The Tobin Tax - a Game-Theoretical and an Experimental Approach

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Abstract

In the nineteenseventies, James Tobin suggested the introduction of a transaction tax on the currency market to cope with exchange rate volatility. We investigate the consequences of the introduction of such a tax on an asset market model from a game-theoretic and an experimental point of view. Our main results include in respect to our model that contrary to the situation in game-theoretic equilibrium, the Tobin tax i) reduces trade volume, ii) reduces volatility, iii) increases market efficiency, and iv) decreases earnings inequality.

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1 A tax to reduce volatility

Foreign exchange markets are the most liquid financial markets in practice. The traded volume has even increased within the last years: the daily average turnover on the foreign exchange spot market has surged to 621 billion US dollar in 2004 (cf. the triennial central bank survey by Galati et al. (2005)). But the enormous trading volume is not the only striking feature of currency markets: the prices of the currencies, that is, the exchange rates, also incorporate information very rapidly. This yields volatility. It can not be denied that instable exchange rates can have dire consequences for whole economies. Exchange rate uncertainty affects international trade, the liquidity of firms which have foreign debts, the behavior of foreign investors, and even fiscal, domestic, and monetary policy. In general, excess price volatility decreases the willingness of investors to engage in trading activities in the concerned markets.

Currency speculation is not the only factor in exchange rate determination, although it seems to have an influence on the short-term development of a currency's value. There exist different sights on the influence of speculative currency trade on exchange rates. In 1936, John M. Keynes partitioned trading parties on financial markets in long-run investors and short-run speculators, whereas speculators play a price-destabilizing role on the market. In his fundamental work *The general theory of employment, interest, and money*[1], he pointed out that the imposing of a transaction tax on markets could increase the weight of long-term fundamentals of the assets against speculators' guesses of the short-term behavior of other speculators, thus stabilizing the asset's price. Friedman (1953) contrasts that stabilizing speculation is equivalent to profitable speculation: If speculators buy an asset when its price is low and respectively sell it when its price is high, this will drive the asset's price towards its equilibrium. This sight on the relation between speculation and stabilisation seems tenuous. For example, de Long et al. (1990) find that because noise traders can earn higher profits than long term investors and both types of speculators are trading, Friedman's model appears incomplete. Carlson and Osler (2000) argue that Friedman's line of reasoning does neither incorporate interest rates nor a risk model, which both could in fact make speculators sell an asset when its price is low and buy it when its price is high, thus destabilizing the price. In general, most post-Keynesian authors assert the opposite of Friedman's theory.

[1] see Keynes (1936)

How can one cope with price volatility? In this article, we focus on a transaction taxation scheme. Sticking to the example of foreign exchange markets, there is a constantly ongoing discussion about imposing transaction costs to reduce exchange rate variation. James Tobin (1978) proposed a transaction tax of up to 1 percent on all spot transactions. He hoped not to affect long-term investors, but to scare away short-term speculators with his tax. The desired effects of such a tax on short-term and long-term currency traders can be illustrated in an example which has been drawn up by Frankel (1996): Consider a home interest rate of ten percent and a transaction tax in the height of one percent. A foreign asset is attractive to potential investors with an investment horizon of one year if it yielded at least 11.11 percent per annum if only the interest earnings were brought back. If the horizon was only one month, the asset should yield at least 22.12 percent annual revenue to remain attractive. The shorter the horizon, the higher the asset yield has to be: A duration of the investment of one week would require a yield of 62.52 percent, and if it was a one-day investment the yield would have to be no less than 378.68 percent.

This approach is highly controversal. In their comprehensive standard work, Grunberg et al. (1996) review current arguments for and against this tax from an economic point of view. Major points of critics are for example that it would be easy to evade the tax by means of financial engineering (e. g., short-termed futures are not subject to this tax) or by shifting markets to countries where the tax is not imposed. Furthermore, Aliber et al. (2003) find in an empirical study that higher transaction costs are positively correlated with exchange rate volatility. Hau (2006) studies data from the Paris stock exchange and comes to a similar conclusion. Spahn (1996) extends Tobin's taxation scheme by modelling a two-tier transaction taxation scheme: like in Tobin's approach, a fixed percentage of up to 1 percent is imposed on all currency spot transactions. If however the exchange rate lies out of the boundaries of a precalculated threshold determined by a crawling peg plus a safety margin, a transaction tax with a significantly higher tax rate of up to 100 percent will be imposed on the transactions. Spahn calls his approach a *Tobin-cum-Circuit-Breaker Tax*. A more detailed view on this approach is provided by Spahn (2002). Already in the same issue of the journal in which Spahn initially published his taxation proposal, Janet Stotsky (1996) animadverts his approach. She claims that variable taxation rates would increase uncertainty on the market, spreads, as well as the administrative burden for tax payers and tax authority. Furthermore, in her opinion the levy of the tax as an instrument of monetary policy under the control of the fiscal authority would require a high extent of cooperation between the fiscal and monetary authorities which she claims does not exist in practice.

In the context of politics, the concept of a Tobin tax is reoccurring in discussions frequently; especially in European countries and after financial crises. The interest in the Tobin tax soon dies once the media coverage on financial crises ceases to exist. A small anecdote describes this phenomenon best. Otmar Issing, chief economist of the German *Bundesbank* in 1990-98, once told journalists when asked about the Tobin tax: "Oh, that again. It's the Loch Ness Monster, popping up once more."[2] Nevertheless, some hesitant steps towards such a tax are taken. In 2004, France and Belgium agreed to introduce a Tobin tax as soon as all other countries of the European Union will do. Germany, France, and Austria claimed pro-Tobin tax positions only in 2005, knowing that if the European Union levied a Tobin tax it would have an own source of fiscal revenues. On the American continent, Brazil's president Luiz Inácio Lula da Silva, Venezuela's president Hugo Chávez, as well as the Canadian House of Commons spoke out in favor of the Tobin tax within the previous 8 years. At the moment, one of the major adversaries of the Tobin tax is the United States of America. It is unlikely that a Tobin tax will be effective if introduced multilaterally without participation of the USA.

There exist different views on the impact of a Tobin tax on financial crises. Whereas some authors, e. g. Tobin (1996a), claim that financial crises caused by an inadequate monetary and fiscal policy mix and sparked off by speculative attacks could at least have been curbed by a transaction tax, some authors assert the opposite. For instance, Grabel (2003) states that concerning the Asian crisis, speculation in real estate and construction is not subject to Tobin's tax proposal in spite of contributing significantly to fragility risk in Asia. Furthermore, Grabel rules out that the ideal tax rate is lower than the expected profits associated with speculation. Rajan (2001) asserts that international capital flows are relatively unelastic with respect to transaction taxes *à la* Tobin, but that the latter ones are an appropriate device for increasing public funds.

[2] described by Tobin (1996b)

Neither Tobin's nor Spahn's taxation proposals have ever been introduced to existing foreign exchange markets, so there is a lack of empirical evidence in favor of or against such taxation schemes. Although there exists some literature on the effects of transaction costs on financial markets (see Habermeier and Kirilenko (2003) and the augmentation of their arguments by Forbes (2003) in the same volume), it is by no means clear that these results can be transfered from e. g. the stock market on the currency market. Nevertheless, some evidence exists from experiments and simulations. In a laboratory experiment, Noussair et al. (1998) evaluate the effect of transaction costs on a double auction. They find that prices are driven towards its equilibrium price in spite of the monetary costs, though market efficiency and turnover decrease. Our study follows a different taxation approach: Noussair and his coauthors impose transaction costs in a fixed absolute height on the market. Contrary to that, Tobin postulated to introduce a transaction cost of a fixed percentage. In recent experimental investigation, Bloomfeld et al. (2005) investigate the behavior and the market impact of noise traders. If a securities transaction tax is imposed, price volatility is not reduced, although they find some evidence that it limits noise trading. Hanke et al. (2006) ran laboratory experiments which included two continuous double auction markets. They imposed a Tobin tax unilaterally as well as on both markets. The results of this study speak out against a Tobin tax: if introduced unilaterally, almost the complete trading activity shifts to the other market. If the traders' ability of evading the taxation is eliminated by introducing the tax on both markets, the volatility increases on the one hand whereas the trading volume and the market efficiency decrease drastically. A half theoretical, half experimental study by Cipriani and Guarino (2007) outlines the negative effect of transactions costs such as a Tobin tax on price discovery. In their model, informational cascades arise in which traders refrain from trading when transaction costs are imposed on markets.

Westerhoff (2003) creates two financial markets in a computer simulation and imposes a transaction tax on either none, one, or both of them. In particular, he distinguishes between orders produced by technical and orders produced by fundamental analysis. He concludes that the tax indeed stabilizes the prices on the market with the tax, but also destabilizes the prices on the respective other market if no tax is imposed on it. Later on, Westerhoff and Dieci (2005) show in a collaborative work with a similar model that both markets stabilize if a tax is imposed on both of them and that other markets are likely to follow if market regulators impose a tax in one market.

We want to emphasize that it cannot be the aim of a Tobin tax to completely eradicate price volatility. If there is zero volatility, then prices most likely don't properly adjust to fundamental values. In his speech at the 2006 meeting of Nobel laureates in Lindau, Robert Engle conjured up some examples for implications of a phenomenon like this: if the prices on a stock market had zero volatility and the fundamental value had not, it would mean that profitable companies don't have more access to capital than less profitable companies. If currencies had zero volatility, this would cause countries who do follow sensible economic policies not to be able to advance past countries who don't. But a high volatility can also do harm to financial markets and its participants. It is not only a measure for the risk of investments, but also an important source of information for the pricing of options. So it seems plausible to carefully tare volatility.

In this study, we investigate an experimental market inspired by a discretized double auction. We don't use the traditional double auction design of Vernon Smith but modify it to derive a complete game-theoretical solution as a benchmark for our investigation. Experiments are run in two variations: First, the market participants are allowed to interact without imposing any stabilisation measures on them. Second, a transaction tax *à la* Tobin of a fixed percentage is introduced. We vary the height of this tax across markets to assess the volatility elasticity with regard to it. Finally, we compare taxed and untaxed markets and evaluate them with respect to trading volume and trade turnover, supply and demand, market prices, volatility, market efficiency, fiscal revenues, and earnings inequality.

2 An asset market model

In this section, we firstly give a brief overview on the trade mechanisms of foreign exchange markets in practice. Thereafter, we draw up a round-based model of an experimental asset market, motivated by the structure of the beforehand described foreign exchange platforms.

2.1 The structure of foreign exchange markets

In existing financial markets, foreign currencies are traded in different ways (see Sarno and Taylor (2001, p. 5)). About 40 percent of the daily turnover of world financial markets are traded in brokered transactions: A broker collects limit orders which consists of quantities and the price of an offer to buy or sell. Then, the broker matches supply and demand curves and finishes the deals. Traditionally, the brokered market is conducted via voice over telephone lines. An even greater fraction of the daily trade is done by market participants who trade with each other directly: the market participants approach each other and the party receiving the call acts as a market maker. The latter one provides the caller with bid and ask prices, whereas the caller decides on the quantity and if to sell, to buy, or to refrain from the deal. Nowadays, this is mostly done electronically. In 1997, about 70 percent of the brokered trade has been conducted via the software systems EBS and Reuters' Dealing 2000-2 (see Payne (2003, p. 5)). Later on, Reuters introduced a new trading system called Dealing 3000. Dealing 2000-2 and Dealing 3000 have been existing in parallel henceforth. These systems have already been reviewed in recent market microstructure studies by Carpenter and Wang (2003) as well as Hupfeld (2002).

