group composition. (d) Consistent with the competitive equilibrium prediction, the minimum price was more frequently realized when the transfers were implemented than otherwise in both the S and L treatments.*

3.2. What motivates Agent 1s to Transfer ECUs to Agent 2s?

The rest of Section 3 reports an analysis of the Agent 1s' transfer decisions in Part 3, utilizing their heterogeneous behaviors (Result 3).

Figure 5 summarizes average relative prices and payoffs experienced by Agent 1s in Parts 1 and 2 of the experiment, before and after the exogenously imposed transfer. The relative payoff (price) was calculated by a given agent's average payoff (price) in Part 2 divided by that in Part 1. Consistent with the observations in Section 3.1, there is an inverse relationship between the relative prices in the market and the relative payoffs of donors in each treatment. The impact of the forced transfer on the relative prices is, however, not uniform across the donors, due to Result 3. While there are many Agent 1s who experienced drops in the trading prices in Part 2 relative to Part 1, there are also many others who experienced the opposite. The impact of the transfer on payoffs also differs substantially by the donor. There are cases in which the relative payoffs are greater than, less than or equal to 1.

A detailed look at Figure 5 by individual voting decision reveals clear patterns. First, the relative payoffs realized in Parts 1 and 2 significantly affected Agent 1s' transfer decisions in Part 3. While 0.0% (14.3%) of Agent 1s decided to transfer when the relative payoffs realized in the exogenous parts were less than or equal to one, 73.7% (69.2%) of them decided to do so when the relative payoffs were greater than one in the S (L) treatment.[17] Second, the donors' experienced payoff changes can be explained by the equilibrium effects of the transfer. This is similar to the negative relationships between relative prices and payoffs seen in Section 3.1. While 68.4% (61.5%) of Agent 1s decided to transfer in

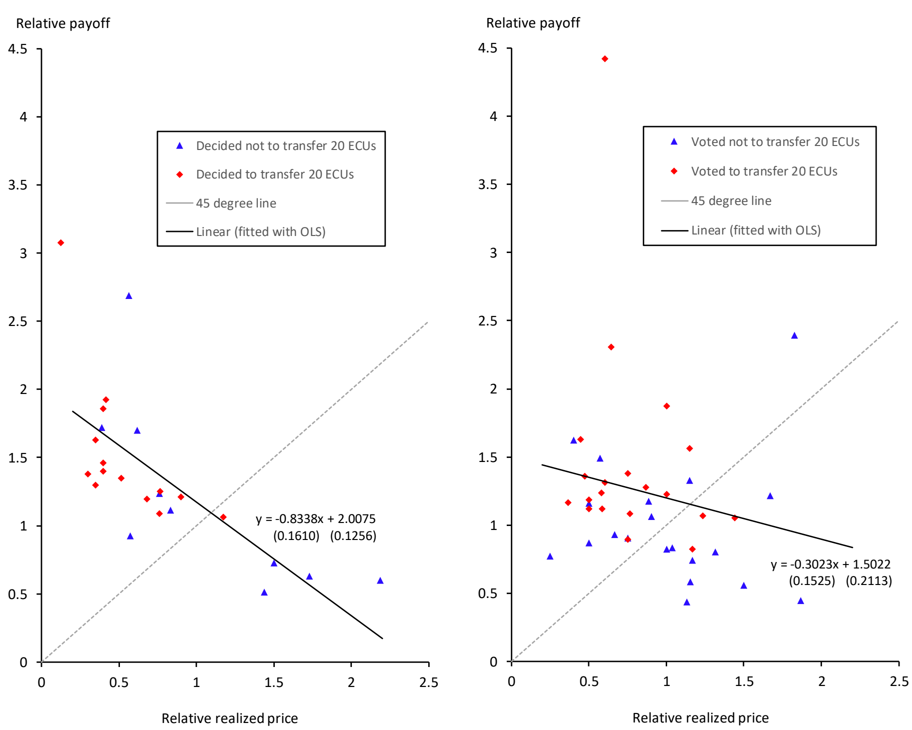
[17] A two-sample test of proportions finds that the frequency of the transfer decisions is significantly higher at two-sided $p = 0.0029$ ($p = 0.0009$) when the relative payoffs are greater than one than otherwise in the S (L) treatment.

Part 3 when average traded prices dropped with forced transfer in Part 2, only 20.0% (28.6%) of them decided to do so when average traded prices rose with transfer in Part 2 in the S (L) treatment.