Note that it is not our intent to claim our setting to be an experimental currency market, albeit its features resemble those of standard foreign exchange trading platforms. It is our firm opinion that exchange rates are not exclusively formed by the speculating motive of day traders. Many market participants use financial devices like simple or swap options to hedge various kind of bilateral businesses and investments against exchange rate risks. Fiscal and monetary policy, the interaction and cooperation of monetary authorities all over the world, correlated commodity markets, and economic trends influence trade decisions to a high extent. All these phenomena are non-existent in our setting. We are convinced that a simple experimental market design such as ours does not capture the complexity of exchange rate formation in the world's economies. Nevertheless, our study should be seen as a market microstructure investigation of the influence of a Tobin tax as a financial stabilizing measure on market participants and their trade decisions. For experimental studies of exchange rates and the currency market, confer for example Kaiser and Kube (2005), Noussair et al. (1997), or Arifovic (1996).

We decided to let the auction design follow the approach of Friedman (1984) closely.

Our own approach draws up a round-based, discrete, and finite-horizon model which is described in the next section. Two key features of our model form the main difference to foreign exchange markets: First, we deal with a finite time horizon. Our main reason for doing so is to avoid end-game effects. The efforts which have been undertaken in experimental literature do not convince us to be able to eliminate these effects completely. Another difference is the existence of a constant dividend. Critics may object that this proceeding introduces only little uncertainty into the market. However, Noussair et al. (2001) demonstrate that with a decreasing fundamental value even bubbles and crashes do occur. Unlike the classic double auction design as for example applied by Smith et al. (1988), we use a central clearing house mechanism.

2.2 Modelling an asset market

We continue by describing a simple discrete asset market, on the base of which we analyse the impact of a Tobin tax. Let there be a finite time horizon of T periods. In each period $t \in \{1, ...T\}$, an asset is traded on one simple double auction market: a total of n market participants decides on their transactions. Each market participant i (with $1 \leq i \leq n$) has an initial endowment $x_{i,0}$ of money (the numeraire) and an initial endowment of $m_{i,0}$ of the asset. The proceeding of one period is split in several steps.

In step 1, every market participant i states two prices: the price $p_{i,t,b}$ he is willing to pay for one unit of the asset (henceforth called bid price) and the price $p_{i,t,a}$ a potential buyer would have to pay him for one unit of the asset (ask price). When every market participant has selected his bid and ask prices, the market ask price $p_{t,a}$ is set to the lowest ask price stated:

$$p_{t,a} = \min\{p_{1,t,a}, ..., p_{n,t,a}\} \tag{1}$$

Analogously, the market bid price is determined by the highest bid price stated by the market participants:

$$p_{t,b} = \max\{p_{1,t,b}, ..., p_{n,t,b}\} \tag{2}$$

An important feature of this auction is that it is only possible to quote positive prices.

A market participant is not allowed to state prices with $p_{i,t,a} < p_{i,t,b}$. Furthermore, a participant must not state a bid price if he has no holdings of the numeraire. Analogously, a participant cannot state an ask price if he has no holdings of the asset. Another constraint the bid price is that a participant must own enough of the numeraire to buy at least one unit of the asset at the bid price he states.

In step 2, the market bid price and the market ask price are made public to all participants. Now, they decide on whether they want to buy or sell units of the asset or if they want to refrain from trade. If a market participant i decides to buy $d_{i,t}$ units of the asset at the market price $p_{t,a}$ in period t, he has to pay $d_{i,t} \cdot p_{t,a}$ units of the numeraire for one unit of the asset to complete the transaction. Note that each participant can decide to buy $d_{i,t}^{\max}$ units of the asset at most in one transaction. The statutory maximum is set to the fixed value of $\bar{d}$. Since the participants are neither allowed to take on short positions in the holdings of the asset nor in the holdings of the numeraire, their buying constraint is:

$$d_{i,t}^{\max} = \min\{\bar{d}, \frac{x_{i,t}}{p_{t,a}}\} \tag{3}$$

If two or more participants are offering the asset at the market price, each buying offer is distributed equally to the offering parties. One special case can arise: if the total supply of the asset is lower than the total demand for the asset, the transactions cannot be completed as described before. Then, the demanding parties are numbered by random. Their transactions are carried out sequentially as a whole. If a participant's demand cannot be met completely, the remainder of the asset is transferred to him and the unprocessed rest of the participants misses out.

A transaction in the opposite direction is carried out analogously: Once participant i decides to sell $s_{i,t}$ units of the asset, he will receive $s_{i,t} \cdot p_{t,b}$ units of the numeraire in exchange. Each participant can decide to sell $s_{i,t}^{\max}$ units of the asset at most in one transaction. The statutory maximum is set to the fixed value of $\bar{s}$. The selling constraint is:

$$s_{i,t}^{\max} = \min\{\bar{s}, m_{i,t}\} \tag{4}$$

If two or more participants are demanding the asset at the market price, each selling offer is distributed equally to the demanding parties. If the total demand for the asset is lower than the total supply, the supplying parties are numbered by random. Their transactions are carried out sequentially as a whole. If a participant's offer is not demanded completely, the remainder of the asset is transferred to the buyer and the unprocessed rest of the participants miss out.

The holdings of the asset $x_{i,t}$ and the numeraire $m_{i,t}$ adjust accordingly after the buying and selling orders are completed. Note that in step 2 each participants can decide either to place buying orders or selling orders or to refrain from trade: it is not possible to buy and to sell simultaneously. This implies that participants who fixed the market price for either buying or selling the asset are not allowed to state orders: they pause in step 2. Another important feature of the asset is that a market participant receives a dividend of μ units of the numeraire for holding one unit of the asset in one period. Before step 1, each market participant receives a payment of μ units of the numeraire for each unit of the asset he held in the end of the previous period and still holds in the actual period. There is no such payment in the first period of the game.

After the final period T, the holdings of the assets of all participants get converted to the numeraire at a fixed rate p_b^*. The participants receive a payoff which is then equal to their holdings of the numeraire multiplied with a conversion factor c. A participant's payoff thus totals to

$$\Pi_i = c(x_{i,T} + p_b^* m_{i,T}) \tag{5}$$

Euro after period T.

In a second variation (treatment) of the model, a transaction tax as proposed by Tobin (1978) is imposed on the market. In all other aspects, this treatment is equal to the control treatment. For each transaction, a tax in the height of a fraction τ of the transferred numeraire has to be paid on the market. The tax has to be paid by the party that initiates the trade by stating an amount of the asset and whether to sell or to buy that amount. Hence, the trade constraints adjust. In the case that a trader i decides to buy $d_{i,t}$ units of the asset at the market price $p_{t,a}$, he has to pay taxes in the height of $\tau p_{t,a} d_{i,t}$. His holdings of the numeraire then yield:

$$x_{i,t+1} = x_{i,t} - (1+\tau) p_{t,a} d_{i,t} \tag{6}$$

Analogously, if a trader wants to sell $s_{i,t}$ units of the asset at the market price $p_{t,b}$, he j has to pay taxes in the height of $\tau p_{t,b} s_{i,t}$. The trading constraints adjust accordingly for both cases.

3 On the game-theoretic nature of the model

This section discusses our model from a game-theoretical point of view.

Let

$$\Phi_t = p_b^* + (T - t)\mu \tag{7}$$

be the fundamental value of one unit of the asset in period t. This measure includes dividend payments to expect if the asset was held for the remainder of the game as well as the conversion factor for the asset after the final period T. Figure 1 shows Φ as a function that decreases monotonic over time. In the following, we regard a single period t of the game. In the first step of the period, all participants have to state bid and ask prices for the asset. A participant stating an ask price lower than the fundamental value of the asset will face losses by trading: the asset is worth more in t than what he would receive from a buyer. Analogously, a participant stating a bid price greater than the fundamental value would pay more for one unit of the asset than it is worth. A rational profit-motivated participant i should thus state:

$$p_{i,t,a} \geq \Phi_t \tag{8}$$

$$p_{i,t,b} \leq \Phi_t \tag{9}$$

A participant i is outbidded by other participants if he does not state the lowest ask price (1), or, respectively, the highest bid price (2). Therefore, the bid as well as the ask price should be equal to the fundamental value Φ_t under perfect competition.

From (1), (2), (8), and (9) follows that:

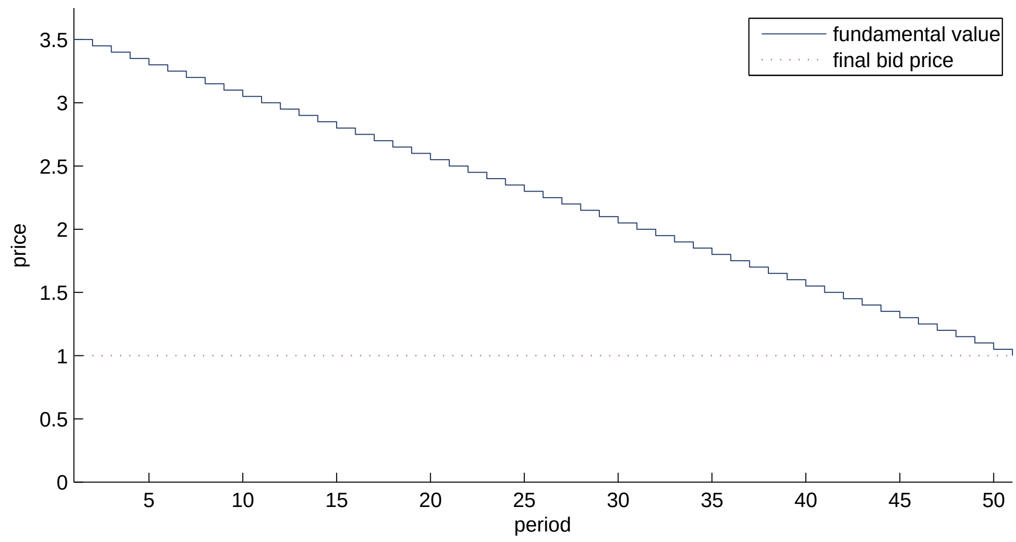

Figure 1: The fundamental value Φ as a function of the time

$$p_{t,a} \geq \Phi_t \tag{10}$$

$$p_{t,b} \leq \Phi_t \tag{11}$$

In step 2, all participants except the participants who made the market price can choose whether they want to take part in the trade and if they decide to do so, whether they want buy or to sell units of the asset. A participant i makes profit by buying units of the asset only if the market ask price is lower than its fundamental value. Analogously, he makes profit by selling only if the market bid price is higher than its fundamental value. If transactions are carried out to a bid or ask price equal to Φ_t, neither party is better off or worse off after the trade. For transactions which do not incur losses on the participants who states the amounts, the following individual rationality constraint yields:

$$p_{t,a} \leq \Phi_t \tag{12}$$

$$p_{t,b} \geq \Phi_t \tag{13}$$

Summarizing, if the bid price is not equal to the fundamental value, no trade can take place between two participants i and j without deteriorating either one of them. The same holds true for an ask price not equal to the fundamental value. If the bid price is equal to the fundamental value, transactions can take place to an arbitrary extent without improving or worsening the payoffs of either party.

If a transaction tax in the height of τ is imposed on the market, (10) and (11) hold still true because the tax has to be paid by the party which is stating the amounts in step 2. This changes the individual rationality constraint to:

$$p_{t,a}(1+\tau) \leq \Phi_t \tag{14}$$

$$p_{t,b}(1-\tau) \geq \Phi_t \tag{15}$$

Concluding the case for a transaction tax, no trade can take place without worsening the standing of either participating party if the market price is not equal to the fundamental value. Contrary to the case where no transaction tax is imposed, it is not possible to engage in trade if market prices equal the fundamental value without making losses. Thus, no trade takes place in equilibrium.

4 Deductions from a behavioral experiment

The model we introduced in section 2 was designed to suit the purpose of running experiments based on it and to find a game-theoretic solution as a benchmark. This permits us to derive an experimental market to investigate behavioral aspects of the impact of a Tobin tax. In the following, we describe the proceedings for the experiment as well as our experimental results.

4.1 Experimental setup and procedures

We have conducted experiments as computer-based laboratory experiments under controlled conditions. The experiment was programmed and conducted with the software z-Tree[3]. In the following, operational details of the experimental software are given. Some screenshots of the experimental software can be found in appendix C. We used calibrated the model with the parameters described in table 1. All data was public information.

[3]cf. Fischbacher (1999)

Each round of the experiment was identical. Firstly, every player had to state his bid and ask prices. He could always see a list of his own and the market's bid and ask prices and average prices of all past periods, his holdings of both numeraire and asset, the dividend received, and his past transactions. After every player had stated his respective bid and ask price, the market price was determined and shown to the players. The transactions constraints were shown to him and he then could decide on whether he wanted to engage in trade. Note that he was only allowed to initiate a transaction if he did not state the market price for neither bid nor ask price. If the player wished to initiate a transaction, he had to choose whether to buy or to sell units of the asset. The respective price (in treatment T, also the tax surcharge) appeared on the screen. The player then could enter the amount of the asset he wanted to transfer. When all orders had been collected, they were carried out. Afterwards, his new holdings, the change in the holdings, and in treatment T also the height of the paid taxes were shown to him. Then the round was over and the next round started.

Table 1: Parameter calibration

$n = 8$	$x_{i,0} = 500 \forall i \in \{1, ..., n\}$
$T = 51$	$m_{i,0} = 200 \forall i \in \{1, ..., n\}$
$\bar{s} = 25$	$\bar{d} = 25$
$p_b^* = 1$	$c = 0.01$
$\mu = 0.05$	

We ran 6 sessions of the untaxed treatment and 6 sessions of the taxed one. In the latter case, a constant tax rate was imposed on the market as described in table 2. A total of 96 subjects took part in the experiment with 8 in one session. All except three of the experimental participants were students[4] of the University of Bonn, Germany. Two participants were employees, and one of them was a senior in a local high school. The experimental sessions were ran at the Laboratory for Experimental Economics in

[4]Their majors included pharmacology, economics, languages, translation, computer science, law, ethnology, medicine, political sciences, social sciences, nutritional sciences, business administration, slavistic sciences, anglistics, sinology, North-American studies, history of art, physics, mathematics, communication sciences, and regional sciences.

Bonn in July 2006. One session lasted approximately 2 hours. In the beginning of each session, written instructions were handed out to the participants (confer appendix D for an English translation of the German instructions). These introductions were then read aloud to the students. After some example calculations and test questions, the session was started. When the session was finished, the students received their converted payoffs (€0.01 for each unit of the numeraire held after converting their assets to the numeraire at a fixed rate of 1:1). The average payoff was €12 (approx. US$ 15.38 at the time of the experiments) in untaxed sessions and €11.89 (US$ 15.23) in taxed ones. Each subject was given a show-up fee of €4, which is excluded from the beforehand mentioned amounts. After an experimental session has been conducted, the subjects were asked to fill out an ex-post questionnaire.

Table 2: Taxation over sessions

treatment	untaxed	taxed					
session	1-6	7	8	9	10	11	12
tax rate (in %)	0	0.5	1	1.5	2.0	2.5	3

We will now continue by presenting the experimental results. A descriptive overview of the data can be found in table 13 in the appendix.

4.2 Trade volume and turnover

The game-theoretical solution shows that the trade volume, that is, the total number of assets traded on one market, could have an arbitrary size in untaxed markets but should be zero in taxed ones in equilibrium. The same holds true for the turnover, which we define as the total transferred money in exchange for the asset on one market. The experimental study of Hanke et al. (2006) comes to a similar conclusion. They show that the influence of a transaction tax on the trade volume of a market is a negative one, especially when there are no tax havens. Considering these facts, the Tobin tax is likely to reduce both trade volume and turnover in our experiment.

Looking at the aggregate trading volume of each taxed and untaxed market, we find that the opposite holds true for the averages which are displayed in table 3 for both types of markets. Alas, the discrepancy in averages is not substantiated by non-parametric tests.

Table 3: Trade volume in untaxed and taxed markets

market	mean volume	std. dev.	min.	max.
untaxed	2196.667	402.1043	1681	2759
taxed	2450.833	378.0314	1978	2948

The correlation of the tax rate with the trade volume makes it safe to deduct that a higher tax rate leads to a decreased trade volume per session: Spearman's rank correlation coefficient[5] has the low value of $\rho = -.8857$ at a one-tailed significance level of $p = 0.0094$. We consider this finding as a first hint that a low tax may do no harm to the volume of the asset traded on the market, and that a high tax may cause the volume to decrease.

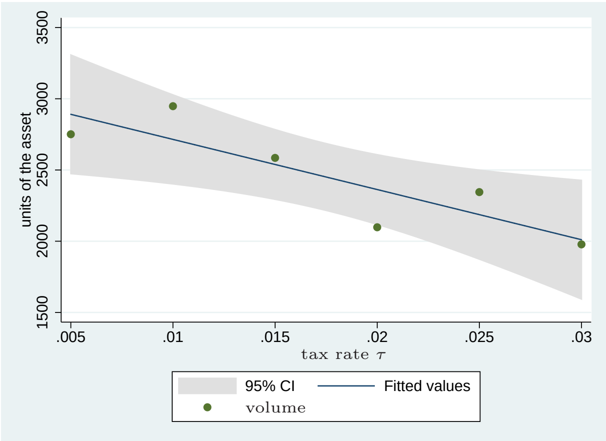

Figure 2: Trade volume and tax rate

An OLS regression analysis unveils more details about the interdependency between tax rate and trade volume. We create a simple regressional model

$$v_i = \beta_0 + \beta_1 \tau_i + \epsilon_i \tag{16}$$

where v_i is the total observed trade volume for market i, τ_i the tax rate for market i, ϵ_i the error term for market i and β_k the coefficients to match for all $k \in \{0, 1\}$. We regard

[5]Note that all econometric methods have been applied to session aggregates

only taxed markets for the sake of comparability. Details of the analysis can be found in table 11 in the appendix.

The fitted curve and a confidence interval are displayed in figure 2. The goodness-of-fit of $R^2 = 0.7589$ suggests at a significance level of $p = 0.0238$ that a linear influence of the tax rate on trading volume exists. We find a positive $\beta_0 = 3066.93$ and a negative $\beta_1 = -35205.71$ for the tax rate in our regressional model. Nevertheless, the argumentative power of these coefficients is weak. We share the opinion of List and Levitt (2005), who compare the role of laboratory experiments to economists with the role of the wind tunnel to aerodynamicists: One can use the results to gain qualitative insights into treatment effects and possible underlying mechanisms that could be causing the occurrence of certain data patterns. However, it is not adequate to extrapolate quantitative laboratory results outside the lab. Thus, it seems inappropriate to us to try to fit the coefficients gained into existing foreign exchange, goods, or asset markets and limit our deductions to the following: A linear and negative cohesion between tax rate and trade volume seems to be likely in the experiments with our model.

Table 4: Trade turnover in taxed and untaxed markets

market	mean turnover	std. dev.	min.	max.
untaxed	4680.155	875.059	3778.99	6075.55
taxed	4713.416	1045.566	3110.53	6144.58

Now that we have investigated the trade volume in taxed and untaxed markets, we look at the trade turnover per session. Summary statistics on this figure are displayed in table 4. It seems likely that trade turnover is lower in untaxed treatments and that the tax rate has a negative influence on it. Astonishingly, there is no significant evidence for a difference between taxed and untaxed markets: A Fisher-Pitman permutation test for independent samples cannot reject the hypothesis of a difference in trade turnover between treatments ($p = 0.95021$, two-tailed). Another indicator for no significant difference in trade turnover between treatments is the existence of three markets with a turnover below and three markets with one above average in both types of markets, that is, the exact binomial confidence intervals are identical at any level of confidence. A correlation analysis of tax rate and trade turnover reveals no significant cohesion between tax rate and turnover (Spearman's $\rho = -0.3143$, $p = 0.27205$ one-tailed). We find no significant influence of the tax rate on trade turnover, neither does the mere existence of a tax influence the trade turnover.

We can conclude that the tax rate has a significant negative influence on trade volume in our experiments. There is no significant difference between taxed and untaxed markets in regard to trade volume. Interestingly enough, we cannot find a similar correlation between trade turnover and the tax rate - *au contraire*: we gather some hints that neither the height of the tax rate nor a tax as such influences the trade turnover.

4.3 Supply and demand

How does a tax influence the behavior of the market participants in respect to supply and demand? We first take a look at the number of traders demanding or supplying units of the asset. In game-theoretical equilibrium, neither supply nor demand should be quoted in taxed markets because the traders who supply or demand the asset have to pay the tax. On untaxed markets, there could be an arbitrary number of supplying and demanding traders in equilibrium. Astonishingly, traders behave differently in our experiment: on average, the number of market participants who supply units of the asset is higher in taxed markets. This effect is significant at $p = 0.04437$ (Fisher-Pitman permutation test for independent samples, one-tailed - summary statistics are shown in table 5). This does not hold true for the number of traders stating a demand.

Table 5: Average number of supplying traders in taxed and untaxed markets

market	mean #s.	std. dev.	min.	max.
untaxed	1.470588	1.379677	0	6
taxed	1.800654	1.417781	0	6

The total supply of assets per market is also lower on untaxed markets than on taxed ones, alas only weakly significant ($p = 0.10064$). This does not hold true for the demand. Nevertheless, the total demand for the asset is correlated negatively with the tax rate

(Spearman's $\rho = -0.8286$, $p = 0.02078$ one-tailed). A significant correlation can not be observed for tax rate and total supply.

Besides the antagonism between observed and predicted behavior, we find it irritating that both supply and the number of suppliers are higher in taxed markets while neither the total demand nor the number of demanding players is affected. A possible explanation for this irrational behavior could be that under the prevalence of transaction costs, traders prefer to keep their holdings in the numeraire rather than in the asset. The with an increasing tax rate observed decline of the total demand for the asset gives further circumstantial evidence for this behavior. In the next paragraphs, we will present further findings to substantiate this theory.

Traders accept facing losses by supplying units of the asset at a price lower than the fundamental value. These losses can be seen as opportunity costs for receiving the numeraire in the actual period t instead of receiving a regular dividend payment in every period between t and T and, after the final round T, the units of the asset converted to units of the numeraire. We define the opportunity cost factor for one supplied unit as

$$\omega_t^S = \max\{\Phi_t - p_{t,b}, 0\} \tag{17}$$

in the control treatment. We have to correct this factor for taxes in the Tobin treatment, so the opportunity cost factor for one supplied unit is

$$\omega_t^S = \max\{\Phi_t - p_{t,b}(1-\tau), 0\} \tag{18}$$

in taxed markets. Analogously, we define opportunity cost factors for one demanded unit

$$\omega_t^D = \max\{p_{t,a} - \Phi_t, 0\} \tag{19}$$

in the control treatment and

$$\omega_t^D = \max\{p_{t,a}(1+\tau) - \Phi_t, 0\} \tag{20}$$

in taxed markets. These opportunity cost factors let us calculate the total costs all traders in one market put up with by supplying units of the asset:

$$\Omega^S = \sum_{t=1}^{T}\sum_{i=1}^{n} \omega_t^S s_{i,t} \tag{21}$$

The measure can be computed for demand, respectively:

$$\Omega^D = \sum_{t=1}^{T} \sum_{i=1}^{n} \omega_t^D d_{i,t} \tag{22}$$

The total opportunity costs per market are displayed in figure 3.