Result 4: *The higher the payoff and the lower the traded price experienced by Agent 1s in Part 2 relative to Part 1, the more likely they were to make a transfer of 20 ECUs to Agent 2s in Part 3.*

In order to examine how demographic characteristics, such as cognitive ability, might influence Agent 1's transfer decisions, a regression was also conducted as an additional analysis. Since subjects experienced strong negative correlations between relative prices and payoffs in the two exogenous parts (Results 1–4), only one of these variables was included as an independent variable in a given regression specification. Since the two cognitive ability measures (CRT, A-level Math) may be related to each other, only one of the two measures was included as an independent variable in a given specification.[18]

Figure 5. *Difference in Interaction Outcomes between Without versus With Transfer, and Regime Choice*



(*a*) S treatment (*b*) L treatment

Notes: Each number on the x-axis was calculated by dividing the average realized price with forced transfer (Part 2) by the average realized price without such transfer (Part 1). Each number on the y-axis was calculated by dividing the average realized payoff with forced transfer (Part 2) by the average realized payoff without such transfer (Part 1). The linear line in panel *a* (*b*) was fitted to all data in the S (L) treatment. The numbers in parentheses in the linear equations are robust standard errors clustered by session.

[18] Table S.2 in the supplementary materials reports estimation results when the CRT scores and A-level Math grades were both controlled. The coefficient estimates for variables *a* and *b* are quantitatively unchanged.

Table 3 presents the estimation results. As shown in columns (1) and (3), the relative prices subjects experienced in the exogenous parts have significantly negative coefficients. In columns (2) and (4), the relative payoffs subjects experienced in the exogenous parts have significantly positive coefficients. Both reinforce Result 4.

By contrast, the estimation results indicate limited roles of subjects' cognitive ability for transfer behaviors. First, the Beauty contest response variable has an insignificant coefficient estimate, close to zero, in each specification. Second, the CRT score variable fails to obtain a significant coefficient (columns (1) and (2)). Third, columns (3) and (4) indicates that possibly, subjects' mathematical skills, measured by the A-level Math grades, negatively affected their decisions to transfer. This means that subjects' numerical literacy may have partially cancelled out the positive experiences of transfer Agent 1s gained in the exogenous parts, perhaps considering that the transfer paradox is a counter-intuitive phenomenon. In sum, these findings suggest that Agent 1s' transfer decisions were motivated more by equilibrium effects.

Lastly, it is noteworthy that as shown in the coefficient estimates for variable *d*, female subjects were more likely than male subjects to choose to make the transfer to Agent 2s. Prior experimental research has documented that female subjects may be more pro-social than male ones (e.g., Croson and Gneezy, 2009). Considering that Agent 1s predominantly hold money compared with the other two agent types in the experiment, female Agent 1s may be motivated to donate some amounts to Agent 2s from other-regarding purposes, ceteris paribus.

Table 3: *Determinants of Agent 1s' Transfer Decision*

Independent variable:	(1)	(2)	(3)	(4)
a. Relative price {= (Avg. realized price in Part 2)/(Avg. realized price in Part 1)}	-1.490** (.589)	---	-3.758*** (1.139)	---
b. Relative payoff {= (Avg. realized payoff in Part 2)/(Avg. realized payoff in Part 1)}	---	.941** (.429)	---	1.438*** (.507)
c. Large-group dummy {= 1(0) for the L(S) treatment}	.013 (.434)	-.015 (.455)	1.276 (.690)	.473 (.464)
d. Female dummy {= 1(0) for female (male) subjects}	.791** (.402)	.598 (.375)	1.952*** (.575)	.581** (.290)
e. Econ major dummy {= 1(0) for Economics major}	.304 (.542)	.499 (.583)	.507 (1.000)	1.417* (.761)
f. CRT score {= 0, 1, 2, 3}	.041 (.266)	-.010 (.279)	---	---
g. A-level Math grade[#1]	---	---	.483 (.381)	.781*** (.269)

	(1)	(2)	(3)	(4)
h. Beauty contest responses	-.002	-.004	-.019	-.030
	(.007)	(.008)	(.017)	(.019)
Constant term	.853	-1.354	1.371	-3.450***
	(.913)	(1.049)	(1.455)	(1.347)
# of observations	64	64	24	24
Wald Chi-squared	37.33	64.84	32.15	75.69
Prob > Wald Chi-squared	.0000	.0000	.0000	.0000
Pseudo R-squared	.1784	.1380	.5314	.3046

Notes: Probit regressions with standard errors clustered by session. The dependent variable is a dummy which equals 1 when an Agent-1 subject *i* chose to make (voted for) a transfer in the S (L) treatment. [#1] A*, A, B, C, D, and E were coded as 1, 2, 3, 4, 5, and 6. Only those who answered the A-level Math grades were used in columns (3) and (4) as data, meaning that a possible selection bias exists in columns (3) and (4). Note, however, that the key results seen in variables (a) and (b) were observed in columns (3) and (4), consistent with the results in columns (1) and (2). *, **, and *** indicate significance at the .10 level, at the .05 level and at the .01 level, respectively.