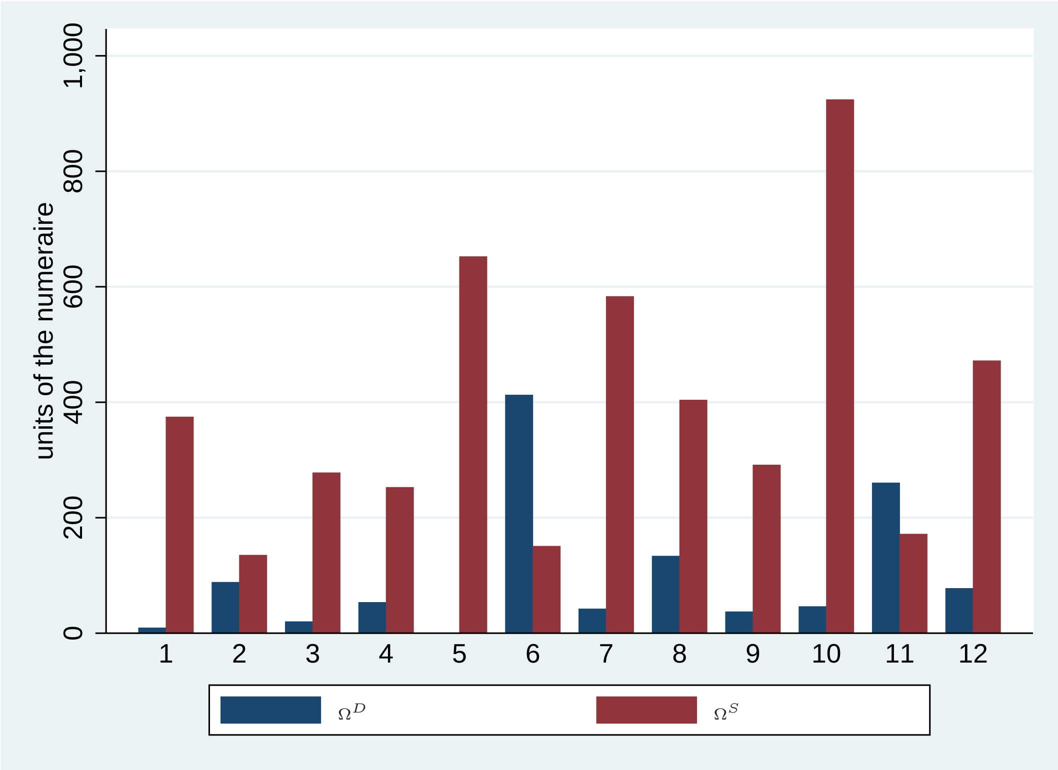

Figure 3: Total accepted opportunity costs per market (markets 1-6: untaxed, market 7-12: 0.5-3.0 percent tax)

We find some weak evidence that the total accepted opportunity costs for supplying units of the assets under value are higher in taxed markets than in untaxed ones (one-tailed Fisher-Pitman permutation test for independent samples, $p = 0.12229$). Furthermore, the risk of falsely rejecting the hypothesis of equal accepted opportunity costs for demanding units of the asset in both types of markets would be very high ($p = 0.98268$, same test but two-tailed). The accepted opportunity costs for supplying units of the asset under its fundamental value are higher than the respective demand opportunity cost. This holds true for taxed ($p = 0.03125$), for untaxed ($p = 0.09375$), and for both types of markets as a whole ($p = 0.004638$, Fisher-Pitman permutation test for paired replicates).

The behavior of our experimental subjects in supplying and demanding units of the asset has two seemingly irrational components: a) the accepted opportunity costs for supplying units of the asset under value are significantly higher than the accepted opportunity costs for demanding units of the asset over value, and b) the accepted opportunity costs for supplying units of the asset under value are significantly higher in taxed markets. The latter effect cannot be confirmed for the demand opportunity costs. What we observe here seems to be a phenomenon which could be explained by mental accounting. Firstly coined by Thaler (1980), mental accounting describes that people group their assets into non-fungible mental accounts. In a later work, Shefrin and Thaler (1988) apply this theory to derive the behavioral life cycle hypothesis, which basically states that assets are divided into current income, current wealth, and future income. According to the authors, the accounts are widely non-fungible and people hold different marginal propensities to consume for each of these accounts. This could be a plausible explanation for the incline of our subjects to accept costs for receiving units of the numeraire in exchange for units of the asset at the current period instead of getting the numeraire for the asset free of cost in a later period.

Another concept well-known in behavioral finance, hyperbolic discounting, was firstly observed by Chung and Herrnstein (1967) using pigeons; later on it was reproduced in experiments with human subjects. Hyperbolic discounting describes the phenomenon that preferences sometimes are dynamically inconsistent: people tend to prefer smaller payoffs to larger payoffs when smaller payoffs are received sooner in time. Not only is the behavior of the experimental subjects in our experiment described by this concept; a Tobin tax even increases this propensity: For receiving cash in exchange for the asset, people accept higher opportunity costs in taxed markets. We do not want to exaggerate this finding - the statistical evidence is only weak and a correlation between tax rate and accepted opportunity costs is not significant. Anyway, this effect of a Tobin transactions tax on hyperbolic discounting should be taken into account in ongoing studies.

4.4 Market prices

With a significant negative influence of the tax rate on trade volume and no significant influence on trade turnover, one might suspect that prices might increase significantly with the tax height. As a price measure for one session, we calculate the average market price

$$\bar{p} = \frac{1}{2n} \sum_{t=1}^{T} (p_{t,a} + p_{t,b}) \tag{23}$$

and base our furthergoing remarks on prices on it. Summary statistics on the average market price are displayed in figure 6. Although there is no significant evidence of increasing prices with increasing taxes (Spearman's $\rho = 0.4286$, $p = 0.19825$ one-tailed), we find that the average market price is higher in untaxed markets. This effect is weakly significant (one-tailed Fisher-Pitman permutation test for independent samples, $p = 0.10606$).

Table 6: Average market prices and fundamental value Φ_t in taxed and untaxed markets

market	mean $\bar{p}$	std. dev.	min.	max.
untaxed	2.827533	1.614946	2.02598	6.10853
taxed	1.994837	.4289407	1.518824	2.77549

The market prices per period of two showcase sessions are shown in figure 4.

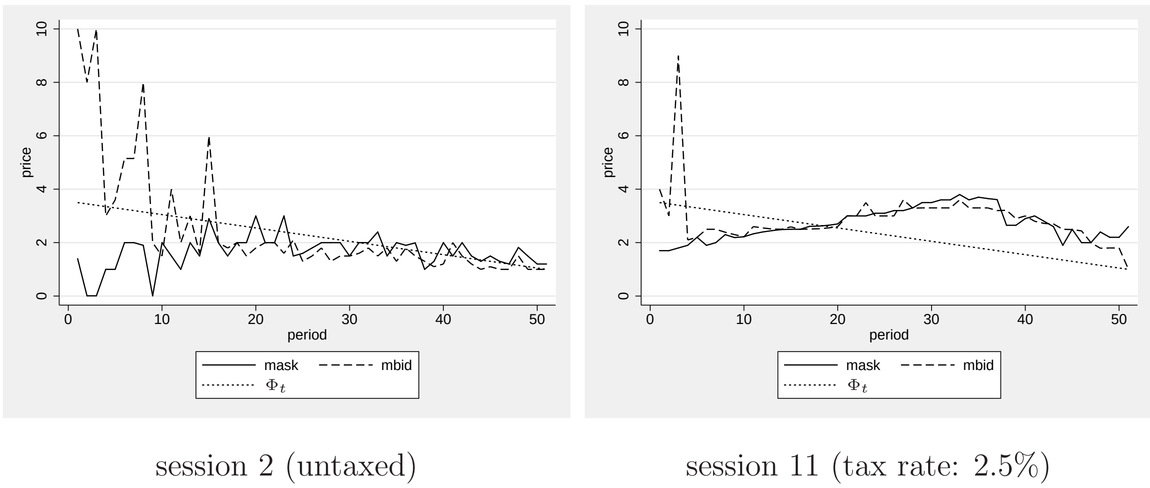

Figure 4: Price per period in untaxed and taxed markets (showcase)

The figures on market prices reveal that in most untaxed markets, there are players which state extremely high bid prices at some time. We have no explanation for this behavior. A situation like this occurred at least once in each untaxed session. It might be the case that some of the players tried to influence following pricing decisions of the other players by stating high bid prices. Since there is no evidence for a behavior like this, this explanation is mere speculation. Nevertheless, some of the market prices were extremely high in taxed markets too, though a situation like the previously described occurred less often.

Taking into account scattered maverick prices and thus comparing the medians of the market prices instead of the mean, we find no significant difference between taxed and untaxed markets. This is also predicted by the game-theoretical solution of the model. If we compare the equilibrium median bid and ask prices (both at 2.25), it is significant that both bid ($p = 0.002685$, Fisher-Pitman permutation test for paired replicates, one-tailed) and ask prices ($p = 0.002929$) are below it. The market median of the bid-ask spread $\Delta p_t = p_{t,a} - p_{t,b}$ is zero in one market and positive in all other markets. Non-negative bid-ask spreads are rational in our model, too.

Concluding the findings on market prices, we find no significant differences in medians across treatments. There are more outliers in untaxed markets and we have no plausible explanation for a behavior like this. Nevertheless, the median bid-ask spreads are non-negative like on existing financial and asset markets.

4.5 Volatility

James Tobin, the inventor of the tax that soon was named after him, thought of two primary goals to achieve with his instrument: First, to lower financial volatility in the currency market; second, to raise funds that could be dedicated to multilateral purposes (see Tobin (1996b)). In this section, we deal with the impact of a transaction tax on price volatility in our market model. Therefore, we need an adequate volatility measure for our model. One measure which increases monotonic with an increasing variability of bid and ask price is the sum of the standard deviation or variance of both prices in one session. Since the variance measures the average squared distance of the observed values to its mean and since both prices have a monotonic decreasing fundamental value, the use of this simple volatility measure seems inappropriate: The variance measures absolute differences of the actual price to the average of all prices where relative changes between all consecutive prices appear more adequate.

Let $X = \{X_1, X_2, ..., X_T\}$ be a time series of positive values. Wishing to obtain a measure for X which increases with increasing distances between all observations, one could sum up the squared absolute value of the percentage change of X in two consecutive periods i and j:

$$\delta(X_i, X_j) = \left(\frac{X_j}{X_i} - 1\right)^2 \tag{24}$$

To address the issue that an increase of $X_i = \dot{X}$ to $X_j = \ddot{X}$ will result in a different value for $\delta(X_i, X_j)$ than a decrease of $X_i = \ddot{X}$ to $X_j = \dot{X}$ (for $\dot{X} < \ddot{X}$ and $j = i + 1$), we introduce a symmetrized measure

$$\delta_{\text{sym}}(X_i, X_j) = \left(\frac{X_i}{X_j} + \frac{X_j}{X_i} - 2\right)^2 \tag{25}$$

which quantifies a positive change of X to the same extent like a negative one. Thus, a volatility measure for X is:

$$\begin{aligned}
\upsilon(X) &= \sum_{t=2}^{T} \delta_{\text{sym}}(X_{t-1}, X_t) && (26)\\
&= \sum_{t=2}^{T} \left(\frac{X_t}{X_{t-1}} + \frac{X_{t-1}}{X_t} - 2\right)^2 && (27)
\end{aligned}$$

Since both bid and ask price are positive *per definitionem*, it is safe to utilize υ for evaluating volatility of both prices in our experiment. Hence, we use the sum of $\upsilon(p_a)$ and $\upsilon(p_b)$ as a means to quantify the price volatility of an experimental session:

$$\upsilon = \sum_{t=2}^{T} \left[\left(\frac{p_{t-1,a}}{p_{t,a}} + \frac{p_{t,a}}{p_{t-1,a}} - 2\right)^2 + \left(\frac{p_{t-1,b}}{p_{t,b}} + \frac{p_{t,b}}{p_{t-1,b}} - 2\right)^2\right] \tag{28}$$

In equilibrium, volatility on taxed markets should be the same as on untaxed ones. We can derive the equilibrium market volatility υ_{eq} by replacing the market bid and ask prices in (28) with the fundamental value Φ_t from equation (7):

$$\begin{aligned}
\upsilon_{\text{eq}} &= 2\sum_{t=2}^{T} \left(\frac{\Phi_{t-1}}{\Phi_t} + \frac{\Phi_t}{\Phi_{t-1}} - 2\right)^2 && (29)\\
&= 2\sum_{t=2}^{T} \left(\frac{p_b^* + (T-t+1)\mu}{p_b^* + (T-t)\mu} + \frac{p_b^* + (T-t)\mu}{p_b^* + (T-t+1)\mu} - 2\right)^2 && (30)\\
&= 2\mu^4 \sum_{t=2}^{T} \frac{1}{\Phi_t^2 \Phi_{t-1}^2} && (31)
\end{aligned}$$

Considering the parameter calibration we used, the equilibrium market volatility equals $\upsilon_{\text{eq}} = 8.13489 \cdot 10^{-5}$. If we compare this benchmark with the data gathered through the experiments, we can deduct that a volatility value as low as the equilibrium market volatility is achieved neither in markets with nor in markets without a Tobin tax. The lowest volatility we observed totals to $2.7784 \cdot 10^{-3}$ in a taxed market and 27.112 in an untaxed one, with a theoretically possible minimum of 0 in both market types.

As mentioned before, the Tobin tax should have no influence on the variability of prices in equilibrium. Does this apply to our markets? Surprizingly enough, no. The price volatility in untaxed markets is always higher than in taxed ones (significant at $p = 0.00108$, Fisher-Pitman permutation test for independent samples, one-tailed). Besides this strong result, the price volatility is even considerably higher on untaxed markets (see table 7).

Table 7: Price volatility in untaxed and taxed markets

market	mean v	std. dev.	min.	max.
untaxed	31933.36	49416.59	27.112	103220.835
taxed	6.05	10.72	.002	26.933

If all players behaved fully rational, the volatility would be equal for markets with and without a Tobin tax. However, this is not the case in our experiments. The only explanation for this seemingly erratic behavior can be the bounded rationality of the market participants. Our next research question is to find any correlation between the tax rate and the volatility. At a first glance, there is no visible correlation between the tax rate and the market's price volatility: Spearman's rank correlation coefficient for both measures has a non-significant value ($\rho = 0.4286$, $p = 0.19825$ one-tailed). Figure 5 shows the price volatility for markets with different tax rates.

Taking a closer look at this figure, we find something irritating: The volatility decreases with an increasing tax, but only for tax rates below 2.5 percent. A tax rate of 2.5 percent and higher induces a drastically increased price volatility. The lack of a broader base of experimental data makes it too early to conclude that there exists a point below which a higher tax rate is correlated with lower volatility and above which a higher tax rate is correlated with higher volatility, but one can see this circumstantial

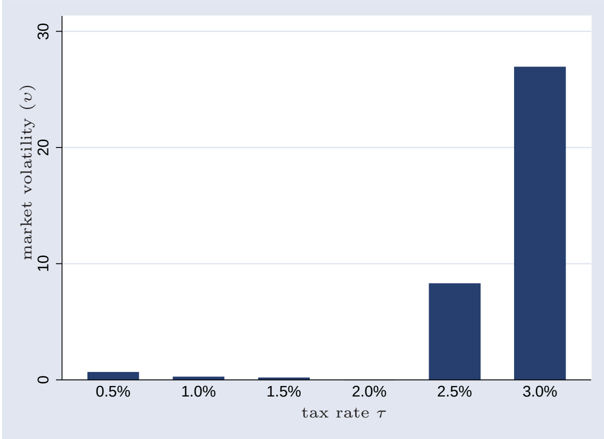

Figure 5: Market volatility and tax rate

evidence as a starting point for furthergoing investigations.

Summarizing our findings concerning the influence of a tax and the tax rate on volatility, we find that Tobin's approach of a transaction tax in fact does reduce price volatility in our markets. This effect is highly significant, albeit neither a libertarian nor a taxed market achieves equilibrium volatility or no volatility at all. We gather some hints that a higher tax rate reduces volatility only if kept below a certain threshold: if the tax rate exceeds 2 percent, the volatility grows. This last point cannot be regarded as finally confirmed - lots of more experiments would have to be conducted ahead of concluding such thing.

4.6 Market efficiency

The concept of market efficiency is a prominent one in the field of finance. In a literature survey, Dimson and Mussavian (2000) provide the reader with a discussion of arguments in favor of and against the efficient market hypothesis, which asserts that information that is known to all market participants is reflected in the market's prices. The model used in our study features a fundamental value which is known to all market participants, so testing the experimental results in regard to market efficiency seems eligible. The idea of comparing the efficiency of a libertarian market with the efficiency of a market with a Tobin transaction tax isn't new: the pioneering experimental investigation of Hanke et al. (2006) takes a closer look at this aspect. Their results suggest that market efficiency decreases if a Tobin tax is introduced on a market. In this section, we evaluate the impact of taxation on market efficiency in our market model.

We base the measure for market efficiency on the volatility measure defined in section 4.5. Instead of measuring the symmetrized squared percentage change of the market price between two periods, we calculate the symmetrized squared percentage deviation of the market price from the fundamental value in the same period:

$$\eta = \sum_{t=1}^{n} \left[\left(\frac{\Phi_t}{p_{t,a}} + \frac{p_{t,a}}{\Phi_t} - 2 \right)^2 + \left(\frac{\Phi_t}{p_{t,b}} + \frac{p_{t,b}}{\Phi_t} - 2 \right)^2 \right] \tag{32}$$

A session with a perfectly efficient market would result in $\eta = 0$ - with decreasing efficiency, η increases strictly monotonic; so we define η as the market *in*efficiency. If all players acted fully rational and knew that all other players acted fully rational, too, the market would be perfectly rational according to the game-theoretical equilibrium. How do the markets in our model behave in respect to inefficiency and the equilibrium inefficiency of $\eta_{\mathrm{eq}} = 0$?

In our experiment, the untaxed markets display a higher η and thus a lower efficiency than the taxed ones. This effect is significant at $p = 0.00108$ (Fisher-Pitman permutation test for independent samples, one-tailed). A closer look at the descriptive statistics of the market inefficiency reveals an even more striking result (cf. table 8): the mean market inefficiency is higher by more than $7 \cdot 10^4$ in untaxed markets.

Table 8: Market inefficiency in untaxed and taxed markets

market	mean η	std. dev.	min.	max.
untaxed	61163.66	131093.80	17.11	326777.70
taxed	8.73	5.07	2.65	17.00

So far, it appears that imposing a tax on our market decreases market inefficiency to a great extent. Although Hanke et al. (2006) find the opposite in their article, this is only seemingly a contradiction: On one hand, they use a different auction as a market vehicle for their investigation. Different auctions also react differently to changes in the parameters. On the other hand, their article focuses on evadability by allowing traders to switch to a second untaxed market.

Just like we did when we investigated our markets' price volatility, we continue by assessing the impact of the tax rate on market inefficiency. Here, we find that the height of the imposed tax has in fact a positive influence on the market inefficiency: Spearman's rank correlation coefficient for the tax rate and a market's inefficiency η has the significant value of $\rho = 0.8286$ ($p = 0.0208$, one-tailed). Figure 6 displays market inefficiencies for differently taxed markets.

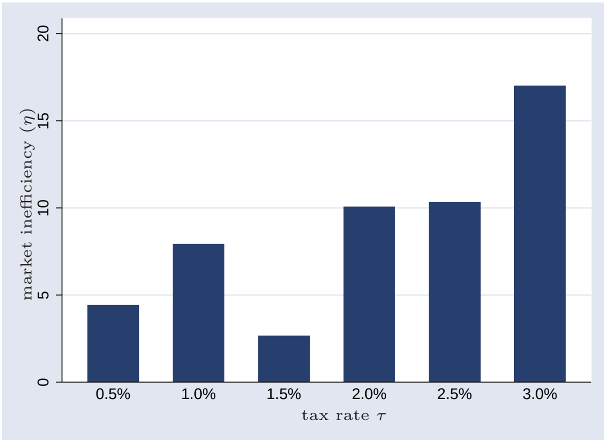

Figure 6: Market inefficiency and tax rate

This finding sheds a new light on the influence of transaction costs on the efficiency of our markets. Although the introduction of a tax decreases inefficiency significantly, this effect is weaker with a growing tax. We assume that inefficiency might even be higher than in taxed markets than in untaxed ones if the tax rate exceeds a certain value, because under the highest tax rate evaluated by us in an experiment (3.0 percent), η is only 0.6 percent lower than the lowest observed η in an untaxed market. It seems that a small tax decreases market inefficiency *per se*, but that a considerably high tax rate causes the market participants to act even less rational than on untaxed markets.

4.7 Fiscal revenues

In the frequently occurring political discussions, Tobin's stabilisation approach is often regarded as a means to levy taxes and thus as a potential source of vast fiscal revenues. Many studies claim that if tax escape routes tax existed, actual tax revenues would be far below the expected. Experimental evidence on that hypothesis is given by Hanke et al. (2006). Neither is our model appropriate nor is it our goal to investigate the effect of evadability. If the possibility of tax evasion did not exist, there is still more to be taken into account: A higher tax rate might influence the trade turnover negatively. It is of crucial importance to estimate elasticity parameters of trade turnover in regard to the tax rate before concluding anything about the height of fiscal revenues. Since our market setting does not provide the market participants with a possibility to evade the tax, the trade of the asset must take place under the transaction costs imposed. Nevertheless, the existence of transaction costs might decrease the trade turnover to an extent that fiscal revenues rather decline than increase. In game-theoretical equilibrium, no tax revenues are raised at any tax rate because no trade takes place at all if the tax rate is greater than zero and no tax is raised at a tax rate of zero.