4. Conclusion

Built on the theoretical framework of a three-agent pure exchange economy conducive to the emergence of a transfer paradox, this paper experimentally showed that a transfer of endowment from one agent to another could influence the market clearing price, through which the donors benefited from the transfer. A comparison between different group sizes also found that the equilibrium effects of transfer were strongest in the treatment with the larger group size, resonating with the idea that having a larger number of market participants encourages them to behave competitively. Further, given an option to adjust the endowment distributions, the majority of subjects who were theoretically predicted to benefit from a transfer voluntarily did so. Individual decisions to transfer were mainly driven by the equilibrium effects of the transfer on prices and payoffs, not by their cognitive ability. This suggests that a transfer paradox could be initiated endogenously in real human societies.

It is worth noting that, while the results found in the experiment are affirmative, this study is a first step to uncover the empirical relevance of the transfer paradox. One may wonder how a transfer paradox can occur in more complex environments, for example ones in which there are more than three types of agents or more than two goods in an economy. In such an environment, for instance, people's cognitive ability may play an important role in transfer decisions. Alternatively, the distribution of initial endowments and the utility functional forms of the agents could affect subjects' behaviors. This paper specified that all three agents have Leontief payoff functions, since this setting is one of the most established and tractable frameworks in the transfer paradox literature. Other functional forms, such as Cobb-Douglas and quasilinear, have also been shown in the theoretical literature to drive a transfer paradox. Further, one may also wonder how the transfer paradox emerges under different market institutions (e.g., double auctions). How robust the transfer paradox is empirically to different utility functional forms, endowment distributions and/or market institutions would be an interesting avenue for future research.

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Appendix: Impact of Transfers (Simulations)

Suppose that Agent 1 gives away t ECUs to Agent 2. The adjusted distribution of endowments is then given by:

$$w_1{}' = \binom{100-t}{20};\ w_2{}' = \binom{20+t}{100};\ w_3{}' = \binom{0}{80}.$$

The budget condition of each agent then reduces to the followings:

$$x_1 + py_1 = 100 - t + p \cdot 20. \tag{A1}$$

$$x_2 + py_2 = 20 + t + p \cdot 100. \tag{A2}$$

$$x_3 + py_3 = 80p. \tag{A3}$$

The feasibility condition in the market and the equilibrium condition of the Leontief utility functions are not affected by such a transfer and are given by the following:

$$x_1 + x_2 + x_3 = 120. \tag{A4}$$

$$y_1 + y_2 + y_3 = 200. \tag{A5}$$

$$2x_1 = y_1. \tag{A6}$$

$$x_2 = y_2. \tag{A7}$$

$$3x_3 = y_3. \tag{A8}$$

Each agent's equilibrium quantity of good *x* can thus be expressed as a function of *p*:

$$x_1 = \frac{100-t+p\cdot 20}{1+2p};\ x_2 = \frac{20+t+p\cdot 100}{1+p};\ x_3 = \frac{80p}{1+3p}, \tag{A9}$$

and the payoff of each agent is given by:

$$u_1 = 2x_1 = \frac{200-2t+40p}{1+2p};\ u_2 = x_2 = \frac{20+t+p\cdot 100}{1+p};\ \text{and } u_3 = 3x_3 = \frac{240p}{1+3p}. \tag{A10}$$