This predicted outcome cannot be observed in our experiment. Spearman's rank correlation coefficient of a market's fiscal revenues and the tax rate totals to $\rho = 0.8857$ (significant at $p = .009423$, one-tailed). This considerably high value suggests that there indeed is a positive cohesion between tax rate and fiscal revenues. Again, we conduct an OLS regression of the simple model

$$R_i = \beta_0 + \beta_1 \tau_i + \epsilon_i \tag{33}$$

where R_i is the total fiscal revenues from market i, τ_i the tax rate for market i, ϵ_i the error term for market i and β_k the coefficients to match for all $k \in \{0, 1\}$. The regression analysis displays a high goodness-of-fit value of $R^2 = 0.7637$ (all estimation results and can be found in table 12 in the appendix). Actual values and the fitted curve with a confidence interval are shown in figure 7.

Although the estimates feature a high goodness-of-fit value, we want to emphasize that the explanatory power of this regressional analysis is not too strong: six observations are too few to claim that the fit is in fact conclusive. We can consider the regressional result as another hint for linearly increasing fiscal revenues with an increasing tax rate under our market setting, at least if the tax rate is kept lower than or equal to 3 percent.

We feel it is important to stress that this result must not be overinterpreted. As mentioned already before, our setup doesn't allow for traders to evade the tax. If we

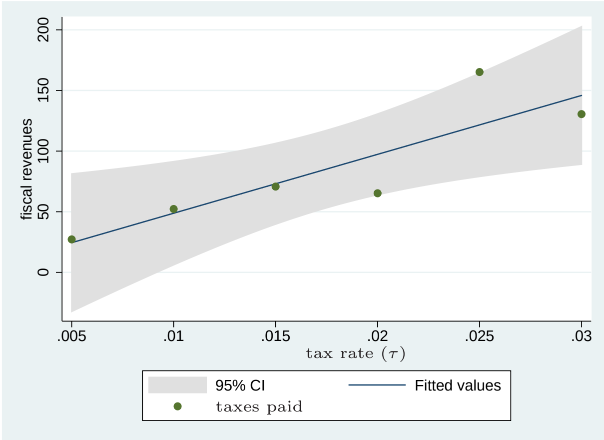

Figure 7: Fiscal revenues and tax rate

created such a possibility, it would be likely that the fiscal revenues will decrease. However, even with no tax escape routes, increasing transaction costs might decrease trade volume to an extent that derogates the fiscal revenues. We have shown that one cannot observe a phenomenon as such with relatively low tax rates in our markets and consider this an important finding.

4.8 Earnings inequality

The next question our study deals with is the distribution of payoffs among market participants, an issue that has to our knowledge never been investigated before in the context of a Tobin tax. Although this aspect is rather irrelevant from a macroeconomic point of view, we think it is important to investigate it for the sake of market microstructure.

In equilibrium, our market yields equal payoffs for every participant in either treatment. However, this is not the case in any of the 12 markets. Moreover, there has not even been a single experimental subject who received the equilibrium payoff of 12.00 €. The next research question this study deals with is: Is there a tendency in taxed markets to level out differences in the earnings of each participant?

To assess earnings inequality in the different treatments, we compare the Gini coefficient, Theil's entropy as well as Theil's mean log deviation, the Kakwani, Piesch, and Mehran indices, the standard deviation of logs, the coefficient of variation, and the relative mean deviation of all player's payoffs in all sessions. Note that each measure would be zero in equilibrium. We find that earnings inequality is significantly lower in taxed markets (cf. table 10 in the appendix) - this holds true for all inequality measures but the Piesch index. Figure 8 displays the Lorenz curves of all payoffs in equilibrium (bisecting line), taxed treatments (middle curve), and untaxed treatments (lower curve).

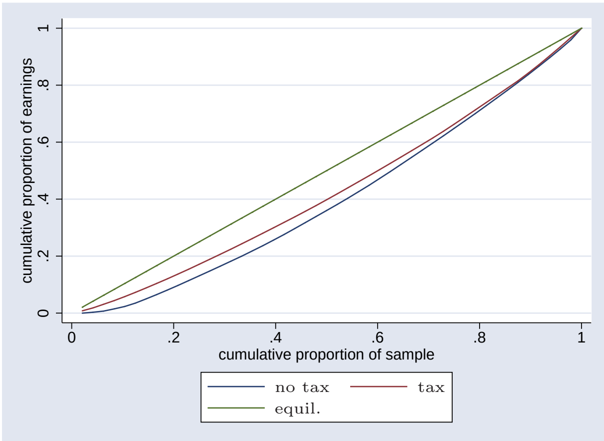

Figure 8: Lorenz curves for both treatments

How is earnings inequality correlated with the tax rate? Spearman's rank correlation coefficient is negative for tax rate and all investigated measures of inequality, although this effect is not significant. This is only a weak indicator for a negative influence of the tax rate on earnings inequality.

Summarizing our findings on market inequality, we can say that the payoffs of the participants of a market with a Tobin transactions tax imposed are distributed more equally among players than on untaxed markets.

5 Concluding remarks

Our study investigates the consequences of a Tobin tax on a discretized double auction market. We compare the beforehand derived game-theoretical solution with the results gained by a series of laboratory experiments. A comparison of the equilibrium values with the figures gained by experiments reveals that players act boundedly rational in regard to several aspects of the market. Firstly, we investigate the trade turnover and trade volume and find that trade turnover stays uninfluenced by a tax, whereas the trade volume decreases linearly with the tax height. Contrary to that finding, both trade volume and turnover could be of arbitrary height on untaxed markets but should be zero on taxed ones in equilibrium. Regarding supply and demand, there should neither be supply nor demand on taxed and supply and demand of arbitrary height on untaxed markets in equilibrium. Astonishingly, the average number of suppliers is higher in taxed markets. Furthermore, supplying traders accept higher opportunity costs for supplying units of the asset under value on taxed markets than on untaxed ones. This can be seen as support for the theory that the irrational behavior of hyperbolic discounting is fortified by a Tobin tax. Concerning market prices, we see that there are more outliers in untaxed markets. The markets display non-negative median bid-ask spreads in every session.

In the experiments we conducted, neither zero nor equilibrium volatility is ever achieved. In equilibrium, a tax should make no difference in volatility. Nevertheless, we observe strong volatility reducing effects of a Tobin tax: all taxed markets feature a smaller volatility than all untaxed markets. There is no statistically significant correlation between tax rate and volatility, although our results suggest that volatility decreases with an increasing tax, but only to a certain tax height. A growing tax rate above 2 percent increases the volatility drastically in our experiment, albeit the statistical evidence is not strong enough to definitely conclude this point. The equilibrium market inefficiency is never achieved by the experimental markets, although the observed inefficiency is significantly higher in untaxed markets. Nevertheless, an increasing tax rate also increases market inefficiency. The fiscal revenues collected by a Tobin tax increase with an increasing tax rate in our experiment. This is not surprising, because the trade turnover does not differ significantly with increasing taxes and only the trade volume decreases. Furthermore, we find evidence that earnings inequality is lower on untaxed markets.

Concluding the results of our study, we can say that a Tobin tax in fact improves the situation with regard to volatility and market efficiency, but only if kept at a low point: The best market performance can be observed if there is a Tobin tax with a very low tax rate. Another point which we want to emphasize is that the participants of our markets are boundedly rational. Our study shows the crucial importance to take irrational behavior into account when creating theories on how a Tobin tax might affect markets. Finally, we want to stress that we investigate a simple experimental asset market. There are some authors who claim that the foreign exchange market behaves in fact like any arbitrary stock or asset market. We are convinced that this is definitely not the case and that the interlinks between foreign exchange and other markets forbid to treat these markets equally.

Still, there is room left for future work. One could introduce the possibility of escaping the tax by creating another libertarian market. Furthermore, it would be possible to investigate the trade behavior if trading derivates like futures or swap options were introduced. With respect to the fact that only roughly one third of the daily global average foreign exchange trade turnover is traded via spot transactions[6] and that the original idea of James Tobin was to only tax spot transactions, this could give further valuable insights into how markets react when such a tax is introduced. Furthermore, one could investigate other financial stabilisation schemes by the means of the laboratory. For example, Paul Spahn's approach to a transaction tax has never been evaluated in an experiment. Our investigation thus should only be seen as a starting point for further behavioral and experimental studies of stabilisation schemes.

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A Symbols

μ - dividend paid for each unit of the asset

η - market efficiency

τ - tax rate

Π_i - payoff of a participant i

Φ_t - fundamental value of one unit of the asset in period t

υ - volatility

c - conversion factor for a participant

$\bar{d}$ - statutory demand constraint

$d_{i,t}$ - demand of participant i in period t

$d_{i,t}^{\max}$ - demand constraint of participant i

i - participant number

m - total holdings of the asset of all participants

$m_{i,t}$ - holdings of the asset of participant i in period t

n - number of normal participants

p_t - average price in period t

$p_{t,a}$ - market ask price in period t

$p_{t,b}$ - market bid price in period t

p_b^* - bid price for the asset after the final period

$p_{i,t,a}$ - ask price of participant i in period t

$p_{i,t,b}$ - bid price of participant i in period t

$\bar{s}$ - statutory supply constraint

$s_{i,t}$ - supply of participant i in period t

$s_{i,t}^{\max}$ - supply constraint of participant i in period t

T - total number of periods

t - actual period

$x_{i,t}$ - holdings of the numeraire of participant i in period t

B Tables and figures

Table 10: Different measures of earnings inequality

inequality measure	**without tax (mean)**	**with tax (mean)**	**significance**
Gini coefficient	.1875074	.1370911	0.09632*
Theil's entropy	.0854972	.0350746	0.06277*
Theil's mean log deviation	.2661607	.0372477	0.05411*
Kakwani index	.0486117	.0209698	0.06385*
Piesch index	.1360516	.1045064	0.13095
Mehran index	.2904188	.2022604	0.07467*
standard deviation of logs	.967887	.2833992	0.05086**
coefficient of variation	.3696102	.2682073	0.09740*
relative mean deviation	.1407252	.1025833	0.07792*

p-levels: Fisher-Pitman permutation test for independent samples, one-tailed

Table 11: OLS regression of trade volume and tax rate

variable	Coeff.	Std. Err.	t	$P > \|t\|$	95% CI
τ	-35205.71	9922.063	-3.55	0.024	$[-62753.78, -7657.652]$
cons.	3066.93	193.204	15.87	0.000	$[2530.512, 3603.355]$

$n = 6$, $F(1, 4) = 12.59$, $Prob. > F = 0.0238$, $R^2 = 0.7589$, Adj. $R^2 = 0.6986$, root MSE= 207.53

Table 12: OLS regression of fiscal revenues and tax rate

variable	Coeff.	Std. Err.	t	$P > \|t\|$	95% CI
τ	4855.723	1350.519	3.6	0.023	$[1106.082, 8605.365]$
cons.	.2193	26.297	0.01	0.994	$[-72.794, 73.233]$

$n = 6$, $F(1, 4) = 12.93$, $Prob. > F = 0.0229$, $R^2 = 0.7637$, Adj. $R^2 = 0.7046$, root MSE= 28.248