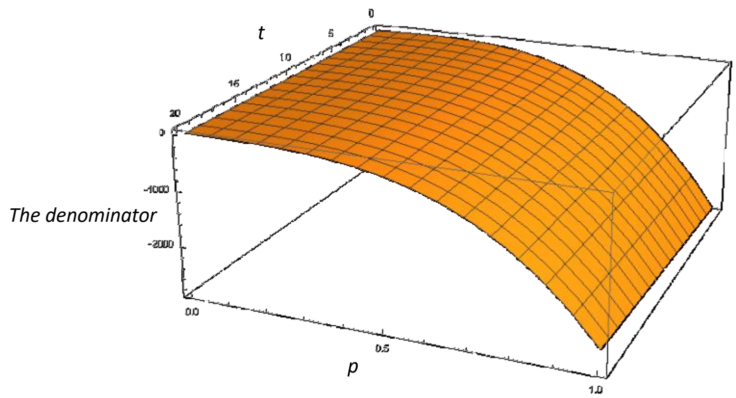
Substituting these optimal quantities to condition (A4), the following condition can be obtained for the equilibrium price:

$$\frac{100-t+p\cdot 20}{1+2p}+\frac{20+t+p\cdot 100}{1+p}+\frac{80p}{1+3p}=120. \tag{A11}$$

Condition (A11) suggests that the equilibrium price depends on the size of *t*. This also suggests that the equilibrium price is monotonically decreasing in *t*. To see this, applying the Implicit Function Theorem to Condition (A11), the following derivative can be derived:

$$\frac{dp}{dt}=-\frac{p(1+p)(1+2p)(1+3p)^2}{20+160p-40p^2-1440p^3-1580p^4-t-6pt-7p^2t+12p^3t+18p^4t}.$$

Notice that $\frac{dp}{dt}$ is negative if *t* is not too large because the denominator is then negative (the numerator is always positive provided that $p > 0$). The following graph shows that the denominator is always negative when $t \leq 20$:



Note: the figure was depicted using Mathematica.

Table A.1 below summarizes how the equilibrium price and each agent's utility depend on *t* based on simulations. For simplicity, the summary table includes the cases where *t* is a non-negative integer. It shows that the payoff of Agent 1 (Agent 2) is larger (smaller), the larger transfer she makes.

Summary: *Provided that the size of transfer t ≤ 20, the payoff of the donor (Agent 1) is increasing with the size t, and the payoffs of the recipient (Agent 2) and the third party (Agent 3) are oppositely decreasing with the size t.*

Table A.1. *The Impact of Transfer, t, on the Competitive Market Equilibrium*

t	(a) Equilibrium price *p*	(b) Allocation of good *x*: (x_1, x_2, x_3)	(c) The payoff of Agent 1 (u_1)	(d) The payoff of Agent 2 (u_2)	(f) The payoff of Agent 3 (u_3)
0	1.000	(40.00, 60.00, 20.00)	80.00	60.00	60.00
1	.967	(40.34, 59.83, 19.83)	**80.69**	*59.83*	*59.49*
2	.933	(40.71, 59.65, 19.65)	**81.41**	*59.65*	*58.94*
3	.899	(41.09, 59.45, 19.45)	**82.18**	*59.45*	*58.36*
4	.865	(41.50, 59.25, 19.25)	**83.00**	*59.25*	*57.75*
5	.831	(41.94, 59.03, 19.03)	**83.88**	*59.03*	*57.09*
6	.796	(42.41, 58.80, 18.80)	**84.82**	*58.80*	*56.39*
7	.761	(42.91, 58.54, 18.54)	**85.83**	*58.54*	*55.63*
8	.725	(43.46, 58.27, 18.27)	**86.92**	*58.27*	*54.81*
9	.690	(44.05, 57.98, 17.98)	**88.09**	*57.98*	*53.92*

10	.653	(44.69, 57.66, 17.66)	**89.38**	*57.66*	*52.97*
11	.616	(45.39, 57.30, 17.30)	**90.78**	*57.30*	*51.91*
12	.578	(46.17, 56.92, 16.92)	**92.33**	*56.92*	*50.75*
13	.540	(47.03, 56.49, 16.49)	**94.06**	*56.49*	*49.46*
14	.500	(48.00, 56.00, 16.00)	**96.00**	*56.00*	*48.00*
15	.459	(49.11, 55.45, 15.45)	**98.21**	*55.45*	*46.34*
16	.416	(50.39, 54.81, 14.81)	**100.78**	*54.81*	*44.42*
17	.371	(51.91, 54.04, 14.04)	**103.82**	*54.04*	*42.13*
18	.322	(53.79, 53.10, 13.10)	**107.58**	*53.10*	*39.31*
19	.267	(56.26, 51.87, 11.87)	**112.52**	*51.87*	*35.61*
20	.200	(60.00, 50.00, 10.00)	**120.00**	*50.00*	*30.00*
No solutions for positive competitive equilibrium price if $t \geq 21$.					

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