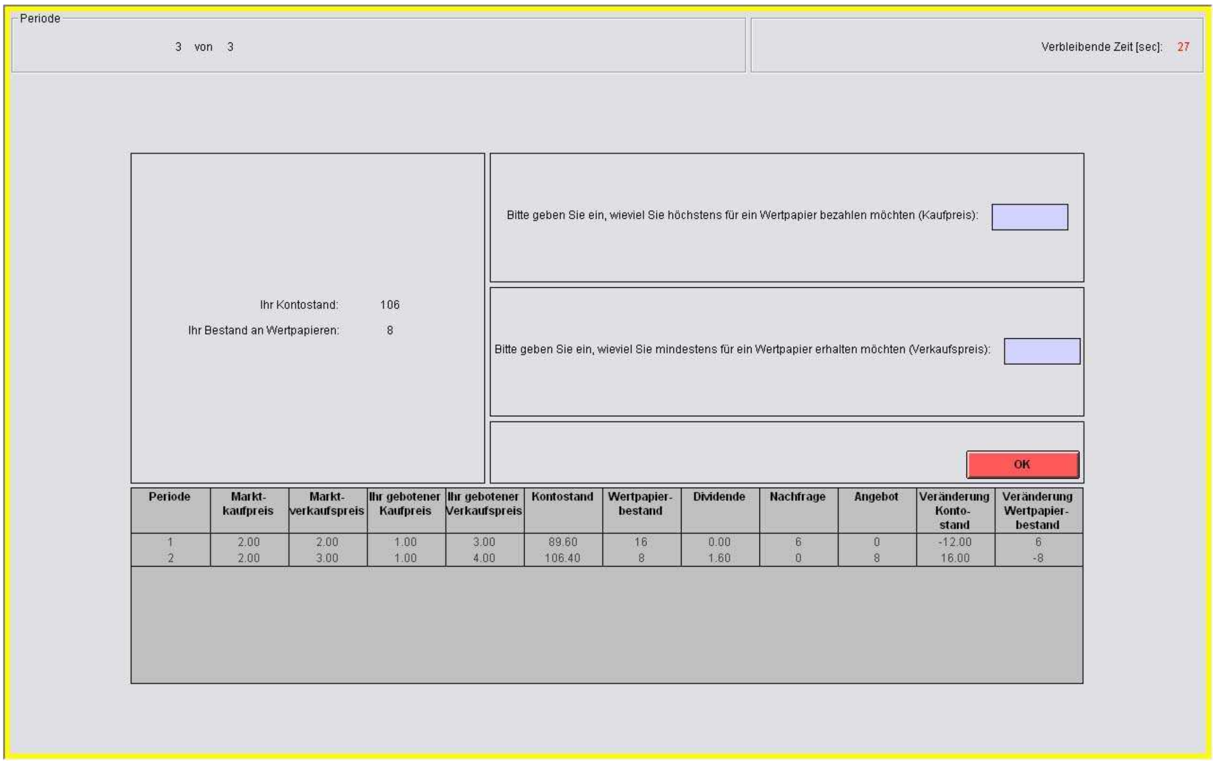
Table 13: Descriptive statistics per market

	tax rate	fiscal revenues	volatility	market volume	trade turnover	market ineff.	total supply	total demand	#d[1]	#s[1]	Ω^D	Ω^S
1	0	0	27.112	1681	4335.00	51.212	10080	6144	0.92	1.55	9.05	374.55
2	0	0	103220.8	2024	3873.90	326777.7	7720	10592	1.73	1.69	88.25	135.2
3	0	0	87598.3	1936	4803.46	39877.32	13472	13080	1.41	1.78	20.00	277.96
4	0	0	65.614	2554	5214.03	17.115	10504	13184	1.63	1.16	53.18	252.65
5	0	0	652.276	2226	3778.99	201.102	9024	10312	1.51	1.43	0.60	652.23
6	0	0	36.018	2759	6075.55	57.488	6920	16448	2.37	1.22	412.57	150.71
7	0.005	27.21	0.659	2751	5332.06	4.419	13040	10680	1.63	1.94	42.09	583.24
8	0.01	52.26	0.256	2948	5101.23	7.92	10384	18936	2.1	1.45	133.61	403.71
9	0.015	70.75	0.176	2585	4631.24	2.656	10368	11016	2.18	1.86	37.22	291.32
10	0.02	65.24	0.003	2098	3175.77	10.06	9112	9752	1.69	1.41	46.18	924.16
11	0.025	165.2	8.293	2345	6309.78	10.327	15584	7648	1	1.78	260.38	171.63
12	0.03	130.51	26.933	1978	4241.58	17.001	10648	5880	1.47	2.35	77.37	471.92

[1] #s: mean number of suppliers per period, #d: mean number of demanders per period

C Screenshots

C.1 Screenshot of step 1 (control treatment)



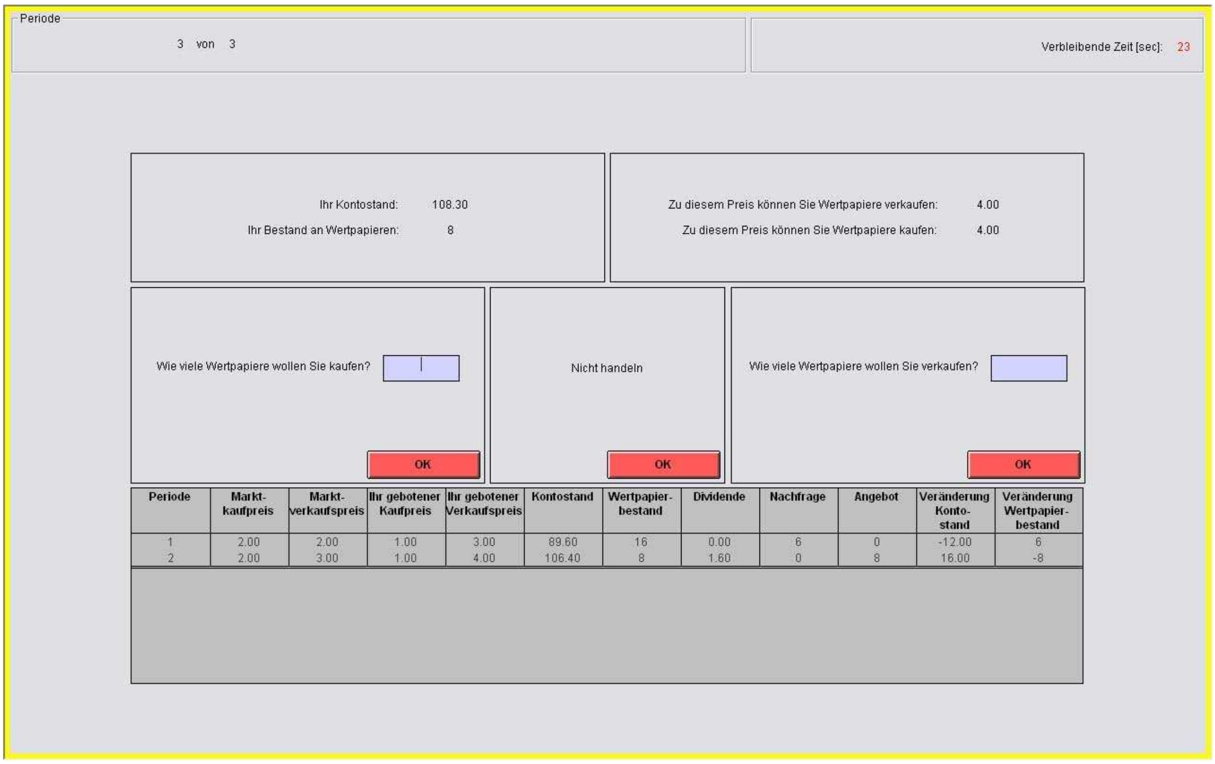
Translation:

- von: of
- Verbleibende Zeit: remaining time
- Bite geben Sie ein, wieviel Sie höchstens für ein Wertpapier bezahlen möchten (Kaufpreis): Please state how much you are willing to pay at most for one asset (bid price)
- Bitte geben Sie ein, wieviel Sie mindestens für ein Wertpapier erhalten möchten (Verkaufspreis): Please state how much money you want to receive at least in exchange for one asset (ask price)
- Ihr Kontostand: Your account balance
- Ihr Bestand an Wertpapieren: Your asset balance

Periode	Markt-kaufpreis	Markt-verkaufsreis	Ihr gebotener Kaufpreis	Ihr gebotener Verkaufpreis	Konto-stand
period	market bid price	market ask price	Your bid price	Your ask price	Account balance

Wertpapier-bestand	Dividende	Nachfrage	Angebot	Veränderung Kontostand	Veränderung Wertpapierbestand
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance

C.2 Screenshot of step 2 (control treatment)



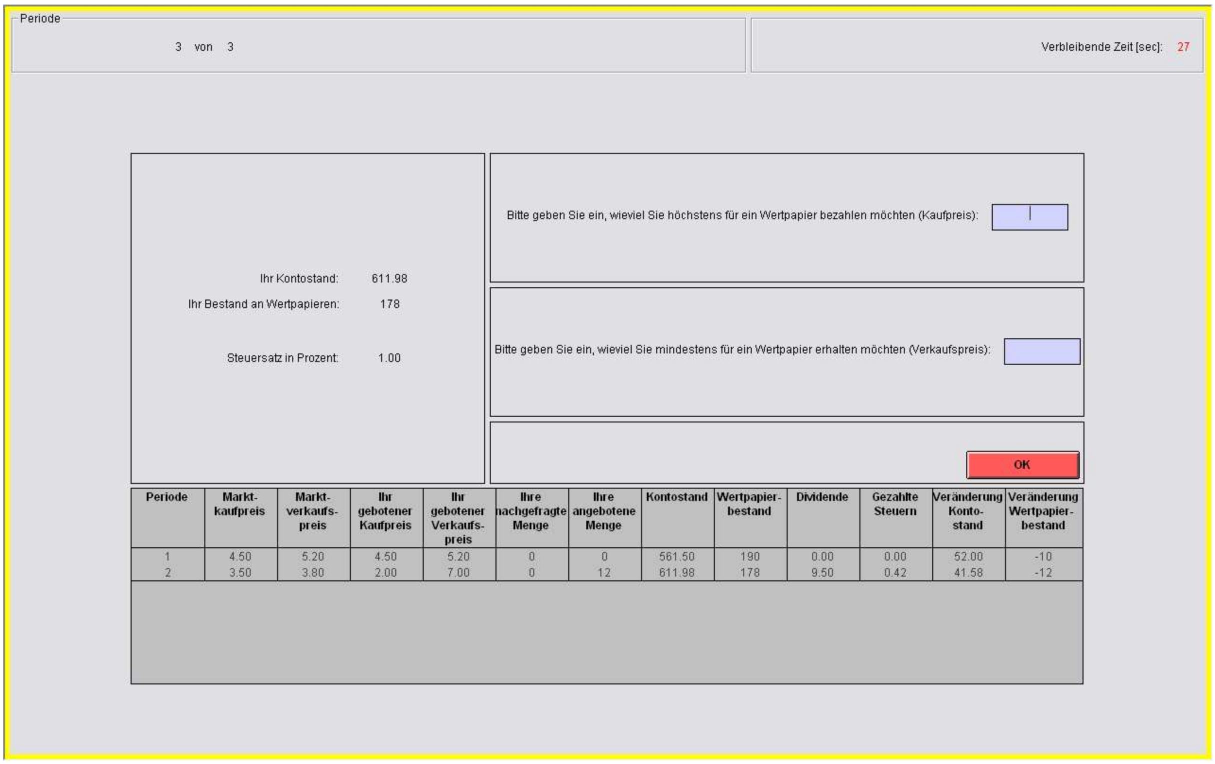
Translation:

- von: of
- Verbleibende Zeit: remaining time
- Ihr Kontostand: Your account balance
- Ihr Bestand an Wertpapieren: Your asset balance
- Zu diesem Preis können Sie Wertpapiere verkaufen: You can sell assets at this price
- Zu diesem Preis können Sie Wertpapiere kaufen: You can buy assets at this price
- Wie viele Wertpapiere wollen Sie kaufen: How many units of the asset do you want to buy
- Wie viele Wertpapiere wollen Sie verkaufen: How many units of the asset do you want to sell
- nicht handeln: refrain from trade

Periode	Markt-kaufpreis	Markt-verkaufsreis	Ihr gebotener Kaufpreis	Ihr gebotener Verkaufpreis	Konto-stand
period	market bid price	market ask price	Your bid price	Your ask price	Account balance

Wertpapier-bestand	Dividende	Nachfrage	Angebot	Veränderung Kontostand	Veränderung Wertpapierbestand
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance

C.3 Screenshot of step 1 (Tobin treatment)



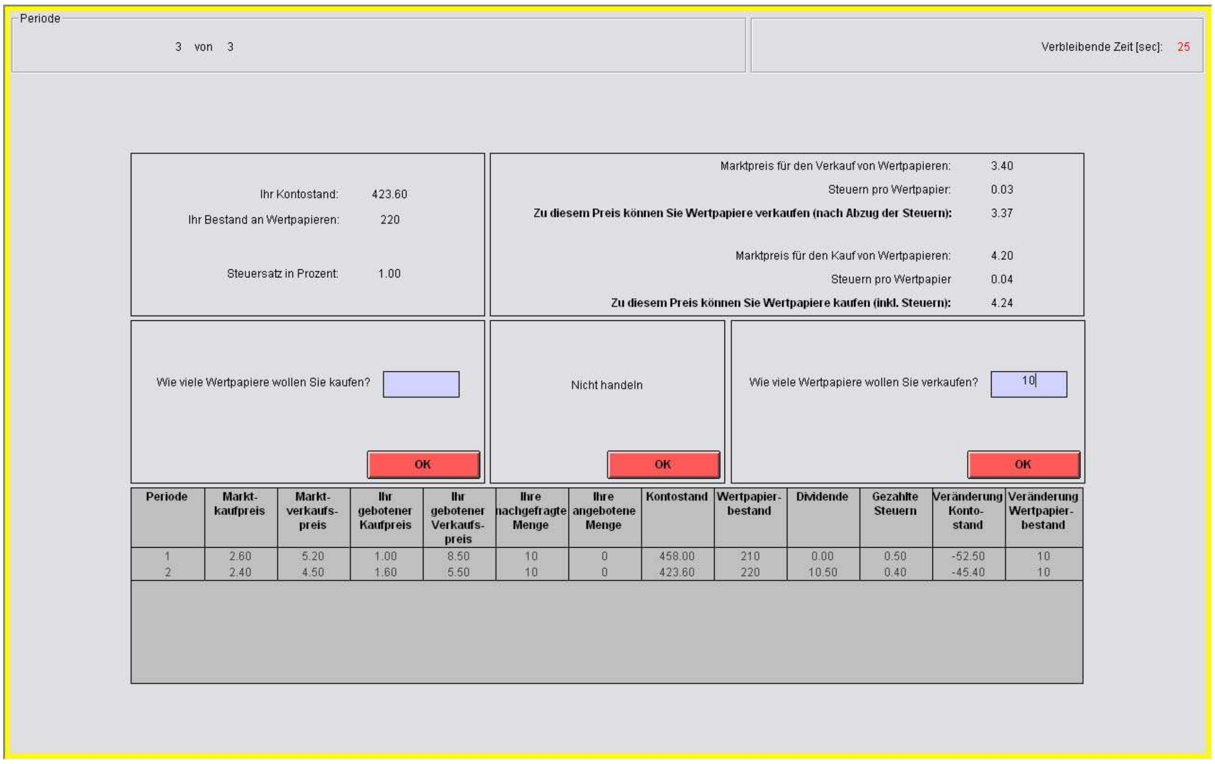
Translation:

- von: of
- Verbleibende Zeit: remaining time
- Bite geben Sie ein, wieviel Sie höchstens für ein Wertpapier bezahlen möchten (Kaufpreis): Please state how much you are willing to pay at most for one asset (bid price)
- Bitte geben Sie ein, wieviel Sie mindestens für ein Wertpapier erhalten möchten (Verkaufspreis): Please state how much money you want to receive at least in exchange for one asset (ask price)
- Ihr Kontostand: Your account balance
- Ihr Bestand an Wertpapieren: Your asset balance
- Steuersatz in Prozent: tax rate (percent)

Periode	Markt-kaufpreis	Markt-verkaufsreis	Ihr gebotener Kaufpreis	Ihr gebotener Verkaufpreis	Konto-stand	gezahlte Steuern
period	market bid price	market ask price	Your bid price	Your ask price	Account balance	tax paid

Wertpapier-bestand	Dividende	Nachfrage	Angebot	Veränderung Kontostand	Veränderung Wertpapierbestand	
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance	

C.4 Screenshot of step 2 (Tobin treatment)



Translation:

- von: of
- Verbleibende Zeit: remaining time
- Ihr Kontostand: Your account balance
- Ihr Bestand an Wertpapieren: Your asset balance
- Marktpreis für den Verkauf von Wertpapieren: Market price for selling one unit of the asset
- Steuern pro Wertpapier: tax amount for one unit of the asset
- Zu diesem Preis können Sie Wertpapiere verkaufen (nach Abzug der Steuern): At this price you can sell the asset (after taxes)
- Marktpreis für den Kauf von Wertpapieren: Market price for buying one unit of the asset
- Zu diesem Preis können Sie Wertpapiere kaufen (inkl. Steuern): At this price you can buy the asset (including taxes)
- Wie viele Wertpapiere wollen Sie kaufen: How many units of the asset do you want to buy
- Wie viele Wertpapiere wollen Sie verkaufen: How many units of the asset do you want to sell
- nicht handeln: refrain from trade
- Steuersatz in Prozent: tax rate (percent)

Periode	Markt- kaufpreis	Markt- verkaufsreis	Ihr gebotener Kaufpreis	Ihr gebotener Verkaufpreis	Konto- stand	gezahlte Steuern
period	market bid price	market ask price	Your bid price	Your ask price	Account balance	tax paid

Wertpapier- bestand	Dividende	Nachfrage	Angebot	Veränderung Kontostand	Veränderung Wertpapierbestand	
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance	

D Translation of the instructions

D.1 Control treatment

Welcome to this experiment!

General information

This experiment gives you the opportunity to earn money with your decisions. The size of your earnings depends on your own decisions and on the decisions of the other members of your group. You will receive a show-up fee of €4.00 irrespective of the result of the experiment. Please read the explanations of the experiment carefully. All participants receive identical explanations. We would like to ask you not to communicate with the other participants from now on. If you have any questions, please feel free to ask us. All decisions are taken anonymously. You will shortly draw a random number. This number corresponds to the number of the booth in the laboratory.

The course of the experiment

In the beginning of the experiment, you will receive 500 units of the experimental currency ("Taler") and 200 units of an experimental asset. You will be in a market together with 7 other players. In the course of the experiment, you can trade the assets at prices which are determined by yourself. For each asset which you own in the end of a round, you will receive a dividend of 0.05 Talers in the beginning of the following round. The experiment runs for 51 rounds. In the process, each round consists of two steps:

1. Each player indicates how Talers much he/she is willing to pay for one unit of the asset at most (bid price) and how much Talers he/she wants to receive for one unit of the asset at least (ask price). The ask price has to be at least as high as the bid price. If you should run out of assets, you cannot enter any ask price; similarly, you cannot enter any bid price if you do not have any more money. After each player has specified the bid and the ask price, the market prices are determined: The market bid price is defined by the highest bid price, the market ask price by the lowest ask price of all players.

2. Those players who determined the market prices are not allowed to enter anything in the second step. All the other players decide whether they want to buy or sell

assets at the market prices or whether they want to refrain from trading. They are only allowed to sell assets which they own and only able to buy assets for which they can pay. The maximum trading volume is limited to 25 assets per round. If one of the prices should have been set by more than one player, demand and supply will be equally shared between these players.

If the amount of the asset demanded is higher than the supply at market price (i.e. the amount of the asset owned by those players who set the market ask price), the demanding players act in random order; if the supply is exhausted, the remaining potential buyers will miss out. A similar procedure is followed with the potential sellers in the case that the supply is higher than the demand of the players who defined the market price.

The end of the experiment

In the end of the experiment, you will be told your final account balance and the amount of the asset you possess. You will be paid for every unit of the asset that you possess at a fixed conversion rate, then. The rate of conversion is 1, thus, you will receive 1 Taler for each asset you own. Afterwards, a short questionnaire will appear on your screen. Please answer the questions as carefully as possible.

Payments

The overall balance of your account (including the money transferred to you for your asset stock) will be converted at a rate of 1 Taler : 1 Cent and paid out to you.

D.2 Tobin treatment

Welcome to this experiment!

General information

This experiment gives you the opportunity to earn money with your decisions. The size of your earnings depends on your own decisions and on the decisions of the other members of your group. You will receive a show-up fee of €4.00 irrespective of the result of the experiment. Please read the explanations of the experiment carefully. All participants receive identical explanations. We would like to ask you not to communicate with the other participants from now on. If you have any questions, please feel free to ask us. All decisions are taken anonymously. You will shortly draw a random number. This number corresponds to the number of the booth in the laboratory.

The course of the experiment

In the beginning of the experiment, you will receive 500 units of the experimental currency ("Taler") and 200 units of an experimental asset. You will be in a market together with 7 other players. In the course of the experiment, you can trade the assets at prices which are determined by yourself. For each asset which you own in the end of a round, you will receive a dividend of 0.05 Talers in the beginning of the following round. The experiment runs for 51 rounds. In the process, each round consists of two steps:

1. Each player indicates how Talers much he/she is willing to pay for one unit of the asset at most (bid price) and how much Talers he/she wants to receive for one unit of the asset at least (ask price). The ask price has to be at least as high as the bid price. If you should run out of assets, you cannot enter any ask price; similarly, you cannot enter any bid price if you do not have any more money. After each player has specified the bid and the ask price, the market prices are determined: The market bid price is defined by the highest bid price, the market ask price by the lowest ask price of all players.

2. Those players who determined the market prices are not allowed to enter anything in the second step. All the other players decide whether they want to buy or sell assets at the market prices or whether they want to refrain from trading. They are only allowed to sell assets which they own and only able to buy assets for which they

can pay. The maximum trading volume is limited to 25 assets per round. If one of the prices should have been set by more than one player, demand and supply will be equally shared between these players. Taxes arise for each unit of the asset traded. These are always paid by the player who decides to buy or sell units of the asset in the second step. Correspondingly, he/she pays more for assets he/she buys and receives less for assets he/she sells. The tax rate as well as the corresponding prices in- and excluding taxes are shown on your screen. The player who determined the market price always receives or pays exactly the price offered by him/her.

If the amount of the asset demanded is higher than the supply at market price (i.e. the amount of the asset owned by those players who set the market ask price), the demanding players act in random order; if the supply is exhausted, the remaining potential buyers will miss out. A similar procedure is followed with the potential sellers in the case that the supply is higher than the demand of the players who defined the market price.

The end of the experiment

In the end of the experiment, you will be told your final account balance and the amount of the asset you possess. You will be paid for every unit of the asset that you possess at a fixed conversion rate, then. The rate of conversion is 1, thus, you will receive 1 Taler for each asset you own. Afterwards, a short questionnaire will appear on your screen. Please answer the questions as carefully as possible.

Payments

The overall balance of your account (including the money transferred to you for your asset stock) will be converted at a rate of 1 Taler : 1 Cent and paid out to you.